# A HISTORY OF LAND USE IN ARID REGIONS

*Edited by*

L. DUDLEY STAMP

U N E S C O

ARID ZONE RESEARCH — XVII

# A HISTORY OF LAND USE IN ARID REGIONS

Titles in this series :

I. *Reviews of research on arid zone hydrology*

II. *Proceedings of the Ankara Symposium on Arid Zone Hydrology*

III. *Directory of institutions engaged in arid zone research*

IV. *Utilization of saline water. Reviews of research*

V. *Plant ecology. Proceedings of the Montpellier Symposium/Écologie végétale. Actes du colloque de Montpellier*

VI. *Plant ecology. Reviews of research/Écologie végétale. Compte rendu de recherches*

VII. *Wind and solar energy. Proceedings of the New Delhi Symposium/Énergie solaire et éolienne. Actes du colloque de New Delhi/Energía Solar y eólica. Actas del coloquio celebrado en Nueva Delhi.*

VIII. *Human and animal ecology. Reviews of research/Écologie humaine et animale. Compte rendu de recherches*

IX. *Guide book to research data on arid zone development*

X. *Climatology. Reviews of research*

XI. *Climatology and microclimatology. Proceedings of the Canberra Symposium Climatologie et microclimatologie. Actes du colloque de Canberra*

XII. *Arid zone hydrology. Recent developments*

XIII. *Medicinal plants of the arid zones*

XIV. *Salinity problems in the arid zones. Proceedings of the Teheran Symposium/Les problèmes de la salinité dans les régions arides. Actes du colloque de Téhéran*

XV. *Plant-water relationships in arid and semi-arid conditions. Reviews of research*

XVI. *Plant-water relationships in arid and semi-arid conditions. Proceedings of the Madrid Symposium/Échanges hydriques des plantes en milieu aride ou semi-aride. Actes du colloque de Madrid/Intercambios hídricos de las plantas en medios âridos y semiâridos. Actas del coloquio celebrado en Madrid*

The reviews of research are published with a yellow cover; the proceedings of the symposia with a grey cover.

*Published in 1961 by the United Nations*
*Educational, Scientific and Cultural Organization*
*Place de Fontenoy, Paris-7e*
*Printed by Berger-Levrault, Nancy, France*

Place Fontenoy
Bibliothèque
UNESCO
Library
PARIS-7e

© Unesco 1961
*Printed in France*
NS. 60/III. 21/A

# FOREWORD

*Unesco's Arid Zone Programme, first discussed in 1949, became one of the Organization's three Major Projects at the ninth session of the General Conference in 1956. While this change has brought a substantial increase in the resources available for the promotion of arid zone research, notably through direct support of certain institutions in a region extending from North-West Africa through the Middle East to South-East Asia, the collection and dissemination of scientific information resulting from studies of arid zone problems remain the essential objectives.*

*Sixteen volumes have so far been published in the Unesco* Arid Zone Research *series. They include digests of research on particular subjects, such as hydrology, plant ecology, utilization of saline water, human and animal ecology, climatology, plant-water relationships, and the proceedings of symposia on the same subjects organized as part of the programme.*

*One of these volumes, the* Guide Book to Research Data for Arid Zone Development, *was prepared with the more practical object of assisting experts and administrators in their evaluation of the many facets of problems of arid zone development, and of facilitating the integration of the numerous physical, biological and human factors which they must take into account.*

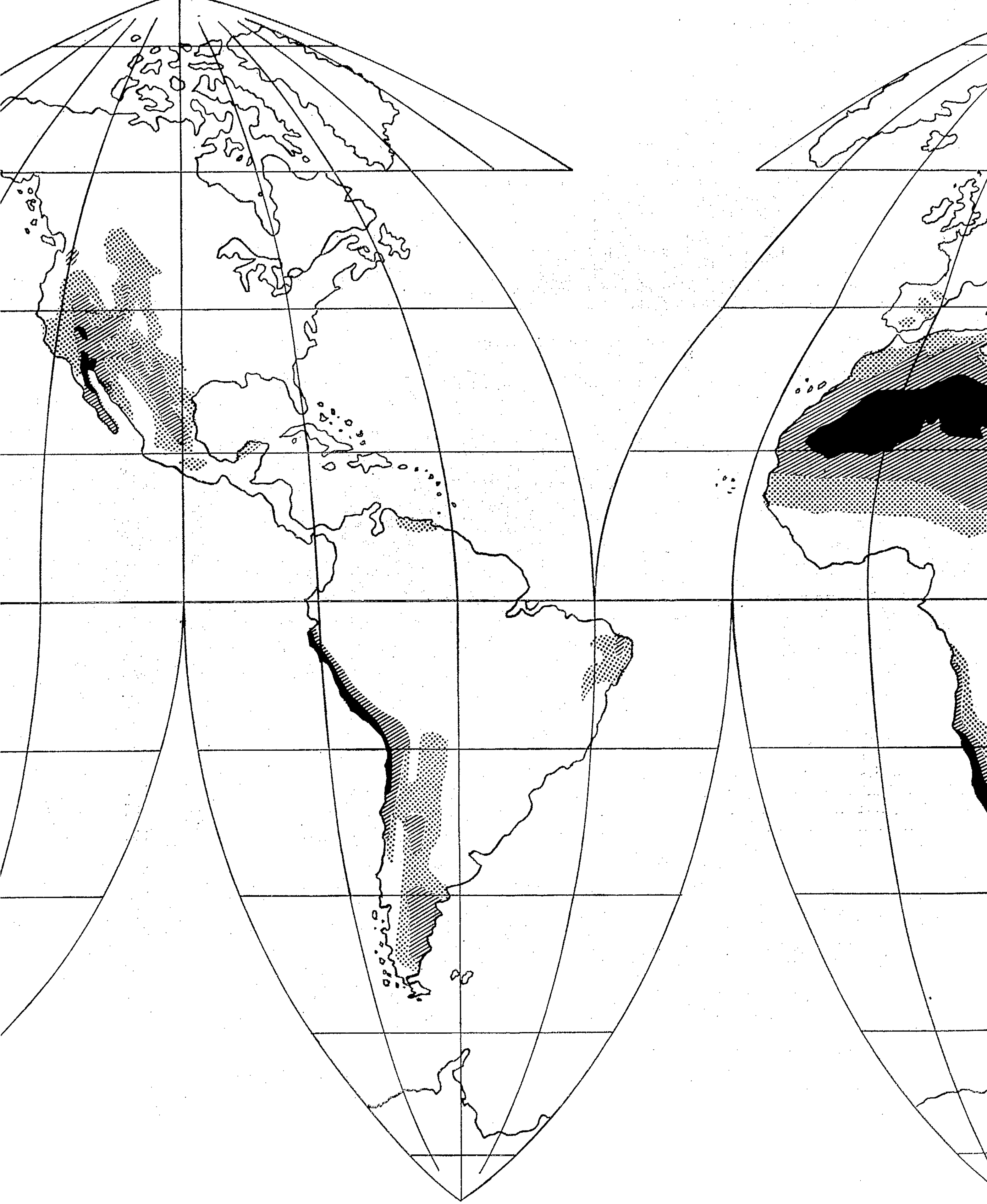
*In many cases, however, an additional factor is too often neglected—it is the history of land use in the area under consideration, which may explain certain features of the terrain and have a bearing on the planning of future work. The Unesco Advisory Committee on Arid Zone Research has been very conscious, from an early stage, of the particular importance of historical developments in the land use of arid regions and has recommended that a review of present knowledge on this matter be attempted.*

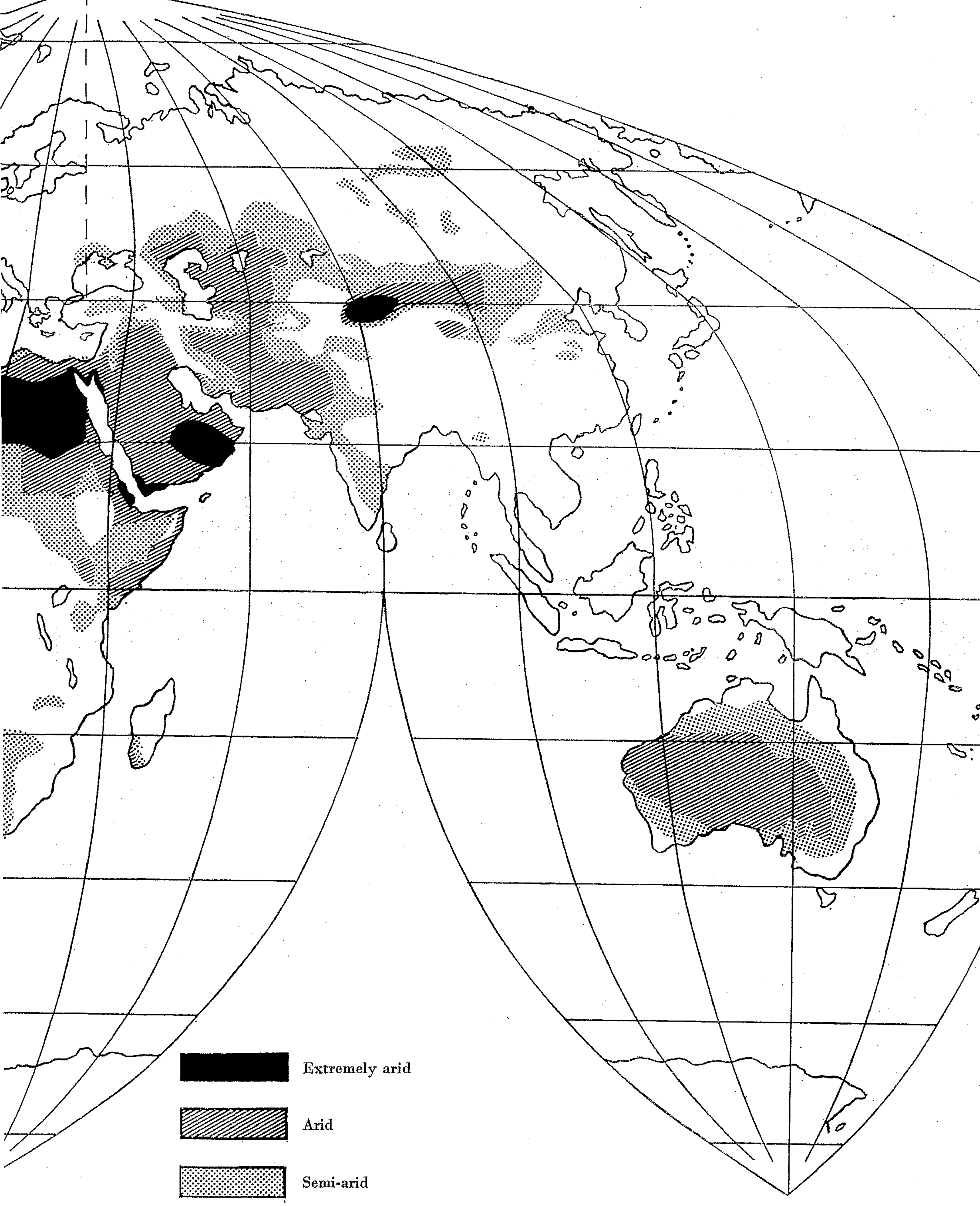
*This volume has been prepared for that purpose and is primarily intended for those having a practical interest in improving the utilization of arid and semi-arid lands. It is not meant as a history of agriculture in certain geographical regions, but endeavours to build up a synthesis of the various factors—geological, climatic, biological as well as human—which have determined the history of land use. In arid and semi-arid areas, climatic factors control any rational adaptation of cultivation and land use methods and give them a precarious character. It becomes therefore particularly important to know how men achieved success and prosperity or why the land was abandoned. In this way, this book supplements the* Guide Book *in emphasizing the evolution of methods and techniques and their interaction with the environment.*

*The general structure chosen for the book is a division into chapters devoted to the main geographical regions of the arid world. A similar pattern has been followed roughly within each chapter, but the emphasis has been placed on the specific characteristics of each particular region. A division by subjects, such as irrigation, salinity, erosion, etc., rather than by geographical areas could have been envisaged and would undoubtedly have been of the greatest interest. It was felt, however, that the study of the historical development of these fundamental aspects of land use of arid regions on a world wide basis was not sufficiently advanced to allow for such treatment. An attempt has nevertheless been made to deal with climate and its variations, and with public health hazards in land use, in special chapters.*

*The task of the authors has been particularly delicate since they had to treat a vast subject—on which comparatively little adequate work has been done—from many different angles at the same time, making use not only of the historical records, but of the geographic, geological, pedological, botanical, agronomical and archaeological factors as well. The keen interest they have shown and the co-operation they have extended to the Secretariat are warmly acknowledged. Finally, in order to ensure a harmonious balance between the various chapters and the coherence of the whole volume, to present the detailed scope of the work and to draw some general conclusions from its contents, a general editor with a sound knowledge and experience of land use problems together with a wide culture was required: Unesco has been fortunate in obtaining the valuable and sustained co-operation of Professor L. Dudley Stamp for this most difficult task.*

# CONTENTS




Extremely arid
Arid
Semi-arid

# ACKNOWLEDGEMENTS

In the complex task of editing this volume, I have been greatly assisted by the generous help of many friends and colleagues. First I should like to thank Mr. Michel Batisse, Head of the Division of studies related to natural resources, Natural Sciences Department of Unesco, for his expert guidance throughout and for placing at my disposal the wide range of knowledge he has acquired in the course of his association with the arid zone studies. For advice in some of the many technical fields embraced in this history I am indebted especially to Professor F. Kenneth Hare of McGill University and through him to Dr. C. Warren Thornthwaite; to Mr. Gordon Lowther, Curator of Anthropology and Assistant Curator, McCord Museum, McGill University.

With the exception of Central Asia, I have at one time or another crossed all the great deserts of the world and in my early days spent two years of intensive study on the geology, geomorphology, soils and ecology of one of the smaller but facinating arid zones—the Dry Belt of Burma. I have drawn freely on the notes made on those various journeys in checking and editing this volume, as well as on the wealth of material now being collected for the 'World Land Use Survey'.

# INTRODUCTION

*by*

L. Dudley Stamp

*Professor Emeritus of Social Geography, London School of Economics, University of London*

## THE SCOPE OF THE WORK

It may be said at the outset that this composite work has been prepared in the hope that in facing the many and complex problems of the arid zones of today, there is something which we can learn from the past. It is intended that the volume should have a practical interest for those concerned with the improved use of arid and semi-arid lands. In recent decades, new techniques of study especially in dating the past have imparted a growing precision to matters which previously were only the subjects of vague speculation, and it is becoming possible to piece together, stage by stage, the sequence of land use over the centuries, sometimes millennia, of human occupation. The story is still very far from being complete; there are fascinating problems of correlation between one region and another and apparently some great contrasts; but the time seems opportune to bring together a synopsis of the present state of knowledge, region by region, by those whose scientific work has identified them with the different parts of the world's arid zone.

From the inception of its work the Arid Zone Unit of Unesco faced an initial problem in the definition of aridity and the delineation of those parts of the earth's surface to be designated very arid, arid, and semi-arid. To set, as it were, the limits of the study, I have reproduced here the maps specially prepared for this purpose by Dr. Peveril Meigs, together with the definitions adopted.

It is perhaps superfluous to remark that the fundamental cause of the arid zones is climatic. Whilst it is simple enough to describe the climates of the hot and the mid-latitude or so-called temperate deserts of the world, to give figures of temperature and precipitation, to describe the usually irregular precipitation régime and to indicate the less abundant or less well-known data on such features as insolation, radiation and evaporation or evapo-transpiration, it is far from simple to attempt an explanation of the causes. The old concept of two main high pressure belts, shifting northwards and southwards with the seasons, encircling the earth just outside the tropics, associated with outblowing winds and below which were the great deserts, gave place to a concept of great air masses of contrasted character and behaviour. In the past few years innumerable observations on the upper atmosphere, necessitated largely by practical requirements of modern aircraft and developments in communication and intercontinental missiles, have vastly enlarged our knowledge of the circulation of the air and have necessitated the recasting of our fundamental concept of climatic causation. So rapid and far-reaching have been the additions to knowledge that any account of the restless atmosphere tends to be out of date even before it reaches publication.

Yet the causation of the arid zone is clearly of basic importance and I am greatly indebted to Professor Kenneth Hare for preparing a lucid statement on the present state of knowledge. There are two implications from his study. The first is that the general circulation of the atmosphere, including the main pressure belts and planetary wind systems, would seem to be determined by the size, shape and movement of the earth and the physical character of its atmosphere, so that variations are only theoretically possible within certain limits. The extratropical high pressure belt and its attendant arid lands must have lain between a belt of westerlies and the belt of trade-winds and can only have shifted north and south within quite narrow limits at least within post-Pliocene times. In other words the arid zone must have remained a permanent feature with a strictly limited shift north and south. In the second place since the cause of aridity remained, the arid zone must have remained with comparatively minor swings towards less arid or pluvial conditions and towards extreme aridity.

Another very important conclusion follows from the study of present-day conditions. The arid belts are not continuous round the earth, neither are pluvial belts. Pockets of arid conditions interrupt humid belts—a good present-day example is the arid region of north-east Brazil. This phenomenon is due to what is now commonly called the cellular structure of the atmosphere. It follows that in the past when glacial advances resulted in moister conditions equatorwards any such 'pluvial belts' would have been interrupted by pockets or cells of aridity.

If this fundamental concept of atmospheric circulation is correct, it sets limits within which the historical records must be viewed. Dr. Butzer's chapter on climatic change since the Pliocene follows on naturally but there clearly cannot be world-wide correlation of 'arid' and 'pluvial' periods. If indeed cells of aridity interrupted pluvial belts and vice versa, the sequence in one region may well be complementary to that in another. Human migrations may well have been prompted by deteriorating conditions in one region and improving conditions in a neighbouring tract. To some extent the same difficulties exist in correlating glacial periods. Even if four main ice advances can be traced both in Europe and North America were they synchronous or staggered in time?

The chapters which follow deal successively with the main regions of arid lands. In each case the author was asked to avoid making his account a mere history of agriculture, but rather to present a synthesis of geological, climatic, biological and human factors which appeared to have influenced the sequence of land use. In particular to know the favourable factors through which men achieved success and prosperity on the one hand or to determine the unfavourable factors which led sooner or later to the abandonment of land cannot but assist in the elucidation of the problems of the present day.

It might have been more logical to begin the regional survey with Australia where the story of the interaction between the white man and an arid environment is a well-known and well-documented story of less than two hundred years. The aboriginal inhabitants, there measured in a few thousands, had not emerged from the Stone Age: they neither knew the arts of tilling the soil nor herding animals and so their influence on the environment was minimal. They knew fire—though not for the purpose of boiling water—but unlike inhabitants of most of the semi-arid tropics elsewhere, had no reason to burn off the natural vegetation to improve pasture, and such bush fires as occurred were more likely to have been occasioned by lightning. Though the Australian story, so well told by Sir Samuel Wadham, may be one of a primitive environment almost untouched by man, when settlement did take place from the end of the eighteenth century it was by the white man, well equipped mentally and technically with many centuries of experience behind him.

Australia in this respect is unique and it seemed better to attempt to deal first with those parts of the arid zone where man's battle with Nature has been waged over a very long time. The extremely difficult but fascinating task of dealing with the ancient civilizations of the Near and Middle East —roughly from the Mediterranean and Egyptian border in the west to the Pakistan frontier in the east and northwards to include the Anatolian-Iranian Plateaux—has been undertaken and ably executed by Dr. R. O. Whyte. This great region poses most, if not all, of the problems of the arid lands. First the most obvious if most baffling of all : why should man so early have chosen the arid or semi-arid lands, there apparently to wage unceasing war with Nature, in preference to the cooler lands with reliable rainfall? Even if human settlement in the cooler, moister lands of north-west Europe, even to the margins of the ice-sheets, was contemporary, there must still have been abundant room. Why therefore choose the hard way? Was it because man, lacking a protective fur, is naturally a tropical animal; was it because these lands yield the wild animals suitable for domestication and soon to be so used, or the large seeded grasses waiting simply to be improved by cultivation? Or was it because the very struggle against Nature in the semi-arid margins caused man to organize himself and so to develop himself as a social animal, capable of concerted action? Through many millenia it is clear that man suffered fluctuations in fortune which it is difficult to dissociate from climatic change. Familiarity with famine is clear enough from the Biblical narrative: how far plague, pests and pestilences were responsible for mass migrations and abandonment of land is far from clear. The modern curses of irrigated land, waterlogging (associated also with spread of disease) and salinification, were known of old and must certainly have played their part in a changing pattern of land use.

The history of land use in Egypt, so freshly and vigorously narrated by Professor Hamdan, is at one and the same time a history of one of the oldest and greatest civilizations on earth and a reminder of the complexity of the work of improving the arid lands —very far from a simple problem of supplying water. The difficulties in interpretation of the evidence are at once apparent. Does the siting of pre-historic settlements on the margins of the Nile Valley indicate a pluvial period when the valley itself was a vast morass and the vegetated margins more attractive, or merely that primitive man learnt how to use water for irrigation first on a tiny scale at the mouths of subsidiary wadis? In the long centuries which followed of using Nile water and the gradual, now almost complete, change from basin irrigation to perennial irrigation, the values of physical factors have completely changed. The once vital Nile mud and silt which built up year by year the fertile valley floor is now regarded simply as a nuisance, clogging the reservoirs. A high flood on which the old winter crops depended is now a danger which may inundate the new summer crops; the river once encouraged to spread over its floodplain as widely as possible, is now carefully restricted to its fixed channel. Egypt has not yet reached final adjustment to the many factors involved in irrigation; expert opinion still differs radically as to future aims.

The dry north-west of the Indo-Pakistan subcontinent, which is discussed by Professor Bharadwaj, shares some features with the Tigris-Euphrates basin—its climate to some extent, its physical setting and cultural heritage—and also some features with the Nile—the reliance of the unhappy valley of Sind on the waters of the Indus. Once again is illustrated the strange fascination of arid lands to early man, once again the puzzling rise and fall of civilizations and the abandonment of sites. The meeting place of the lower air currents of the Indian monsoon with the westerly air-streams in the upper atmosphere, the Indo-Pakistan dry belt has particularly fascinating climatic problems. The sequence of climatic change may well be quite different from that determined elsewhere.

The Dry Belt stretching from the south-east of Europe eastwards into the heart of Asia, discussed by Professor Kovda, lies well outside the tropics and differs widely from the hot deserts of the extra-tropical high pressure belts. If for no other reason, the intense cold of winter is a factor almost unknown in most other regions discussed in this book. Russian scientists have been the pioneers in the modern concept of pedology or soil science and more work has been carried out on the soils of arid lands in the USSR than in other parts of the arid zone. The development of soils is closely linked with the evolution of land forms and it becomes clear how close, but at the same time how complex, is the relationship between geological structure and parent material, geomorphological evolution of land forms, soils, natural vegetation, and land use—potential as well as actual.

The Sahara with its northern margin merging into the Mediterranean lands of the Maghreb (Morocco, Algeria and Tunisia), discussed by Professor J. Despois, and its southern margins passing through the Sahel or Sahelian Zone into the tropical savannas and grasslands of West Africa, poses a new set of problems which are studied by Dr. Monod and Dr. Toupet. In the absence of a great source of water comparable with the Nile, the Sahara exhibits the reaction of man to the arid regions as such. The Sahara has no Fertile Crescent comparable with that of the Syrian saddle: its immense and immensely dry heart has produced a human response in nomadism based on the camel and so tenuous cultural links between the semi-arid margins to north and south. To the north of the Sahara, across the Mediterranean, lies the continent of Europe where the succession of glacial advances and retreats during the Pleistocene has been so continuously and intimately studied. In contrast to the east-west Himalayan chain of Asia, no physical mountain barrier separates Europe from North Africa, so that the sequence of glacial and interglacial periods in Europe must have been reflected in some marked way over the Saharan wastes. The one view is that the glacial episodes in Europe correspond with pluvial periods in the Sahara when rainfall, and consequently vegetation, were more abundant than at present and the environment more conducive to human settlement and activity. On the other hand, it may be that the zone of maximum aridity simply moved southwards during the ice advances of Europe with corresponding shifts on the foci of human development. The greatest interest attaches to the question : what is happening at the present day? The great African empires of a few centuries ago—Ghana, Mandingo or Mali and Gao had their centres in regions which are now so arid as to be almost devoid of permanent settlements. It would seem therefore that the Sahara is still extending, at least southwards. But how far any extension, even if proved, is due to climatic deterioration and how far to man's own misuse of land in overgrazing, in exposing soil to erosion or in cultivation leading likewise to an extension of a man-made desert is another matter.

Monod and Toupet emphasize a significant principle which appears to have been much overlooked. It is an important aspect of the adjustment between the vegetation, especially of semi-arid margins, and grazing animals whether wild or domesticated. A bad season, when little or no rain falls, results naturally in a sparse growth of herbage with the result that a large number of animals, especially the young, are unable to survive. Next season, with even average rainfall, the vegetation recovers rapidly because there are few animals; moreover it covers more of the surface and so forms a natural check to surface erosion which is hastened by the trampling feet of many animals. Man, by bringing in fodder for his animals in bad years, prevents the operation of this natural adjustment.

The masterly summary of the New World scene by Dr. Pedro Armillas shows first of all the early date at which man reached the New World. Even if the date of possibly 37,000 years ago for hearths created by man in Texas be subject to a wide error, it is now clear that the great civilizations in both North and South America were evolving in parallel to their counterparts in south-western Asia at the same time. In America, too, the arid margins seem to have attracted man just as they did in the Old World, whilst better watered lands remained sparsely inhabited if occupied at all. In the New World there is the same puzzling sequence of occupation and abandonment of land, and possible correlation with climatic change.

When the European, with his high level of technical skill, invaded the Americas following the discovery of the continent by Columbus in 1492, a phase of conquest of the existing settled lands, which included the empires of the arid zones, was followed in due course by a phase of land settlement. As lucidly described by Professor Richard Logan the vast arid and semi-arid region lying between the Rocky Mountains and the ranges bordering the Pacific Ocean remained a great empty void virtually unknown to the white man till the middle of the nineteenth century. The arid lands played little part in the early development of the United States of America; today their importance is considerable and increasing, but this is the story of the herdsman and farmer used to more humid conditions adapting his mode of life to new and at first strange conditions.

By a fortunate coincidence Professor Logan has recently spent a year in the arid regions of South West Africa, and so has been able to contribute a comparative view of the changes in land use under European influence in an area which parallels in some respects conditions in western North America.

Professor W. J. Talbot in his careful and well documented chapter on South Africa has a story to tell which is both fascinating and of the utmost importance. Arid South Africa, at the time when the Bantu were moving southwards towards the area and the early white settlers were beginning to penetrate north-eastwards from the Cape, was very sparsely peopled by nomadic or semi-nomadic primitive peoples. Though more numerous than the Australian aborigines and at a different cultural level, they had interfered only slightly more with the natural vegetation than had their Australian counterparts. On the other hand, grazing animals were more numerous and varied and because arid southern Africa is continuous with the well-populated regions to the north, herds of herbivores would naturally increase in years of good rainfall and herbage. But the great interest in Professor Talbot's contribution lies in the account he gives of the successive introductions—of animals, plants and techniques—by the invading white man. Failures have been more numerous than successes in this sequence of trial and error; what is particularly to be noted are the secondary effects of so many of the introductions. South Africa affords many examples of the role played by fluctuations in world demand and world prices. Few better examples could be found than the rise and fall of ostrich-farming unless the Karakul ('Persian lamb') industry repeats the story. The present use of many thousands, even millions, of acres depends upon the vagaries of women's fashions in the sophisticated circles of London, Paris and New York.

As already noted, Sir Samuel Wadham's contribution on Australia describes a unique example of the penetration of technocratic man into a particularly isolated, specialized and untouched environment. Even more than in South Africa it is noteworthy as illustrating the dominant role played by fluctuating world prices and world demand for primary produce in determining land use in a region remote in distance from consuming centres.

That the incidence of human disease, both endemic and epidemic, has played a very important part in all tropical lands, including their arid margins, may be familiar enough, but is little known in detail. Dr. Paul Russell's survey of the incidence of malaria and bilharziasis deals with the two principal plagues of mankind associated not so much with arid lands as such as with the irrigated areas within them. The cause of both is now well known and to that extent easily controllable, yet he makes clear how, unless there is a better understanding between irrigation engineer and medical officer the benefits brought by the former may be completely cancelled out by the spread of these two diseases. Still today in some areas more irrigation means more disease and human suffering—a very serious paradox of our age.

Although their importance is very great, malaria and bilharziasis are far from being the only plagues affecting human settlement in arid lands. Dr. Jacques May has considered in outline some of the other problems of public health. The lessons of history are clear enough: technical progress in engineering or agriculture, which would seem to open up a new era for arid lands, have been negatived by repercussions on the conditions of human life. The danger is still there. It cannot be too strongly emphasized that there must be the fullest understanding and collaboration between the experts in their separate fields.

Having thus noted briefly the highlights presented by the separate regional contributions, is it possible to generalize regarding other features than climate in arid regions? What can one say which is generally applicable to such other factors of the environment as geology and land forms, subsurface structure, water supply, weathering and soils, or of vegetation cover?

Geologists have long recognized that the cycle of weathering and erosion in arid lands is quite different from those found in more humid conditions. It follows that the resulting land forms are also different and often highly characteristic of the varying degrees of aridity.

This history of land use in arid lands is concerned only with the few thousand years of man's occupance of the earth's surface. This is a truly infinitesimal period when compared with the hundreds of millions of years of the earth's geological history. The rocks now exposed at the surface, or lightly hidden by a thin mantle of soil or superficial deposits, bear witness to this long history. Whether or not the continents as we know them have drifted apart, whether or not the great Pacific Ocean is a scar left by the departure of the mass which is now our satellite the moon, whether or not the poles and the axes of the earth have changed in position from time to time, it is clear that the arid zones of the world today are not a primeval feature of the earth's surface. In the arid lands are to be found representatives of the rocks laid down, under the most varied conditions, in all past ages. The importance of this lies in the fact that the solid geology, the underlying structure and the range of rocks present are just as varied in arid lands as in any other part of the earth's surface. There is, indeed, no connexion between present climatic conditions and the rocks of the solid crust and the same applies to deposits of economic minerals. Coal seams which represent remains of vegetation of hot, steaming swamp forests are found in rocks underlying the heart of today's deserts; oil, originating in brackish sea margins is likewise to be located in the most arid land masses. In the deserts may be found rocky ridges built up of the most ancient of known rocks side by side with volcanic cones scarcely yet cool from their geologically recent eruption. Some deserts are underlain by vast stretches of limestone, others by sandstones, shales or slate; elsewhere huge masses of granite, once molten and solidifying at great depths, have since been exposed at the surface by the removal in time of the overlying rocks. There is, in fact, little if any limit to the range of rocks present in arid lands, little if any restriction to the range of minerals valued by man—economic minerals—to be found in the deserts and their margins.

What is distinctive in arid lands is the sequence of weathering and erosion. Whereas in humid climates the major role is played by water in its various forms—as rain, hail, snow—through the action of frost, running water and moving ice on a surface partly protected by vegetation and soil, in arid lands sun and wind play the major roles, together with occasional but violent bursts of rain, on a surface largely unprotected by either vegetation or soil.

Bare rocks, fully exposed to the sun's rays (insolation), often from a cloudless sky by day, become intensely heated in the surface layers with an enormously powerful force towards expansion; on the margins of a rock face, the surface layer may be in shadow and remain cool, firmly anchored to the whole mass. The obvious result is for the heated surface layer, thus tied at both ends, to burst away as a comparatively thin sheet, rather like one skin of an onion. Not infrequently the separation of the surface layer in this so-called onion or spheroidal weathering due to insolation takes place with an explosive crack like a pistol shot. Though the efficacy of insolation of this type has been questioned recently by some writers it would seem to be particularly well seen on exposed surfaces of granite and granitic gneisses. There are two results: smooth rounded surfaces of rock, not infrequently almost spherical masses, and a debris of angular fragments. But most rocks consist of a mixture of minerals which may have differential degrees of expansion when heated. The tendency is for the rock fragments to disintegrate into smaller fragments, individual minerals particles and even dust. Although the spheroidal weathering of granite is typical, other types of rock break into sharp angular fragments and the result closely resembles shattering due to frost. So sharp may be the surfaces of the rocks from which fragments have been flaked off that the stoutest boots are cut to pieces in a short trek across the desert.

Insolation leaves a mass of rock debris well suited to the maximum action of wind. According to the strength of the winds only fine dust, or dust and silt, or dust, silt and sand, or dust, silt, sand and small pebbles, are removed leaving once again bare rocks. The wind sorts the removed material mainly according to particle size: by blowing sharp particles against a rock face the latter may be smoothed and polished (giving one form of 'desert patina'), and upstanding masses of rock may be undercut. The sand particles become themselves rounded and polished—a characteristic feature of wind-borne sands in contrast with the continuing angularity of smaller grains when waterborne.

Even in the most arid areas in the heart of the great deserts, rainstorms do occur even if only at intervals of years. Rain may fall with great violence on the unprotected surface, imperfectly provided with drainage channels, so that each storm produces raging torrents, sweeping rock debris from mountains, hills and ridges to lower levels. Even large blocks of rock are moved and roughly rounded in the process, so that rock fans of coarse boulders are left as an aftermath. Where the water sweeps out over a flat surface huge shallow temporary lakes are formed: over the surface a film of mud or silt is left when the water evaporates.

Away from the extreme aridity of the heart of the desert, the parts played by rain and running water become more marked. Where there is an upstanding rocky ridge, a rock-sand cone or fan forms at the foot with its apex pointing up to where an intermittent torrent discharges from its mountain gorge. Several such fans may join up to form a piedmont belt along the foot of a ridge giving place to a plain over which the finer debris may be spread. Where rain falls on unconsolidated rocks the well-known 'badland' type of country is developed: the existence of boulders within the mass of finer material will result in earth pillars, each capped by a resistant mass. Where horizontal or near horizontal strata include harder or more resistant beds the well-known mesa type of country results.

It now becomes clear that certain characteristic land forms or types of country will be developed in arid lands and that they are likely to be repeated from one region to another. There is a very close correlation between the different types of country and their possible utilization by man.

In the first place vast areas of the arid zones are occupied by bare rock. Except where they may have mineral resources, the rocky mountain deserts must always remain negative areas in so far as human settlement and development are concerned. A distinction must however be drawn between the rocky deserts due to extreme aridity and those, often so very similar in superficial appearance, which are largely man-made, where the destruction of the natural vegetation cover—scrub and forest for timber and firewood, grass and low herbage by overgrazing—has exposed first the soil for removal by erosion and then the bare rock. The poor, bare, eroded hills of South China, for example, though closely resembling the rocky hills of arid lands actually occur where rainfall conditions are excellent for good forest growth. Without doubt, many settlements on the margins of the arid zones have in due course been abandoned because of man's misuse of natural resources; this includes not only the destruction of forest and grazing of the hills, but also the consequent exposure of more fertile lands to uncontrolled torrents from the now barren hillsides. The rocky deserts vary widely in character from the smooth boulder strewn granite inselberge to the waste of volcanic debris making up the *harrah* of Arabia or Syria, or to the limestone and sandstone mesas of the Nubian desert. Though rather different in character the badlands developed on unconsolidated sediments offer but little more incentive to settlement by man. The rock screes and boulder cones of the piedmonts may be almost as unattractive or useless for settlement as the rocky deserts but they often have a function in water storage to be noted later.

Of common occurrence and wide extent but varied origin are the so-called gravel deserts—stretches frequently almost level with a gravelly surface of rounded or sub-angular stones of varied size and often showing the polishing or patina due to wind action. The stones are usually loosely scattered on a hard level surface and can be cleared to leave an excellent motor track. However, the gravel plains rarely offer attractions for settlement or development.

In popular imagination the desert is associated with sand. Though sandy deserts are very widespread they are in actual fact less extensive than rocky deserts. In the semi-arid margins the sand may be 'fixed' by vegetation but in the heart of the true desert the sand is constantly being moved by wind. According to the strength of the wind, ridges of sand parallel to, or dunes (including the crescentic *barchans*) at right angles to, the dominant wind direction may be formed (as noted especially by Professor Bharadwaj in the Great Indian Desert or Thar). Wide stretches of soft moving sand are difficult to cross, even by experienced desert nomads, and the real sandy deserts tend to be completely uninhabited. A good example is the so-called Empty Quarter or Rub el Khali of Arabia.

The fine material blown by the wind from desert regions is deposited as a mantle of loess especially on the less arid margins or wherever wind velocity lessens. In contrast to the water-borne deposits, laid down in near-horizontal sheets, loess is typically unstratified and is deposited as an irregular blanket over hill and valley alike; lying thickly in basins or hollows, thinning out against ridges the higher parts of which are likely to remain uncovered. It is wrong to refer to loess as soil but it is magnificent soil-forming material. Although, too, it is an aeolian deposit transported and laid down by wind, there is a natural tendency for its movement to be arrested and for it to be deposited where the atmosphere becomes moister. Some loess deposits are partly re-sorted by rainwater or streams on these margins and deposits known in some countries as brickearths and adobe (or by the French as *limon*) are of this origin. Provided water is available—from rain, streams or underground sources—loess regions are inherently fertile and so attractive to human settlement and development.

It is a short step to the lacustrine silts and muds left over the floors of basins after the latter have been temporarily flooded by rainstorms sweeping down mud, silt and sand from the surrounding hills. Such desert basins are very common: they rarely have outlets and the water is lost by evaporation. In the course of time any soluble salts are left behind and potentially fertile lands are ruined for cultivation by salt accumulation. In certain cases, notably the caliche or sodium nitrate deposits of northern Chile or the borax deposits elsewhere, the salts may be economically valuable. More often the desert basins are rendered useless by them. Where sufficient water is available for irrigation and drainage can be arranged it is sometimes possible to wash the salts out of such lake deposits and some valuable agricultural areas may result.

Where rivers flow through arid regions, deriving their waters from more humid regions, they bring and deposit alluvium. Such is the origin of many of the most fertile and valued tracts in arid lands—the valley and delta of the Nile in Egypt, the plains and deltas of the Tigris-Euphrates in Iraq, the Indus valley and delta in Sind, are outstanding examples. As with loess it is wrong to refer to alluvium as soil, but it is magnificent soil-forming material, especially where, as in Egypt, it is derived from a great variety of rocks, and so is rich in most of the mineral requirements of plants. Whereas the old system of basin irrigation in Egypt enabled the annual Nile flood to gently deposit its load of fine silt as a thin film, thus building up and renewing the soil year by year, modern methods of irrigation distribute only water over the land, the silt being trapped behind the barrage or dam where it is simply an embarrassment.

An important aspect as yet imperfectly studied or applied is how to arrest the alluvial material and spread it where it will build up new and fertile lands. In recent decades too much attention has been paid to attempts, sometimes futile, to prevent erosion, while the equally vital question of building-up lands with eroded material has been neglected. In the north of the Indus Plain of West Pakistan some dams have been so constructed as to arrest mud and silt-laden flood water and allow the material to settle before surplus water is led off through masonry lined sluices.

Ultimately, except for the exploitation of minerals, the utilization of arid lands depends upon the availability of water. Speaking generally the arid lands are devoid of surface water save where a great river passes through them or where a lake lies in a basin, usually a basin of inland drainage losing its surplus water by evaporation. Consequently, underground water resources are of special interest and importance. Where the solid rocks underlying arid lands are of ancient crystalline schists and gneisses—e.g. over large parts of Africa—the characteristically irregular system of cracks and fissures results in an irregular and uncertain distribution of underground water: there is no regular water table. A well dug with great difficulty and expense even to great depths may be completely dry, whereas a few yards away a shallower well fortunately tapping an underground fissure may yield a good supply. It has been frequently observed that the African of the semi-arid margins is not water conscious: he prefers to rely on a precarious rainfall rather than to seek security in a well supply. The main reason, however, for this attitude is not far to seek—it is the nature of the subsoil over much of the continent.

Where the strata underlying arid lands are of bedded silts, sands and gravels, underground water behaves as it does in more humid lands and there is a regular water table, though it may be at too great a depth to be reached by ordinary wells. Where the strata are arranged in the form of a basin, artesian conditions may exist. The arid heart of Australia has a number of huge artesian basins: here as elsewhere there still remains the long-standing controversy regarding the origin of the water. Is it constantly if slowly renewed from rain falling on the distant margins of the basin, or is it water of 'plutonic' origin which will not be renewed when used up? Australia is typical of a widespread feature of artesian waters: from great depths they are at a high temperature and highly mineralized. A considerable content of salts is permissible if the waters are to be used for stock, but not if the water is to be spread over the lands as irrigation water. Recent discoveries of artesian water or water at depth under other arid lands—notably the Sahara—may considerably alter the economic possibilities of these lands.

Two special aspects of arid land hydrology call for comment. Although there may be no surface streams, it is common to find in desert or semi-desert regions developed on porous sedimentary rocks, a complete underground system of regular water courses. Sometimes, but not always, the surface shows the existence of main valleys with tributary valleys below which water is comparatively near the surface. This is marked by an increase in the scrub vegetation of the desert—sometimes difficult to detect on the ground but standing out clearly when seen from the air. Indeed, complete underground river systems may be detected and easily mapped from air photographs. The oases of desert lands are of course due to the water table reaching sufficiently near the surface for the water to be accessible to plant roots. Dr. Armillas notes some interesting cases of man-made oases in South America where sand is dug out to a sufficient depth for plant roots to tap underground water.

The second special aspect is the very common case where the ridges surrounding or adjoining desert basins attract a heavier rainfall than the basins themselves—it may be a winter snowfall also. The water runs off after a storm in short-lived torrents until it reaches the piedmont gravel fans, sometimes to flow over the surface, but more often there to sink into the loose sediment and to be lost to sight. But such gravel and alluvial fans form natural reservoirs into which a tunnel, sloping very gently upward from the plain into the fan, may be driven so as to tap the stored water. Such tunnels variously known as *foggara* (North Africa), *qanat* or *kanat* (Iran, Iraq, etc.) or *karez* (Baluchistan) have the advantage that the water is protected from evaporation till it is actually brought out on to the fields or into settlements. A very large number of desert margin settlements are thus associated with the plain-ward margins of alluvial and rock fans. They may be called oasis settlements. The great settlement of Damascus, with its lovely gardens, is essentially of this type. A modern and important development is the substitution of pipes for the old expensive tunnels.

Two widespread features of arid lands are closely linked with hydrology. One is the mechanical action of the raindrops during the occasional rainstorms in compacting the surface. On a very dry surface rainwater does not readily penetrate: the mechanical force exerted by the falling raindrops tends further so to compact the surface that the rain instead of penetrating and benefiting the soil runs off the surface, collecting into rivulets and then into torrents sufficiently powerful to cut through surface layers and to start gulley erosion. These features are accentuated by a second phenomenon—the tendency for the development of what is often called a desert crust (*croûte désertique*). Waters do not circulate freely in semi-arid and arid soils so that, as noted later, semi-arid soils present only a feebly developed profile; in arid lands potential evaporation is in permanent excess of rainfall. In place of the downward leaching of humid lands there is an upward movement of water and its loss by evaporation. Salts are left behind: concretionary nodules of iron oxide or calcium carbonate are formed in the subsurface layers or efflorescences of sodium nitrate, sodium chloride, calcium sulphate and other highly soluble compounds formed on the surface. But even more important is the frequent formation of a thin hard surface crust sometimes predominantly of iron oxide (iron pan) or limestone or worse still of silica. Even where irrigation water could be made available, vast areas must remain useless where such crusts have been formed. On a small scale even pebbles may exhibit a hard surface—another form of desert patina.

Soils, strictly speaking, do not exist in the deserts, only the varied types of soil-forming material already noted. In the semi-arid regions it is a different matter. In 1950, Mr. G. Aubert, on behalf of the International Union of Agronomic Sciences, prepared a paper for Unesco on the soils of the semi-arid regions of Africa. Although his paper deals primarily with the two roughly parallel belts north and south of the Sahara with an average annual rainfall of between 100 mm. (4 in.) and 500 mm (20 in.) with marked seasons and a wide temperature range, his descriptions of soils and soil-forming processes are of broad general application in arid margins. Many of the more important aspects of soils and soil formation in arid lands have been considered in this work by Professor Kovda.

The study of the natural vegetation of arid and semi-arid lands is obviously a vast subject which cannot be considered in detail in this history of land use. In some of the chapters which follow the authors have enlarged upon aspects which they have considered of special significance. To a very considerable extent the vegetation of semi-arid lands is an impoverished modification of that found in neighbouring but better-watered country. It follows that, if more water is made available, the vegetation will develop into that characteristic of those neighbouring areas. But it is also clear that one can match with irrigation water the equivalent of rainfall in such a way that quite different climatic conditions can be created. Professor Hamdan discusses this in relation to the agriculture of Egypt. In those parts of the Nile Valley where the temperature range is comparable, irrigation water equivalent to 80 in. of rainfall will 'convert' the land to a tropical monsoon climate. Using the word 'oasis' in the widest sense, many vegetation oases have been made to reproduce conditions quite alien to surrounding vegetation.

In arid lands the struggle of vegetation is first to obtain moisture and secondly to conserve it. Water is frequently available in depth, hence the development of extremely long roots. This may render the vegetation extremely difficult to clear, and this factor alone has ruined a number of reclamation schemes. The long-rooting system often allows the plant an extraordinary power of survival—important where poor scrub pasture has been overgrazed. In the conservation of moisture many plants exhibit reduced leaf surface; the form assumed by many species of *Acacia* is so different under arid and moist conditions that it is difficult to believe that only a single species is involved. Similarly transpiration may be hindered by the reduction in number of stomata, development of leathery or wax-coated leaf surfaces, and in other ways. Even a slight amount of irrigation water may thus render a dry grazing area more palatable. This history of land use is too early to be able to deal with the effects of overhead irrigation or artificial rain, now proving so very effective with many crops.

Many examples are given in this work of the fluctuations of animal life in rhythm with the vegetation cover—the arrival of herbivores and attendant carnivores in vast numbers when good rainfall has increased arid zone vegetation. There is no doubt that the numbers of nomadic man have fluctuated in the same way together with his flocks and herds. But man is a thinking animal, and where he is concerned it becomes very difficult to generalize: the chapters which follow must be allowed to speak for themselves.

# THE CAUSATION OF THE ARID ZONE

*by*

F. Kenneth Hare

*McGill University, Montreal, Canada*

The object of this chapter is to inquire into the reasons for the widespread aridity of subtropical latitudes, where the arid zone is situated. On a world scale there is a sharp minimum of rainfall near 30° latitude in both hemispheres, and in places—notably in west coastal Chile and Peru—rainfall is almost unknown. Since this aridity affects oceans as well as continents, it is apparent that there must exist some effective process whereby rainfall is suppressed, for there is no shortage of water for evaporation. We shall look for this process among the dynamical factors associated with the general circulation of the atmosphere.

The immediate causes of the aridity can be listed at once. First, we may place the tendency for divergent wind-flow at low levels, especially in the poleward parts of the trades. This divergence requires that general subsidence of the air column occurs throughout the lower troposphere, where the water vapour is concentrated. Dynamical warming associated with this subsidence tends to lower the relative humidity and disperse cloud; it also creates an impressive degree of hydrostatic stability, so that convection currents and shower-type precipitation are inhibited. At sea the trades have a shallow, moist layer capped by a stable or inversion layer, above which the air is very dry. Over land, as in the Sahara, in northern Mexico, Australia and much of the Middle East (in summer) the dryness may extend to ground level. Hence surface divergence, general subsidence, low humidities and an absence of deep convection form a causally connected sequence over much (but not all) of the subtropical world.

The second cause of aridity, not truly independent of the first, is the existence of high pressure near the 30th parallels. Over the oceans, this high pressure is visible at sea level, but inland it may be necessary to ascend to levels of 2-3 km. before the anticyclonic régime manifests itself. In the middle troposphere (2-6 km.), a layer very significant in the propagation of disturbances, the subtropical high pressure belt is continuous in both hemispheres, though considerably modified in form over southern Asia in summer. The subtropical high pressure belts separate the circumpolar westerlies from the tropical easterlies. As is well known, both westerlies and easterlies are affected by travelling wave-perturbations, which account for a good part of the precipitation in both régimes. The amplitude of both sets of waves is a minimum near the axis of the subtropical highs; hence the subtropics are least likely to be affected by rain-bearing disturbances. This constitutes the second cause of widespread aridity.

In general it should be stressed that, while low humidities through a deep layer in the lower troposphere invariably lead to aridity, very dry climates may occur in areas of high atmospheric humidity. Thus parts of the arid south-western United States are dry, not because of low humidities, but because of the ineffectiveness of rain-making disturbances [1].[1] A further point is that remoteness from the sea is not a guaranty of drought; high moisture contents occur deep in the interior of Amazonia, more than 1,200 miles from the ocean along any possible direct streamline, and rainfall is heavy. Yet extremely low rainfalls occur in many areas along oceanic coasts, as in Chile, Peru, Morocco and South West Africa. The point is, of course, that local sources of evaporation play a small role in precipitation, which tends in most instances to fall from moist airstreams whose humidity is derived from very remote surfaces. Recent research into vapour transport [1, 3] has emphasized that the true sources of the precipitable water over many large regions are very different from the usual idea. Proposals to modify the rainfall régime within the arid zone by flooding depressions some thousands of square kilometres in area are doomed to failure; the effects achieved would be very small in scale.

1. The figures in brackets refer to the bibliography at the end of the chapter.

Clearly, then, we have to look for the causes of the aridity in the general circulation of the atmosphere; the persistent tendency towards divergence and subsidence in the subtropics, and the quasi-permanence of the subtropical highs, are facts that both belong to the largest scale of meteorological phenomena, and it is to these features that the term general circulation applies. Comprehension of this circulation has made great strides in the past decade, during which upper air data have become plentiful. But we are still far from a convincing picture, especially in the tropics and in the stratosphere. Hence the account that follows is necessarily rather qualitative.

## THE ROLE OF THE TROPICS IN THE GENERAL CIRCULATION

The general circulation serves as the vehicle whereby vast quantities of heat, momentum and water vapour are transported about the globe. Especially significant is the meridional flux of these elements, which are present in excess within the tropical world, but are in deficient supply nearer the poles. Since the mean circulation of the atmosphere is zonal (i.e., east-west or west-east) in all latitudes, no obvious mechanism exists whereby the required transport can be effected. Modern research into the general circulation has been largely directed at discovering this mechanism for the poleward flux. Out of this research fairly clear answers have already emerged as to the causes of subsidence and high pressure in the subtropics. We shall examine the main findings, concentrating for the moment on heat and momentum, water vapour being more difficult to discuss.

The need for a poleward momentum transport is fundamental, though it is difficult to visualize. The earth and its atmosphere possess absolute angular momentum by virtue of their eastward rotation about the polar axis. The total of this eastward momentum must remain constant if no external torque acts on the earth, but exchanges are possible between rigid earth and mobile atmosphere. Thus an easterly windstream is one whose angular momentum is slightly less than that of the earth below, whereas a westerly wind has a slight excess of momentum. Friction between these winds and the earth's surface constantly tends to decrease the windspeed, whatever the direction. An east wind that decreases in speed is actually undergoing an acceleration towards the east; hence its absolute angular momentum increases. The easterly surface winds of the tropics are thus involved in an upward flux of momentum from earth to atmosphere. The reverse is true in mid-latitudes, where the frictional drag on the westerlies produces a large downward flux from air to earth. Since both trades and westerlies are maintained from year to year, it is obvious that the gain in momentum in the trades must balance the loss by the westerlies, and that there must be a large-scale transfer of momentum polewards across subtropical latitudes. Starr and White [14] calculated that the total flux northwards across 31° N. was $26.4 \times 10^{25}$/gm./cm.$^2$/sec.$^{-2}$ in the year 1950. It may be added that the polar easterlies are negligible as a momentum source.

The northward heat flux, also a necessity, arises from the gain in energy experienced by the tropical world by radiative processes. Between the 35th parallels, net solar radiation exceeds outgoing terrestrial radiation over the year as a whole, so that there is a large net income in energy. Since tropical temperatures are remarkably constant from year to year, and even from month to month, it follows that a means must exist for transporting the excess heat polewards. Some of the export will be in the form of sensible heat and some in that of latent heat (if the energy was used to evaporate water, which was then removed as vapour). In whatever form, however, the need for export is unarguable. It has been computed [14] that the transfer northwards across 31° N. in 1950 was $5.9 \times 10^{14}$ cal./sec.$^{-1}$.

Both heat and momentum are elements that are readily transported by moving air or water. Ocean currents transport a part of the tropical excesses, but much the larger part is carried away by the wind. In fact the entire circulation of the atmosphere may be thought of as the result of the need for this transport, together with the required changes in form of the energy. We have already seen, however, that the mean circulation is zonal in all latitudes. The existence of vast westerly vortices around the poles and of a great girdle of equatorial easterlies seem at first sight to offer no suitable transport mechanism, since they all blow at right angles to the required direction.

To overcome this difficulty, successive meteorologists in the first three decades of this century supposed that there existed vast, vertical meridional plane circulations, involving enormous mass transfer

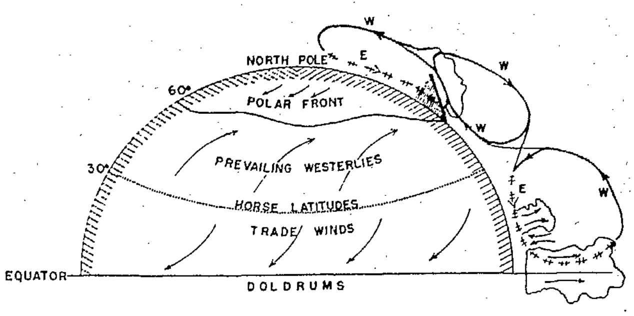



FIG. 1. The three-cell meridional overturning circulation model (Rossby [11]). It is now doubtful whether the two northern cells exist, the required poleward transport of momentum, water vapour and heat being carried by horizontal eddies (cyclones and anticyclones).

across latitude circles. Rossby's 1941 version [11] forms Fig. 1. Three cells were envisaged in each hemisphere.

In the tropics, the trade-wind cell involved an equatorward flow at low-levels (the north-south-component of the trades), uplift at the intertropical front zone, poleward flow at some unspecified higher level (in the so-called counter trades), and subsidence near latitude 30° within the subtropical high pressure belt, over the arid zone. In mid-latitudes there was a poleward flow at low levels and an equatorward flow above. Finally, it was supposed that subsidence at the pole must lead to outflow at low levels, polar air-masses reaching the mid-latitude westerlies at the polar front zone.

This classical picture of the general circulation, in which the poleward transfer of heat and momentum is carried out by vast overturning motions involving net transports of mass across latitudinal rings, has fallen into partial disrepute. At latitudes polewards of 30°, careful measurement fails to reveal the existence of mean meridional cells, or reduces them to a scale too small to support the required transport of heat and momentum. In 1926, Harold Jeffreys [5] pointed out that horizontal large scale eddies—the

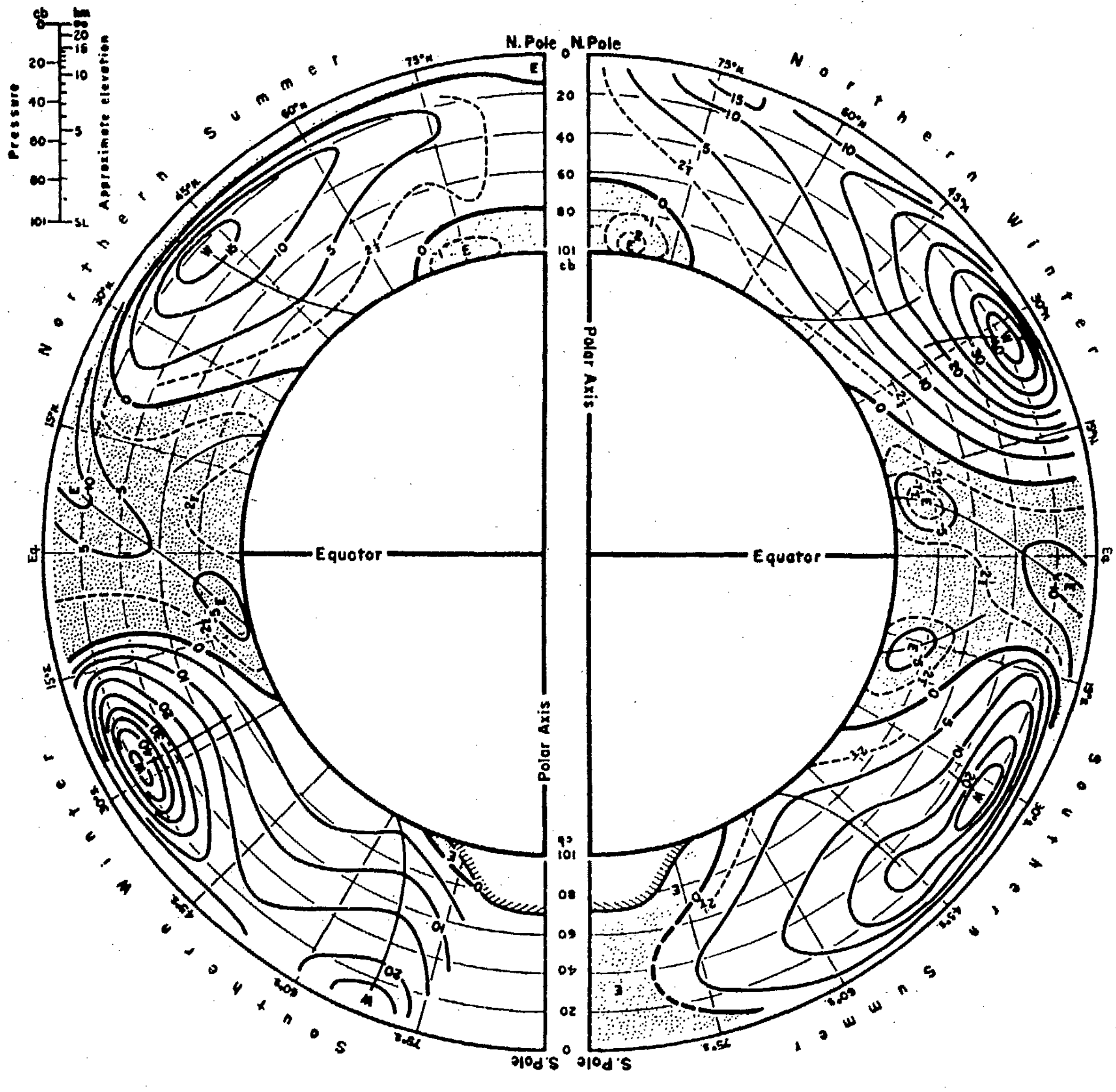



Fig. 2. The zonal component of mean motion as a function of height and season for both hemispheres, averaged over-all longitudes (after Mintz [7]). Lines of equal speed are in metres per second, positive towards east. Note that the maximum of the westerlies lies roughly above the axis of the subtropical high pressure belt (given by the line of zero zonal motion).

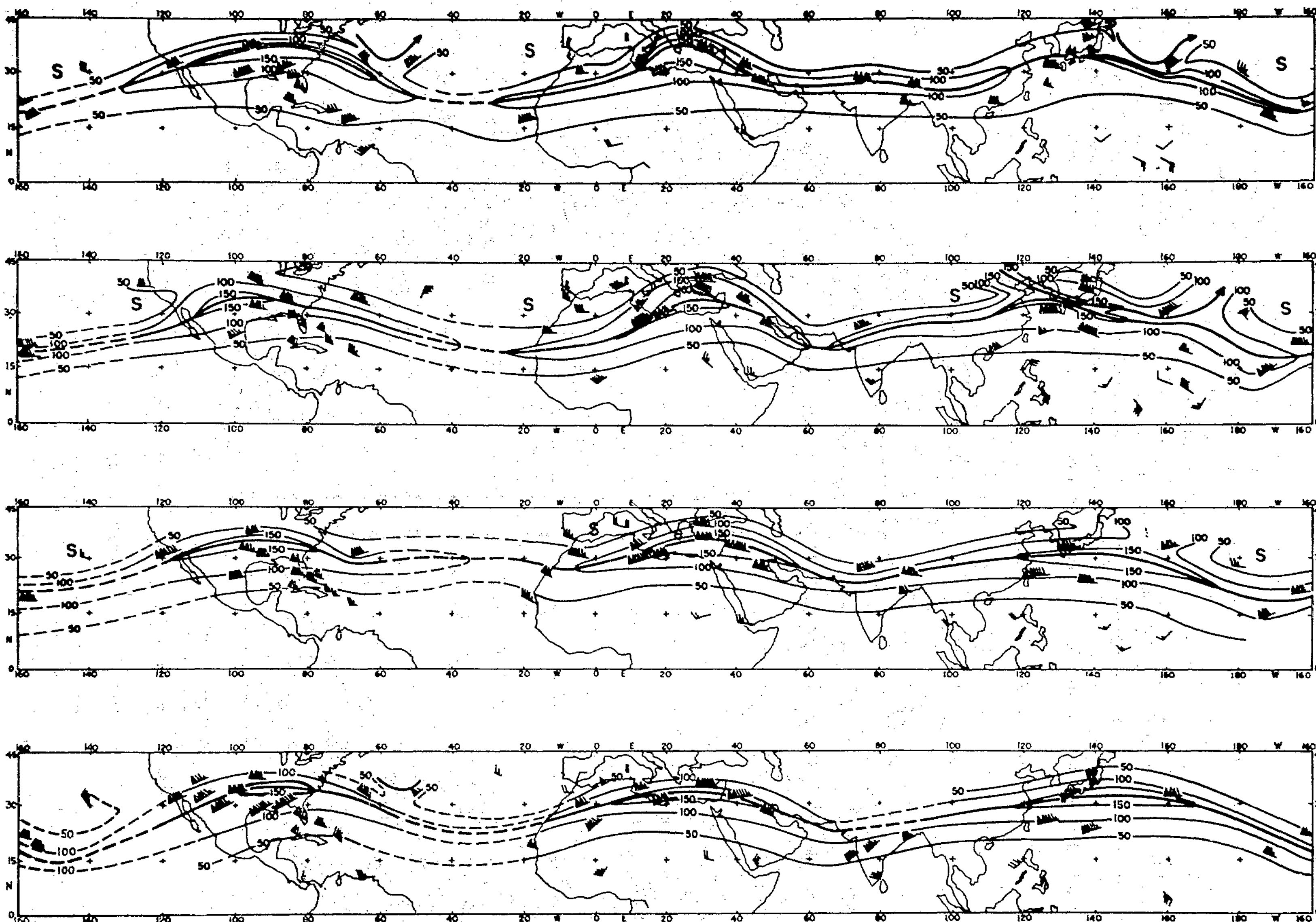


FIG. 3. The subtropical jet-stream, 25-28 February 1956, after Krishna Murti (from *W.M.O.*, No. 71, 27, 1958, World Meteorological Organization, Geneva). Analysis is at 200 mb (roughly 40,000 ft.). Lines of constant speed in knots. Arrows show direction and speed at sounding stations. One thick feather equals 50 knots, one full thin feather equals 10 knots and a shorter thin feather signifies less than 10 knots.

familiar cyclones and anticyclones—could carry out much if not all the required transport. This represented the introduction into general circulation theory of ideas similar to those developed by Osborne Reynolds in the study of small-scale turbulence in fluids.

Recent work by many groups, notably Starr and White [14], Priestley [9], Bjerknes and collaborators [2] and Rossby [12] has demonstrated the effectiveness of horizontal eddy transport. The two northern cells of Fig. 1 are now largely discredited, though Palmén [8] has retained the mid-latitude cell in a subsidiary role, and Sheppard [13] has questioned whether we can entirely reject the old meridional circulations. Only in the tropics, between the 30th parallels, does meridional overturning remain an undisputed fact, and even here a sizeable part of the required transport of heat and momentum may be carried out by horizontal eddies. This tropical cell has become known as the Hadley cell, after George Hadley, F.R.S., who predicted its existence as long ago as 1735 [4].

The descending arm of the Hadley cell lies in subtropical latitudes, more or less coinciding with the surface site of the subtropical high pressure belt. It is highly probable, however, that the existence of these high pressures, and the general subsidence that accompanies them, is also related dynamically to the behaviour of the zonal westerlies to the north. Figure 2 shows a representation of the zonal component of motion across the averaged meridional plane, following Mintz [7]. It will be noted that the axis of the subtropical high pressure belt (given by the zero isotach's intersection with the ground) is not far in latitude from that of the maximum westerlies in the upper troposphere. In winter the subtropical jet stream (of which an example is shown in Fig. 3) actually lies almost above the subtropical highs at sea level. Arguments based on the concept of dynamic stability suggest that anticyclonic eddies should form south of the maximum westerlies as the latter attain certain values of meridional shear. Hence the requirements of the Hadley cell and the dynamics of the westerly jets tend to agree in producing subsidence and anticyclonic flow in subtropical latitudes.

These results require a re-examination of the traditional picture of the tropical circulation. In this picture, the surface trades converged on the equator, being heated as they did so, and then rose to diverge polewards as counter trades, which in turn descend in the subtropics; this picture had the form of a direct thermally-driven circulation. In actual practice, however, it has become difficult to maintain such a picture of the causes of the circulation [10, 12]. It is quite clear that the mean meridional circulation cannot of itself bring about the required transport of heat and momentum. In the upper troposphere, the so-called 'counter trades' turn out to be nothing but the southern edge of the mid-latitude westerlies. Within them, the northward flux of momentum and heat is carried out in part by travelling eddies, the mean meridional circulation contributing the rest.

Before we leave this discussion of the general circulation, we must take note of one vital point bearing on all theories of climatic change. We have seen that the tropical easterlies serve as the momentum source for the mid-latitude westerlies. It is often argued that at times of glaciation the westerlies must be expanded and accelerated and driven into lower latitudes, all of which must tend to increase the frictional drain on momentum. Hence the easterly momentum sources must also be expanded. This may be partly achieved by an expansion of the polar easterlies, but the actual emplacement of the ice-sheets makes this unlikely [15]. Hence the tropical easterlies remain a necessity, and in all probability will need to be more strongly developed. It follows that only a limited equatorward displacement of the subtropical highs can be invoked, a fact consistent with the arguments of Butzer in the next chapter.

## BREAKS IN THE GEOGRAPHICAL CONTINUITY OF THE ARID ZONE

All the preceding arguments have applied to the earth as a whole, i.e., to conditions averaged over all longitudes. Such arguments can point out the general causes of aridity in the subtropics, but they can have little to say about the very striking variations that occur along latitude circles. In both hemispheres there are gaps in the arid zone, where there is abundant or even excessive rainfall.

These exceptions arise from the cellular structure of the subtropical high pressure belt. This takes two forms. First, there is the well-known tendency (especially marked in the northern hemisphere) for separate high pressure cells to form over the great oceans. This tendency is true only in the lower troposphere; at higher levels pressure may actually be higher over the continents, especially in summer. Nevertheless, the tendency extends high enough to affect a considerable depth of the moist layer of the troposphere, which travels clockwise round the western flank of the ocean cells to inject itself into the westerlies. The second cause of cellularity is the profound reorganization of circulation that takes place over subtropical Asia in summer, the so-called monsoon.

In the northern hemisphere, the oceanic high effects produce breaks in the arid zone over the western Atlantic and Gulf of Mexico, and over the Philippine-Marianas sector of the Pacific. The Atlantic zone is due to the familiar Bermuda high. This feature is quasi-permanent in summer, and is often well marked in other seasons. In consequence, the whole of the subtropical Americas east of the Sonoran Desert are covered for much of the year by a deep, powerful flow of very humid air. This current moves north-westwards across the Caribbean, the Gulf of Mexico, the West Indies and the southern United States. Thereafter it turns north-eastwards to enter the mid-latitude westerlies, forming the major part of the moisture supply for rainy eastern North America.

The entire latitude belt between 10° N. and 35° N. in these longitudes, then has a very abundant supply of precipitable water for much of the year. This area, moreover, is very prone to atmospheric disturbances. In summer and autumn, the characteristic tropical perturbations are very common. Easterly waves and hurricanes produce widespread rainfall in the warmer months. In the cooler season, the frequent injection of cold air-masses leads to cold frontal or shear-line rain.

Analogous situations occur in the southern hemisphere in east coastal Australia, South Africa and South America. High moisture contents coupled with frequent disturbances enable belts of moderate rainfall to link the normal rainy belts of the tropics and mid-latitudes. By contrast, the west coasts of South Africa and South America are intensely dry because of divergent southerly currents round the east end of oceanic highs.

The anomalous climates of south-east Asia arise from the so-called monsoonal circulation. The facts of this circulation are too well known to require repetition. The next effect, however, is to produce continuous advection of high moisture contents from the Indian Ocean over much of the continent in summer. This advection combined with widespread convergence and the frequent development of shallow disturbances permit the well-known summer rains in latitudes normally dry. The effect is sharply cut off in the west, where much drier air is involved in the circulation.

## CONCLUSION

The aridity of the subtropics thus emerges as an aspect of world climate dependent on deep-seated features of the earth's general atmospheric circulation. It does not arise from local or man-made circumstances, but from natural causes involving exceedingly large energy transformations and momentum transports. It is inconceivable that the régime can be significantly altered by human intervention.

It is equally unlikely that any past climatic epoch can have experienced a complete absence of subtropical aridity. As we have seen, the maintenance of the mid-latitude westerlies absolutely requires the existence of compensating easterlies in the tropics. Similarly the transfer of momentum and heat northward in the tropics requires the existence of a Hadley cell, with subsidence (and hence low humidity and drought) at some subtropical latitude. Hence it seems likely that the arid zone can have been no more than constricted in extent and driven a few degrees equatorward at the height of the recent glaciation; it can hardly have been eliminated altogether.

## BIBLIOGRAPHY


1. Benton, G.; Estoque, M. A. Water vapor transfer over the North American continent. *J. Met.*, vol. 11, 1954, p. 462-477.
2. Bjerknes, J. (ed.) *Large-scale synoptic processes, final report*, (*Contract* AF 19(604)-1286). Los Angeles, University of California, Department of Meteorology, 1957.
3. Flohn, H.; Oeckel, H. Water vapour flux during the summer rains over Japan and Korea. *Geophys. Mag.*, vol. 27, 1956. p. 527-532.
4. Hadley, G. On the cause of the general trade-winds. *Phil. Trans. Roy. Soc. Lond.*, no. 437, 1735. p. 58.
5. Jeffreys, H. On the dynamics of geostrophic winds. *Quart. J. Roy. Met. Soc.*, vol. 52, 1926. p. 85-104.
6. Kochanski, A. Cross sections of the mean zonal flow and temperature along 80 W. *J. Met.*, vol. 12, 1955. p. 95-106.
7. Mintz, Y. *The observed zonal circulation of the atmosphere, final report.* Los Angeles, General Circulation Project, 1955. (Article I, fig. 1.)
8. Palmén, E. The role of atmospheric disturbances in the general circulation. *Quart. J. Roy. Met. Soc.*, vol. 77, 1951. p. 337-354.
9. Priestley, C. B. H. Heat transport and zonal stress between latitudes. *Quart. J. Roy. Met. Soc.*, vol. 75, 1949, p. 28-40.
10. Riehl, H.; Yeh, T. C.; Malkus, J. S.; La Seur, N. E. The north-east trade of the Pacific Ocean. *Quart. J. Roy. Met. Soc.*, vol. 77, 1951. p. 598-626.
11. Rossby, G. G. The scientific basis of modern meteorology. In: *Climate and man.* Washington, D. C., 1941. p. 599-655. (*United States Department of Agriculture Yearbook.*)
12. ——. On the nature of the general circulation of the lower atmosphere. In: G. R. Kuiper (ed.) *The atmospheres of the earth and planets.* Chicago, University of Chicago Press, 1948; revised edition 1951. p. 16-48.
13. Sheppard, P. A. The vertical transfer of momentum in the general circulation. *Archiv. für Meteorologie, Geophysik und Bioklimatologie*, Series A, vol. 7, 1954. p. 114-124.
14. Starr, V. P.; White, R. M. *Balance requirements of the general circulation.* Air Force Cambridge Research Center, Cambridge, Mass., 1954. 57 p. (*Geophysical research papers*, No. 35.)
15. Willett, H. C. The general circulation of the Last (Würm) Glacial maximum. *Geogr. Ann. Stockh.*, vol. 32, 1950. p. 179-187.

# CLIMATIC CHANGE IN ARID REGIONS SINCE THE PLIOCENE

*by*

K. W. Butzer

*Assistant Professor of Geography, University of Wisconsin, Madison, USA*

## CLIMATE AND GENERAL CIRCULATION: CHARACTER AND VARIABILITY

### GENERAL CONSIDERATIONS

The mathematically defined and areally delimited distribution of arid lands is essentially part of the purpose and scope of statistical climatology. The dry zones are classified as semi-arid, arid and extremely arid and further subdivided according to criteria such as hot, mild, cool or cold. A further and important distinction between summer and winter precipitation régimes can also be applied. Such are the principles so far adopted in the Unesco maps Nos. 392 and 393 by Peveril Meigs on the distribution of arid homoclimates or on considerations of regional climate and ecology prepared under Unesco auspices.

When however the function of climatic variability—of weather on a short-term and on a long-term basis—is to be conceived and assessed, the approach must be that of the meteorologist. Arid climates can then no longer be simply defined and delimited—their existence must be physically explained and accounted for in terms of the dominant atmospheric circulation. This is the essence of dynamic and synoptic climatology, which is concerned with pressure fields, circulatory components, flow-patterns and air-mass characters. It is not intended here to present a dynamic climatology of arid lands, nor is it our object to present a mass of observations on climatological parameters. But it has proved to be difficult and hazardous to formulate opinions on climatic fluctuations, climatic variations and climatic changes without a sound understanding of the principles of the atmospheric circulation. The following is a very brief outline of the dynamical desert types and of the controlling factors of the general atmospheric circulation underlying the geographical distribution of the world deserts. Only on such a basis can the modifications of climate in recent geological times be seen in their proper perspectives and concisely synthesized in the normal range of secular variability.

Two essentially different factors are responsible for climatic aridity: relief and the distribution of land and sea on the one hand, and the physical characteristics of the planetary air circulation on the other.

The negative effect of relief can be encountered in the lee of high mountains running perpendicular to the prevailing winds. This 'rain-shadow' effect is markedly pronounced on leeward mountain slopes and interior basins such as eastern Turkestan (Takla Makan Desert) or the Great Basin and the Great Plains. Moist air-masses reach their condensation level upon orographic uplift on the windward side of mountain ranges, losing a good part of their moisture by precipitation. When the air moves downslope again the absolute vapour pressure is already quite low, while the relative humidity is further decreased by the adiabatic warming during subsidence. Thus very little rain will fall on the leeward slopes and basins. In basin areas surrounded on almost all sides by high mountains, moist winds will rarely ever reach the interior, so that rainfall will at all times be light.

Continental interiors far removed from warm oceans, and thereby from moist air-masses, are generally dry. In the extreme case of Central Asia, moisture-laden winds of westerly origin must pass over thousands of miles of land surface, often of differentiated relief, arriving in the interior weaker and generally dry. Similarly moist air-masses of southerly or easterly origin must first pass over several barriers of formidable mountains, so that little moisture is retained by the time the air descends upon the interior.

Such factors of relief or the distribution of land and sea are responsible for the arid lands of middle and higher latitudes: the Great Basin, the Great Plains, the Patagonian Desert, the great Eurasian steppe reaching from southern Russia across Turkestan to Mongolia, as well as Central Anatolia and interior

Iran. Generally speaking precipitation anomalies related to climatic variations will be somewhat less pronounced in these 'naturally' dry lands than in areas rendered arid through primary features of the general atmospheric circulation. These deserts of lower latitudes are due to the planetary phenomenon known as the 'trade-wind belts'. To understand this dynamical mechanism it will be necessary first to illustrate and define some basic concepts.

Two factors among others tend to dominate the circulation of the atmosphere : (a) the deflective force of the earth's rotation and the frictional drag between earth and atmosphere; (b) the meridional (i.e., north-south) heat exchange necessitated by net heat gain from solar radiation at the equator and net heat loss from terrestrial re-radiation at the poles. Without rotation, the heated air would rise over the equatorial zone and flow polewards at upper levels, while the cooled air would return to the equator as a northerly surface current. Allowing for the effect of the earth's rotation, the upper current would tend to be deflected into a westerly wind and the lower to an easterly. So it is physically conceivable that, theoretically speaking, a simple circulation with easterly components in the lower and westerly components in the upper atmosphere would result, where friction would take care of horizontal exchange between air-masses of different latitudes. However, owing to vorticity change in air-masses moving meridionally, the westerly circulation intensifies from pole to equator, achieving a maximum in about latitude 40°. Farther equatorwards the rotational movement of the earth causes the westerly winds of the upper air to decelerate once again. At about this critical latitude the steepest horizontal temperature gradient between equator and pole is associated with maximum upper air velocities (at about 10-13 km altitude) known as the *jet-stream*. In actual case the jet-stream circulation is so strong as to induce the lower circulation of middle latitudes to take on a prevailing westerly character as well. As a result, westerly winds—the circumplanetary or *disturbed westerlies*—dominate the surface circulation between about latitudes 35° and 75°, easterly winds between 35° and 0° and again in high polar latitudes. The upper westerlies lie at very high altitudes in the domain of the equatorial easterlies, generally at above 18 km.

At the contact zone of the surface westerly and easterly winds, subsiding air from higher levels is associated with the *subtropical belt of high pressure*—a zone of anticyclonic cells known as the horse latitudes. Simultaneously the intense heating of the atmosphere at the equator leads to mass convection and a belt of low pressure tending to follow the zone of maximum seasonal insolation. A secondary circulation system takes care of the thermal exchange between this equatorial low and the horse latitudes, whereby the deflecting force of the earth's rotation results in a north-easterly current on the northern hemisphere, a south-easterly current on the southern. These north-east and south-east *trade-winds* converge upon the equatorial low pressure belt or *intertropical convergence zone* (ITC). The trades form a strong, steady current over the oceans and the western sides of the continents. They are characterized by the so-called *trade-wind inversion*, at which altitudinal temperature jumps of +3° to +5° C. and moisture decreases of 30-50 per cent occur. This trade inversion lies at 700-800 m. in the Mediterranean during summer, at 1,200-1,400 m. and 2,000 m. over the North and South Atlantic respectively, separating two layers of the trades coming from comparatively higher (cooler and moister) and lower latitudes (drier and warmer). The trade inversion acts as an upper limit of convection clouds and is responsible for the low precipitation of the trade-wind current.

The great Saharan-Arabian Desert complex, the Thar Desert of India, the Namib and Kalahari of South Africa, the Californian Desert, the Atacama of Peru, Bolivia and Chile and the great interior deserts of Australia are all situated in the heart of the trade-wind belt and are climatic deserts due to the planetary circulation. Only when the trades blow inshore and are uplifted upon coastal mountains, as in eastern Australia or eastern Africa, do they bring appreciable precipitation.

A great exception to the planetary trade circulation is found in the monsoonal circulation of south-east Asia and, to a lesser extent, West Africa, the Sudan and northern Australia. Due to the great thermal and barometric contrasts of land and ocean in the course of summer cyclonic heating and winter anticyclonic cooling of the continental interiors, a great dynamical circulation system leads to a moist onshore current during summer and dry off-land circulation in winter. The Asiatic monsoons are of such continental dimensions that the earth's rotation deflects the prevailing current to the right on the northern hemisphere, to the left on the southern. Thanks to these

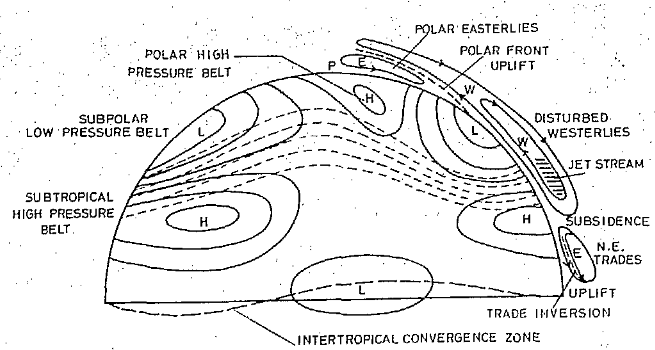



FIG. 1. Model of the general circulation of the atmosphere (northern hemisphere). Short dashed lines indicate upper air pressure distribution, full lines pressured istribution in the lower atmosphere. (Based on Flohn [47] and Hare [51].)

monsoons much of southern and south-eastern Asia, although situated in trade-wind latitudes, is generally quite moist.

A simplified model of the general circulation in the northern hemisphere is given in Fig. 1. For a regional treatment of the circulation features controlling aridity and the meteorological aspects of precipitation the reader is referred to standard texts. (See [13, 51, 52, 80] and also [26, chapter 2].)

### PRESENT-DAY VARIABILITY OF FLOW-PATTERNS

The general circulation is an equilibrium of several forces ultimately reflecting the earth's rotation and the radiation of the sun. Although the former is not of proven, climatically significant variability, the radiation of the sun varies regularly, periodically and possibly also episodically. The most striking of these variations is the contrast of summer and winter, whereby the entire planetary and monsoonal circulation picture is profoundly altered. This is merely a matter of insolation and changing thermal gradients. The less noticeable variations of the solar spectrum, and the particle emissions of the sun and possibly also of the solar constant, do in all probability play some part in modifying pressure distribution and the circulation picture of the planet. Such effects were claimed for particle invasions [43], but were controverted later and we do not yet have an over-all picture of how the various phenomena are associated. In other words slight or even moderate shifts of the general circulation are possible and probable as a common feature, mainly reflecting activities on the sun. Over longer periods such variability can very well attain sizeable proportions. In other words the changing climatic record of historical geology cannot be of surprise to the meteorologist who continually observes small-term shifts of more limited duration, intensity and areal occurrence at the present time.

The short-term patterns of the general circulation occurring over a period of several days or weeks have long attracted the attention of the forecaster, who can sometimes predict the general weather development for several days or weeks ahead when a particular atmospheric flow-pattern establishes itself. Circulation anomalies such as can be followed upon synoptic maps from week to week and month to month are essentially similar in character to those which occurred on a larger scale in historical and geological times. The definition of two major patterns or types some fifteen years ago, largely owing to the work of Hurd C. Willett, marked a milestone in the study of past climates : it had become possible to synthesize and express the dynamics of circulation anomalies and hence of climatic variability. In a series of epoch-making papers, Willett revolutionized past theory on climatic change and expressed the major climatic phases of the recent geological past in terms of present-day weather anomalies. He also gave great impetus to a sophisticated analysis of the recent climatic fluctuation of the last century.

According to Willett [85] and Flohn [48] these circulation types were expressed as zonal and meridional varieties.[1] The *zonal* circulation pattern is characterized by a well-developed jet-stream, hardly disrupted by the cold and warm air-masses travelling in the upper air and issuing from higher and lower latitudes respectively. The subpolar low and the subtropical high pressure belts are well developed, while the zone of maximal temperature gradient, the jet-stream, retires poleward. The trade-wind circulation is regular and disturbed only by shallow cold waves while cyclonic activity in the equatorial belt is relatively moderate. On the other hand, periods of *meridional* circulation type are characterized by weaker planetary westerlies, which are dominated by very extensive quasi-stationary wave movements. Extensive upper air troughs extend far equatorwards and introduce polar air-masses into the tropics, while tropical air-masses are carried far polewards in exchange. In the lower atmosphere the subpolar low pressure belt is largely dissolved while the jet-stream is shifted equatorwards. The subtropical cells of high pressure are weakened and separated by travelling depressions disturbing the normal trade-wind circulation, permitting deep cold waves to enter the tropics and favouring a livelier and intensified cyclogenesis in the equatorial convergence zone. The palaeoclimatic significance of the character and position of the jet-stream is almost axiomatic : the number, intensity and paths of lower middle latitude depressions reflect the intensity and position of the upper air jet (see [26]).

Willett, Flohn and many others have expressed the opinion that the zonal circulation type has been more important in historical and postglacial times and should be considered as the specifically nonglacial or 'interglacial' circulation form. The northward shift on the jet and planetary westerlies, with little or no invasion of cold fronts into the subtropics, is rather unfavourable for precipitation in the trade-wind desert belts. On the other hand these authors consider the Ice Ages of the Pleistocene and the short-term trends to colder weather in historical times (e.g., the re-advances of the glaciers in the seventeenth and nineteenth centuries) as meridional anomalies. An associated breakdown of the trade circulation with penetration of numerous cold waves to the tropics is quite favourable for precipitation throughout the trade desert zone, particularly on the southern and northern margins. Of course both circulation pattern types have existed at all times,

1. The sections which follow should be compared with Professor Hare's analysis in the preceding chapter.

for without them the dynamics of thermal exchange and intrinsic circulatory stability could not function properly. But the ratio of one type to the other varies from year to year. Brezowsky [16] and the present writer [21] have been able to show that the recent climatic fluctuation in middle and lower latitudes of the Old World has been associated with an over-all increase of zonal patterns between the means 1881-1910 and 1911-1940. In this sense the present trend to greater aridity has been zonal in character and coupled with generally higher temperatures in middle latitudes.

Regarding the applicability of the concept of a single meridional flow type, Wallén [83] has found it necessary to distinguish between a *south* or warm *meridional* circulation with essentially south-westerly steering over Scandinavia and a *north meridional* form with north-westerly flow in higher latitudes. The former carries warm air from lower latitudes to northern Europe, the latter cool moist air from higher latitudes. Both meridional circulation forms are quite distinct from the essentially west to east flow of zonal character, and merely reflect a different location and break-up of the quasi-stationary waves of the jet-stream during periods of meridional flow. The distinction of *north-westerly* or *south-westerly steering* over the eastern Atlantic and western Mediterranean must further be applied to both *north* and *south* meridional types, With north-westerly steering in lower middle latitudes moist air-masses enter the Mediterranean Basin over France or Spain, enabling cyclogenesis and frontal activity in the lower atmosphere, coupled with a fresh upper air westerly flow. With south-westerly steering the Mediterranean Basin is generally under the domination of continental tropical air-masses and upper air winds are weak. An exception is provided when the upper air steering in the Balkans and south Russia is north-westerly or northerly. In that case cool air-masses can lead to cyclogenesis and frontal activity in the Near East. Of course the above differentiation of the meridional flow patterns is of local character and applies only to the western half of the Old World. The necessity of differentiating between steering types in north-western and in south-western Europe (in practice both situations are independent of each other) is due to the inapplicability of the simple scheme cold-wet and warm-dry to past climatic fluctuations in lower latitudes [20, 21]. Although warm periods were predominantly dry here, there have also been several distinct warm-moist phases, for example in the Sahara—these can only be accounted for by south meridional circulation accompanied by north-westerly steering in lower middle latitudes. On the other hand the cool-moist phases characterizing the early glacial phases and the true pluvial periods were associated with the north-westerly steering variety of north meridional circulation.

These fundamental concepts of zonal, south and north meridional, as well as lower middle latitude north-westerly or south-westerly steering of circulation patterns, as known from present-day anomalies, will be discussed further in the light of the empirical evidence of past climates. Summarizing briefly, we can set up a simplified general scheme of types (see Table 1).

TABLE 1. Circulation types and weather trends

| Circulation type | Weather trends in: Mediterranean | Weather trends in: Central and North Europe |
|---|---|---|
| Zonal (west steering) | Dry, warm | Moist; mild winters, cool summers |
| South meridional | Warm: with south-west steering rainfall lower; with north-west higher | Rainfall moderate; temperatures higher |
| North meridional | Cooler: with north-west steering rainfall higher; with south-west lower | Relatively moist; temperatures lower |

Specific types of the large-scale weather patterns as employed by the German Weather Service, totaling some 24 types, can be assigned to each of the above circulation forms. The different types of arid zone climates and dominating circulation patterns occurring in Quaternary times can also be synthesized as:

1. Warm-moist. North-westerly (south meridional) and westerly steering. Moist interglacial (sub-pluvial).
2. Cool-moist. North-westerly (north meridional) steering. Early and full glacial (pluvial).
3. Cool-dry. Westerly and south-westerly (south and north meridional) steering. Late interglacial (interpluvial).
4. Warm-dry. South-westerly (south meridional) and westerly steering. Interglacial (interpluvial).

A last factor, not yet fully analysed, is the question of the absolute intensity of the circulation in the sense of the upper air wind velocities and the rate of the condensation cycle. One could suggest the warm-dry and cool-dry periods as characterized by a general slackening of the condensation cycle and a lower vapour content of the atmosphere, and vice versa. A possible explanation would be the temperature gradient between pole and equator; also, for example, the present-day contrasts between summer and winter. It has already been shown that the circulation changes leading over between glacial and interglacial periods preceded world temperature changes [20]. During early glacial periods the temperature gradient would be maximal whereas during late glacial periods it would be greatly reduced owing to the (largely secondary) cooling of the tropics. It is more difficult to account for such features of interglacials however.

## THE CLIMATES OF THE PLEISTOCENE: PLUVIALS AND INTERPLUVIALS

During the greater part of geological time, now estimated to be about 3,000 million years, world temperatures were higher and, above all, more uniform. There were no polar ice caps and the temperature gradient between equator and poles was very considerably less than today, subtropical fauna and flora being able to thrive at the Arctic Circle during a number of stages of earth history. As can be expected with such temperature distributions the general circulation of the atmosphere was slack with widespread aridity even in higher latitudes during several geological epochs. This then is the 'normal climate of geological time'. Those few Ice Ages which have occurred—periods in which polar and continental ice sheets drastically changed the climatological picture—were of comparatively brief duration. The recent Ice Age or Pleistocene period comprised at the very least five or six glacial periods during a time span of not much more than a million years. The reasons for our interest in this, climatologically speaking, phenomenal phase of earth history are manifold. Perhaps the most relevant factor is that the beginning of the Pleistocene saw the first appearance of Man. From that moment onward the earth's history becomes of vital significance to the history of the human race. Before Man first secured a far-reaching mastery over his environment some 10,000 years ago, fluctuating continental glaciers in the temperate zone and variable precipitation over the lower latitude grasslands forced his ancestors to move north or south after the animals they hunted. Even to the present day climatic variability continues in some way or other to exert its influences upon human ecology, especially where technology, rationalization and standards of living are still 'underdeveloped'. Bearing this human factor in mind we have developed this discussion with a broad emphasis on climate and its possible ecological implications and less on a stratigraphical basis.

### THE PLEISTOCENE GEOGRAPHY OF THE EASTERN HEMISPHERE DRY ZONE

Less than ten years after O. Torell was able to prove conclusively that continental glaciers had once penetrated in to the heart of Central Europe did E. Hull recognize the existence of moist phases in lower latitudes, and to which he gave the name 'pluvial' in 1884. Largely due to the work of G. K. Gilbert in the Great Basin and M. Blanckenhorn in the Near East it was recognized that these pluvial periods stood in direct relation to the glacial periods of higher latitudes, it being assumed that both were contemporary. In this way the Pleistocene was conceived of as a Pluvial Age in lower latitudes, a Glacial Age in higher and middle latitudes. Both Blanckenhorn and Gilbert clearly recognized that there were several pluvials separated by drier phases or interpluvials, and that the Pleistocene had not just been a single, uninterrupted moist period. As a matter of nomenclature, a 'pluvial' is today defined as a phase of widespread, long-term rainfall increase of sufficient duration and intensity to be of geological significance.

Convincing geological evidence that pluvials and glacials were more or less contemporary was at first not easy to provide, although archaeological parallelizations long pointed in this direction. Only after the significance of glacio-eustatic fluctuations of the world sea level was recognized, namely that the water content of continental glaciers is ultimately derived from the oceans, was it at last possible to achieve a more reliable means of geological correlation. During the various Pleistocene glaciations millions of cubic kilometres of ocean water were stored up in the continental ice masses so that the world sea level fell by about 100 m. or more; during the warmer, interglacial periods the present ice-caps of Greenland and Antarctica were reduced in size with corresponding rises of the ocean level to somewhat above the present mean sea level. From the Mediterranean area and Ghana for example it has been possible to show the association of pluvial continental deposits with marine regressions, i.e., glacial phases, while from other areas it has been indicated that arid zone deposits were contemporary with high, interglacial sea levels. For the poleward margins of the trade-wind desert belts the essential correlation of glacial-pluvial must be accepted as proven to-day; for the equatorial margins the reliable evidence accumulating points in the same direction.

The climatic and ecologic character of the various climates of the Pleistocene was obviously different in (a) the temperate or cool arid lands, (b) the subtropical or warm lands on the poleward margins of the trade-wind desert belts, and (c) the tropical lands on their equatorial margins. Each of these zones of the Old World will be discussed briefly with respect to the glacial-pluvial phases, questions of chronology being widely omitted. Finally a separate subsection is devoted to the climate and ecological environment of the Old World arid zone during the interglacial periods.

#### *The glacial periods in the middle latitude semi-arid zone*

The great Eurasian steppe zone, Anatolia, the Iranian interior, the Spanish meseta and the Atlas Ranges of Morocco and Algeria fall within the temperate dry climates today, which are usually delimited by the annual isotherm of 18° C. or the January isotherm 10° C. This includes the great interior deserts of topographical (relief) origin and the transitional belt between these and the trade-wind desert belt. The glacial periods of the Pleistocene were here characterized by a cold climate but by little or no increase in precipitation. Reduced evaporation associated with lower summer temperatures (5° C. and more) had a positive effect on the hydrological budget however, and the levels of lakes and inland seas were considerably higher than today, as for example the Caspian Sea by 75 m., so that it overflowed into the Black Sea. For details see [87, p. 320-39], [26, p. 27-32, p. 87-97] and [45, p. 234-36]. Of further interest in the semi-arid region is the temperate or even subpolar character of the vegetation. In the north, pollen profiles show that forests were very sparse and thin while southern Russia remained a steppe, therefore the higher lake levels must be attributed to reduced evaporation alone. Notable is that only very few such lakes overflowed—indicating a wide persistence of semi-arid conditions. River terraces due to streams overloaded with material of fluvioglacial or periglacial origin are widespread along streams originating above the former altitudinal tree limit. These should not be confused with pluvial terraces due to increased precipitation in areas outside the influence of glaciers or solifluction. However, south of the Caucasus and Hindukush, the temperature lowering of the glacials was appreciably less and high lake strandlines here must also be assigned in good part to greater precipitation. We assume a temperate mixed or coniferous forest for the greater part of Anatolia and north-western Iran, grading over into steppe in the flat continental interiors. A tentative picture of the Würm age vegetation of Eurasia is given by Frenzel and Troll [50], of the Near East by Butzer [26], the main features of which have been reproduced in Fig. 2.

*The pluvials in the subtropical arid lands*

The Thar of north-west India, the Fertile Crescent-Syrian Desert, and North Africa belong to the trade-wind deserts where the effect of temperature lowering (about 4° C.) during the glacials was

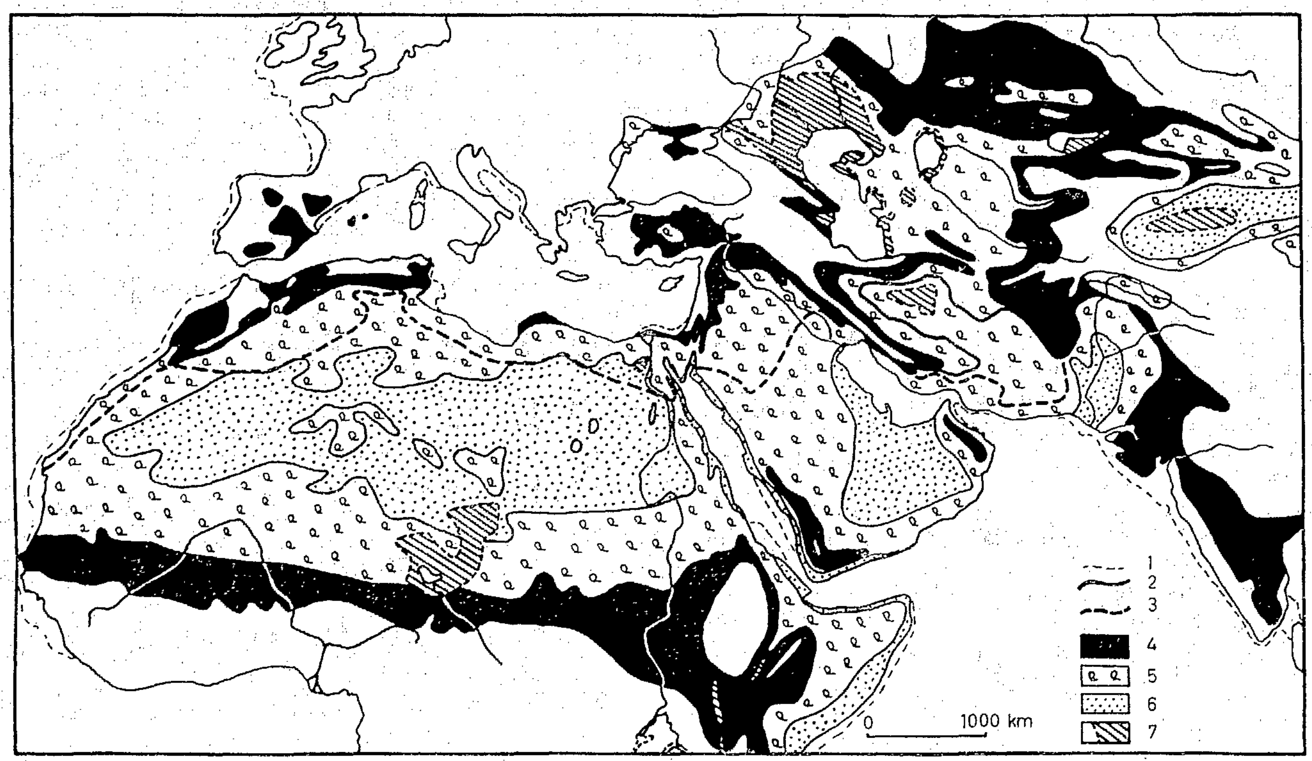



Fig. 2. Theoretical reconstruction of moisture conditions during a glacial-pluvial phase: 1. approximate shorelines of oceans (100 m. isobath); 2. modern 18° C. isotherm; 3. approximate position of 18° C. isotherm during a glacial-pluvial phase; 4. modern semi-arid zone belonging to humid climatic province in pluvial times; 5. semi-arid zone in pluvial times; 6. arid zone during pluvial times; 7. extension of inland seas in pluvial times. Hypothetical moisture zones refer to the moisture classification of C. W. Thornthwaite. (Based in part on Frenzel and Troll [50] and Butzer [26, 27].)

subordinate to that of increased precipitation and a lengthened rainy season. Apart from the Dead Sea, which stood 240 m. higher than at present during an earlier pluvial period, there is generally little evidence of higher lake levels. Instead our knowledge of the character and effect of the pluvials is derived from other sources: wadi terraces and fossil soils indicating greater humidity. For this geological material the reader is referred to [79] for the Indian subcontinent, [70, 89] and [26] for the Near East and [28, 74, 87] for North Africa.

During these pluvial phases Palaeolithic Man was able to wander through what is now barren desert, and one must assume that some plant and animal life was possible in the heart of the Sahara. Of course, with the exception of the central highlands, this area was never the optimal biozone and the existence of perennial rivers or of generally luxuriant vegetation, other than at edaphically suited locations, must be negated. Figure 2 has been extended so as to include North Africa as well as the Sudan, thereby enabling a tentative outline picture of the ecological implications of the subtropical pluvials.

### *The pluvials in the tropical or equatorial arid zone*

The southern margins of the Sahara, East Africa in the wider sense of the word and the dry grasslands and desert of South West Africa, Southern Rhodesia and the northern half of the South African Union belong in the realm of the trade-wind circulation, where Glacial Age temperature lowering was next to negligible (0.5-4° C.) but the precipitation augmentation was quite appreciable. The classical example of raised lake levels and fossil lacustrine deposits holds good for the Sudanese Sahel belt. There were innumerable fresh water lakes situated in the basins between Tibesti and Ennedi or south of the Hoggar. And of course Lake Chad was a huge body of water attaining a depth of perhaps 60 m. Between the fossil dunes of the Sudan—from the White Nile to the Atlantic—there are countless deposits indicating former lakes once attaining 10-20 m. depth. This moist phase can be dated as Middle Palaeolithic, i.e., in the Upper Pleistocene [21]. This period was also associated with red earth formation under humid conditions in the Dakar area. The laterite or mantle-rock of West Africa also belongs to a wetter climate [18], which was contemporary with a marine regression.

The pluvial evidence of East Africa is interestingly coupled with at least two glaciations of the high mountains in Ethiopia and Kenya [69]. Although the inestimable effect of tectonic activity in this particularly disturbed area cannot be discounted, there is certainly sufficient geological evidence in favour of several Pleistocene pluvials, during which coarse gravels were carried by the rivers and all lakes stood very much higher than today. It is assumed that the greater part of the steppe country was forested, some moderate estimates suggesting rainfall increases of about 50 per cent. The only more comprehensive study on the matter is the outline by Sonia Cole [34] with an extensive bibliography. Similarly in South Africa there is a very detailed and thorough Pleistocene sequence, and geological-archaelogical studies of the river terraces of the Upper Zambesi [32] and the Vaal [15] have shown the existence of three or four major Pleistocene pluvials, each of which can be subdivided into two or more stages.

For the sake of convenience what few remarks can be made on the Australian Pleistocene are included at this point. Apart from the Pleistocene glaciations detailed studies are limited to the fossil lake deposits of the Lake Eyre region, where a huge lake attained some 100,000 km.$^2$ and a depth of over 50 m. [37, p. 616]. This recalls the Sahara and Central Asia and presupposes a sizeable improvement of moisture conditions at one time or other.

### *The climate of the Late Glacial and Interglacial periods*

From the foregoing remarks one could obtain the impression that the Pleistocene was altogether much moister than today. This was not so however. During the greater part of the Pleistocene the climate of the trade-wind desert belts was just as arid, or even more so, than it is today. The pluvials were important enough but only comparatively temporary features. It was implicitly noted that each pluvial episode was followed by an 'interpluvial'. Generally the contemporary climate of such millenia was like that of today. However in the Sudanese Sahel and Rhodesia there is evidence that the interpluvials were even much more arid at times.

Since full aridity set in at least 8,000 years before the end of the last glaciation [21, 26, 28, 30], it is not fully justified to simply correlate interglacial with interpluvial as this means a cool-dry climate in Late Glacial times. There are other indications of very brief moist interludes in lower latitudes possibly related to the temporary re-advances of the dissipating continental ice. Such a moist spell has been tentatively identified from the Near East at about 9000 B.C. [26, p. 106-8]. Another factor incompatible with the axiom interglacial = interpluvial is the warm-moist palaeoclimatic type, which will be discussed in detail later, at the height of the postglacial thermal maximum. But similar evidence can also be found during the Pleistocene proper [28], where such a warm-moist climate seems to fall on the threshold interglacial/glacial or into the second half of the interglacials. We cannot tell as yet.

Summarizing in the form of a table we can synthesize the Old World Pleistocene as follows:

TABLE 2. A synthesis of the Old World Pleistocene

| | Northern Europe | Lower latitude arid zone |
|---|---|---|
| *c. 1 million years* | | |
| Lowest Pleistocene | Several cold phases | For the greater part quite moist |
| Lower Pleistocene | Günz glaciation | Pluvial (Kageran?) |
| | G/M interglacial | Interpluvial |
| Middle Pleistocene | Mindel glaciation | Pluvial (Kamasian) |
| | | Major interpluvial |
| | M/R interglacial | Pluvial (Kanjeran) |
| | Riss glaciation | Interpluvial |
| *c. 100,000 years* | | |
| Upper Pleistocene | R/W interglacial | |
| | Late interglacial | Pluvial (Gamblian) |
| | Early, Main Würm | Pluvial (Gamblian) |
| | Late Würm glacial | Postpluvial phase I |
| *c. 10,000 years* | | |
| Holocene | Postglacial period | Minor fluctuations |
| *Present* | | |

In Lower and Middle Palaeolithic times Man was not specialized either as a hunter or food-gatherer. Specialized hunting-cultures first appeared with the Upper Palaeolithic, at a time when the arid zone had reverted to more or less its present conditions, for example, the Sahara was next to uninhabited, except for oases or river valleys, between the Middle Palaeolithic and Neolithic times [28, 30]. As Near Eastern Man did know how to use fire as a hunter's device, it will certainly not have played any great part in modifying the ecological picture of the already desiccated plains.

Reviewing the meteorological implications it may be postulated that the interpluvials were connected with a predominantly south-west steering pattern of meridional type of westerly, zonal flow. Westerly disturbances of higher latitudes did not penetrate the lower latitude belt of dry lands while the tropical summer rains connected with the African monsoons must have been less pronounced—just as during our recent climatic fluctuation [21, 57] one can assume a weaker circulation in the Mediterranean and a northward shift of the subtropical high pressure cells, with a general weakening of the monsoons. Though much of this applies to the greater part of the interglacials it is also applicable to the period of general warm-up and ice retreat during the Late Glacial intervals. Moist interglacial climates may be due to an abnormal frequency of south meridional types of circulation with north-westerly steering in lower middle latitudes or to a very gradual shift favouring north meridional flow at the onset of the glaciations. At any rate the early glacials were characterized by a strong meridional type circulation with predominantly north-westerly flow in northern and western Europe—long before the continental ice supposedly 'deflected' moving cyclones southwards [20]. The gradual standstill of the ice would probably reflect an increasing tendency to generally westerly or south-westerly flow in the upper air, coupled with a slow-down of the condensation cycle.

## PLUVIO-GLACIAL CLIMATES IN THE AMERICAS

As was the case with the Old World arid zone, the glacial phases of the Pleistocene were associated with greater moisture and lower temperatures in the dry lands of North and South America. Two great mountain ranges run more or less north-south through the American South-west and northern Mexico, so that almost everywhere the latitudinal shifts of the temperature zones were quite appreciable. Throughout the area in question the mountain glaciers advanced quite considerably or new cirque glaciers were created in response to a temperature lowering of the order of at least 3° C. [3, 12, 39, 71]. The New World stratigraphic nomenclature for the four classical European glaciations is:

Würm = Wisconsin
Riss = Illinoian
Mindel = Kansan
Günz = Nebraskan

Although there is still much disagreement on the earlier glaciations, particularly of the Rocky Mountains, three pre-Wisconsin glacial stages have been verified [71], although the matter of correlation remains open.

The evidence for greater humidity is as striking as that in the African and Asian dry zone: well over a hundred major pluvial lakes, where little or no perennial water occurs today, are known in the USA alone [10, 33, 45, 46, 53]. The situation is similar in Mexico [19] and in the arid zone of South America [56, p. 545-51; 45; 81].

Regarding the first appearance of Man in the New World, anthropologists are far from agreement. Nevertheless radiocarbon dates now bring us back to the Main Wisconsin period and a first crossing of the Bering Strait (from −50 to −90 m.) could possibly have been effected during the Early Wisconsin period. For that matter southward progress would not have been difficult during the earlier half of Wisconsin time, before the ice had attained continental dimensions. A tentative but illustrative reconstruction of the Wisconsin age pluvio-glacial climate has been made by Dillon [39].

## THE EARLY HOLOCENE: ENVIRONMENT AND ECOLOGY IN NEOLITHIC AND EARLY HISTORICAL TIMES

As already discussed, full aridity, often exceeding that of the present, was achieved some 15,000 years ago. Since that time climate has fluctuated but little—on an average more or less equivalent to that of today. Postpluvial humid fluctuations have occurred, but they cannot be compared with the pluvials proper and are geologically unimportant; their significance lies rather in the ecological environment they provided for Man and animal. With the first appearance of the Middle Stone Age in the Near East after about 10000 B.C., the climatic succession bears witness to the rapidly evolving prehistoric cultures of that area, the beginnings of animal domestication and eventually the food-producing 'Neolithic' economy. From the latter sprang the ancient civilizations of the Nile, Tigris-Euphrates and Indus Valleys. The changing climatic environments enjoyed by Man during these critical and decisive millenia of human history have been widely misunderstood, and we wish to show that although changes of ecological importance have occurred, these have only been of limited influence since that time when Man first crossed the threshold of historical documentation.

### THE POSTGLACIAL SUBPLUVIAL IN NORTH AFRICA AND SOUTH-WEST ASIA

The existence of a minor pluvial phase of postglacial date—separated from the last Pleistocene pluvial by an intensely arid period—was first realized in the Sahara some thirty years ago thanks to the work of Miss G. Caton-Thompson and Miss E. W. Gardner [31]. Even today the evidence from North Africa in favour of this subpluvial (*c.* 5000-2350 B.C.) is the most convincing and best known. It may be subdivided into two classes: faunal evidence, chiefly on the basis of the rock-drawings, and geological evidence, generally of a minute but specific and detailed character.

The two oldest groups of Neolithic rock pictures of the Sahara belong to a group of early hunters and a nomadic livestock-raising culture of East Hamitic affinities. These peoples everywhere left an invaluable record of themselves and their way of life, as well as of a manifold animal life—which nowadays would no longer be able to survive in these areas. The fauna depicted includes not only gazelles, antelopes and ostrich, but a great number of representations show species now limited to the savannas of tropical Africa: elephant, both the single and the two-horned rhinoceros, hippopotamus and giraffe. The African elephant is a woodland or parkland biotype, requiring immense quantities of green fodder daily and a perennial supply of good water, the conditions necessary for the rhinoceros are similar. The hippopotamus is confined to an aquatic environment along perennial rivers or lakes, and is not able to move far over dry land. Even the giraffe is today seldom seen in the treeless steppes but prefers a more parkland country. Further species include the crocodile, now surviving in miniature form in a few small perennial pools (gueltas) at one or two places in the Sahara, and the extinct buffalo *Bubalis antiquus*, also known palaeontologically from older deposits in the Maghrib. Mauny [64] has provided a valuable analysis of the former and present distribution of the four leading species (elephant, rhinoceros, hippopotamus and giraffe) of the western Sahara. The writer [24] has extended this study to the eastern Sahara, together with a survey of existing rainfall, water and pasture conditions in these regions. From a comparison of the present and historical domain of these four indicative species with modern rainfall, a minimum of 150 mm. precipitation seems a prerequisite for the rhinoceros and hippopotamus, 100 mm. for the elephant and 50 mm. for the giraffe. These are of course theoretical values as the local micro-ecology is in all cases dominant, but this at least gives a general idea. On the basis of the palaezoological material, which is substantiated by elephant remains in the Fayum or in Erdi, a tentative attempt to reconstruct the approximate rainfall distribution for the period 5000-3000 B.C. (see [24, figure 2]) is given in Fig. 3. The isohyets thus obtained—which are similar to the recent climatic fluctuation in the Sahara, with increasing aridity on both latitudinal margins simultaneously [21]—suggest for the early Neolithic an increased precipitation in both the winter and monsoon rainfall provinces—and not a northward shift of the Sahara [24]. The marginal belts of vegetation shifted some 100-250 km. towards the core of the desert, while the highlands appeared as more favoured reservoirs of life and water rising above the desert plains, probably with an overlap of summer and winter rains.

The testimony of the rock drawings is amply borne out and verified by the geological deposits [1, 7, 8, 28, 30, 74]. Apart from the stratigraphical profiles indicating greater moisture, which we omit here, there is also evidence of greater or appreciable warmth as well, including a period of red earth formation during a warm, moist phase in postglacial times in Egypt [28, 30]. Similarly a postglacial thermal maximum is born out by such tropical relicts as the water plant *Pistia stretiotes*, Degen's toad (*Bufo vittatus*), the fish *Gymnarchus niloticus*, the Basilisk chameleon, several tropical snakes and mollusca in the Nile Delta and Fayum, as well as in the Maghrib [14].

The faunal and geological evidence is there and it is not surprising that there is floral evidence as well, although our knowledge in that direction is more limited. In the deserts west and east of the Egyptian

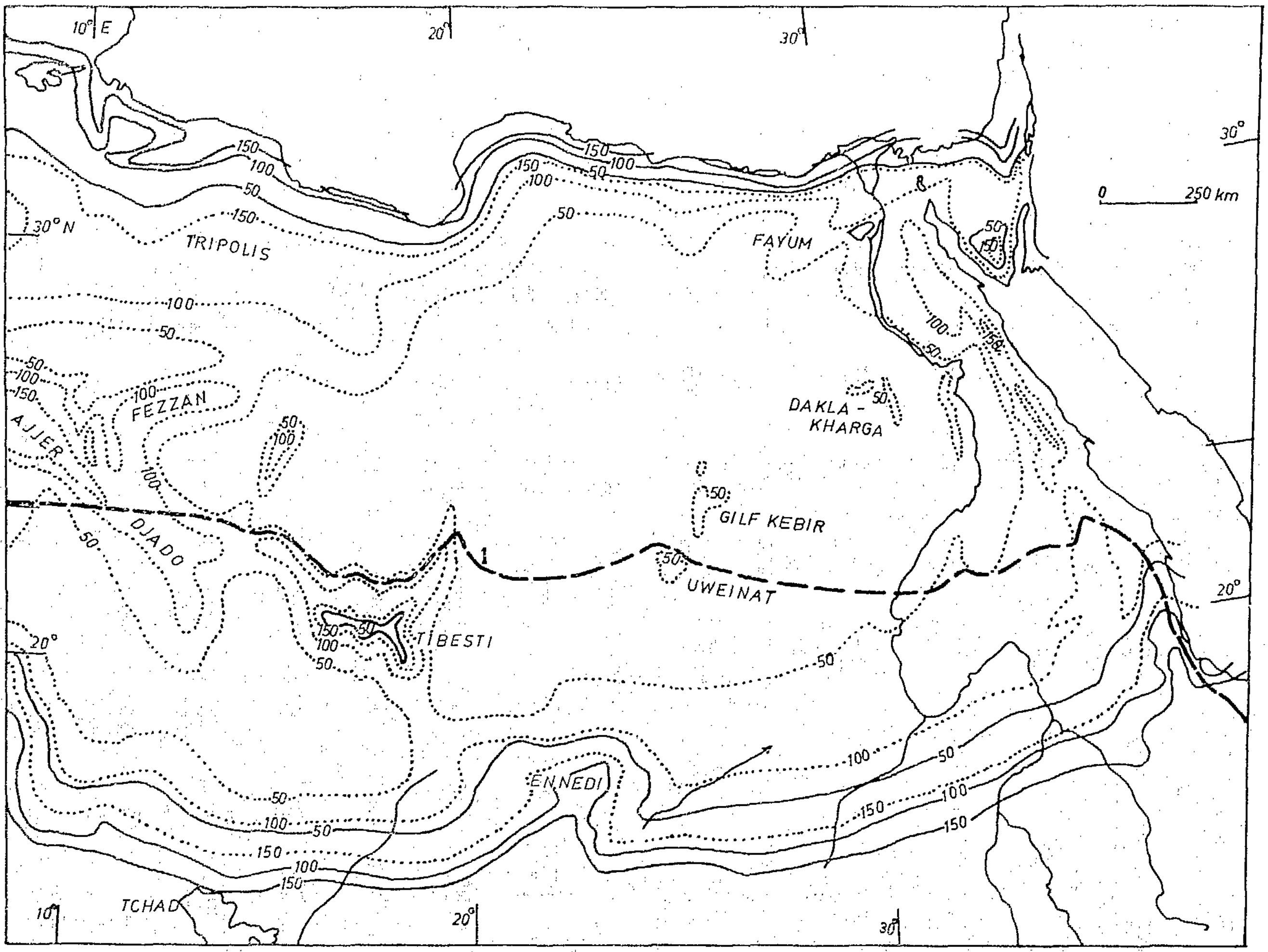



FIG. 3. Modern and Neolithic (5000-3000 B.C.) distribution of precipitation in the eastern Sahara. Full lines indicate modern isohyets in millimetres; dotted lines indicate reconstruction of same for the sixth to fourth millennium B.C.; heavy dashed line (1) indicates boundary between predominating winter and summer rains today. (Modified after Butzer [24, figure 2].)

Nile there are numerous tree stumps of acacia, tamarisk and also of sycamore (*Ficus sycomorus*), which have been archaelogically dated as Badarian to Predynastic [30]. They indicate a savanna-like vegetation, with small trees or copse at edaphically suited localities, e.g., wadi beds where water collects and ground water exists. Such stumps up to 32 cm. in diameter and with roots up to 4.5 m. long have been found to the south of Luxor. In addition to the literary sources there is, surprisingly, historical documentation on several Old Kingdom tomb and temple reliefs [30]. All in all a more generous growth of vegetation, resembling a savanna, can be assigned to the period extending from about 5000 B.C. to the Sixth Dynasty. This was of course limited to the more elevated country or to the marginal tracts—for the core of the Libyan Desert would have remained as lifeless as it is today. On the southern margins of the Sahara there is similar evidence of innumerable dead acacias [67] and, although the dating is uncertain, one can at least suspect a relation to those of Egypt. It is of significant interest that west of Bir el Atrun acacia stumps are between 30 and 40 cm. in diameter and sparsely set at about 3-5 per acre, indicating that an open savanna existed some 200 km. farther north than this vegetation can survive today.

A last feature pertaining to more favourable ecological and hydrological conditions in the Sahara is the groundwater table. From many of the oases of the eastern Sahara there is good evidence that artesian springs once functioned where even in classical times water had to be obtained from artificial wells. For example, at Kharga there are immense deposits of calcareous spring tufas around or in which Neolithic tools have been found in great numbers. They imply the existence over 5,000 years ago of an agricultural settlement established around formerly functioning springs. Similar tufas or clay hummocks have been noted from the wells of Kurkur, Sheb, and Tarfawi [67]. From Uweinat, Merga and Bir el Atrun there is also evidence that the static groundwater table was much higher in 'Neolithic' times—enabling nomadic cattle-breeders to live there until perhaps the time of the Sixth Dynasty (2350 B.C.).

Leaving the Saharan area there is further evidence of postpluvial moist intervals in East and South Africa. These are known as the Makalian and Nakuran intervals, but their chronological status remains very problematical. Until there are better means of dating the subpluvial deposits and later Stone Age cultures of equatorial Africa, it is better to defer an opinion.

In South-west Asia [26] the evidence seems to indicate that there was a moist Neolithic period as well, although the area has not been subjected to intensive investigation. The Dead Sea, for example, has several postpluvial strandlines which are geomorphologically just as fresh and well-preserved as the Neolithic lake deposits of the Fayum. That the Subpluvial was felt even as far as India can be see from deposits in the Narbada Valley, east of Bombay, containing a Protoneolithic industry [79, p. 319]. Even from New Zealand there is evidence, in this case of pollen, of a postglacial warm and moist period [36], just as there is in South China and Hawaii [48]. For reference to the evidence of a warm-moist Atlantic period in other latitudes see [42, 62]. Except for the evidence from south-western North America, the universal moist and warm character of the first half of the postglacial thermal maximum is geologically, floristically and faunistically well founded throughout the world.

In review, from the close of the sixth to the close of the third millenium B.C. there was a markedly greater humidity and rainfall throughout the dry zone of Africa and western Asia, enabling a more exubriant fauna and flora to thrive in areas climatically unsuitable today. These ecological conditions were obviously of great significance to the human habitat and, just as they enabled the savanna fauna to migrate northward through the Sahara, they may have played a favourable role in the rapid, contemporary dispersal of the new food-producing economy from the Fertile Crescent across the highlands of Iran and over the deserts of North Africa.

The *meteorological implications* of the postglacial climatic succession, which is studied more completely in another section, can be well reviewed in connexion with that of central and northern Europe [26, 44, 62].

It is notable that every third-order fluctuation (in $x\ 10^3$ years) to greater or less precipitation has been more or less paralleled in Europe and lower

TABLE 3.

| | Europe | Lower latitudes |
|---|---|---|
| Preboreal (8100-6800 B.C.) | Cool, dry | Extremely arid |
| Boreal (6800-5600 B.C.) | Continental, dry | Arid |
| Atlantic (5600-2500 B.C.) | Warm, humid | Moist, warmer |
| Subboreal (2500-8/500 B.C.) | Warm, drier | Extremely arid |
| Subatlantic (after 500 B.C.) | Cooler, humid | Slightly moister |

latitudes. This can only be explained in terms of the absolute intensity of the upper air circulation and the rate of the condensation cycle. For example the Atlantic and to a lesser extent the Subatlantic were apparently characterized by a generally higher atmospheric moisture content. Greater aridity in both latitudinal zones between 8100 and 5600 B.C. and again 2500-500 B.C. suggests a dominantly south-westerly steering in lower middle latitudes, probably together with a south meridional circulation. For the Atlantic phase the situation must have been different: a longer growing season in Scandinavia would imply a 'warm' circulation pattern, implicitly south meridional with north-westerly steering over the Mediterranean. However, some appreciable zonal components must be assumed to account for the greater precipitation in Europe. An illustrative reconstruction of the vegetation of northern Eurasia during the thermal maximum (largely on the basis of pollen analysis) has been made by Frenzel [49]. This map refers to warm-dry conditions during Subboreal time.

## EARLY HISTORICAL DESICCATION IN THE NEAR EAST (2350-500 B.C.)

Since the close of the third millenium the climate of the Near East and North Africa has fluctuated about a mean closely resembling that of the present. There have of course been moist and dry fluctuations of shorter duration and moderate intensity, and small variations of mean temperature. But generally speaking the climatic variation of the last 4,000 years has not been of sufficient duration or magnitude to leave much geomorphological evidence except in very climatically sensitive areas such as the foreland of glaciers or in the domain of blowing sand. As a result it becomes increasingly necessary to resort to archaeological evidence and literary sources.

Perhaps the best evidence that the Subpluvial had ended in the second half of the third millenium comes from Egypt. Already the transition from the Amratian to the Gerzean period (*c.* 3600 B.C.) was characterized by a decimation of the elephants and giraffes represented on the rock drawings throughout the country. Between the First and Fourth Dynasties (*c.* 2800-2600 B.C.) the exotic savanna fauna disappeared permanently : elephant, rhinoceros and giraffe are locally unknown in Old Kingdom times, and the same is true of the woodland species of the gerenuk gazelle. At Badari the last acacias had apparently died off or been chopped down before the Fourth Dynasty, and since the Fifth/Sixth Dynasty trees were never depicted in desert scenes [30]. A new note of importance is the changing background of the hunt: before 2350 B.C. hunts were carried out on the open steppe or desert. Since the beginning of the Sixth Dynasty however all hunts took place in enclosures, in which the game was obviously collected and kept for the amusement of the king and his courtiers. From a study of the faunal change in Egypt during Predynastic and historical times the writer [30] has come to the conclusion that the animals depicted on reliefs of the Sixth Dynasty and later were almost entirely derived from the wadis of the Eastern Desert or from the littoral steppe west of the delta. There is little question of the appreciable numbers of free-roaming antelopes, gazelles and deer among the brush of the alluvium or on the margins of the desert since that time. Gazelles are of increasing relative importance since the Fourth Dynasty and fallow deer was locally extinct in Egypt by 2000 B.C. The following table, based on a total of 990 mammal representations, omitting hippopotamuses and smaller felines, rodents, etc., illustrates the approximate faunal evolution in Egypt between 3500 and 1100 B.C. [30].

TABLE 4. Relative composition of animal representation (percentage)

| | Rhino, elephant and giraffe | Felidae | Barbary sheep | Addax | Ibex | Oryx | Bubal | Gazellae | Varia |
|---|---|---|---|---|---|---|---|---|---|
| Gerzean to First Dyn. | 15 | 29 | 9 | (—) | 12 | 13 | 6 | 5 | 11 |
| Old Kingdom | — | 3 | 2 | 9 | 19 | 28 | 8 | 27 | 4 |
| Middle Kingdom | — | 4 | 2 | — | 12 | 16 | 11 | 22 | 6 |
| New Kingdom | — | 8 | 1 | — | 8 | 12 | 18 | 26 | 27 |

The local extinction of the savanna fauna in the Sahara and the survival of increasingly modest species, which required little or no permanent water, are not *only found in* Egypt [24]. *It seems that* gradual desiccation forced the once manifold and numerous mammalian fauna to abandon the Saharan wadis and highlands, even though the local extinction of some species may have been delayed a little here and there due to the persistence of some hardy vegetation or a few waterholes.

Geological evidence from Egypt confirms the increasing aridity, intensified aeolian activity and the remarkably lower flood levels of the Nile [29, 30] : in the western Middle Egypt a chain of dunes from the Western Desert invaded the valley covering the alluvium with several metres of sand for a stretch of 175 km. These fossil dunes are now covered by a few metres of mud, and can be found exposed many kilometres east of the present desert edge. Also partly responsible was a reduction of the mud sedimentation associated with lower floods of the Nile. It is of interest that there are six authentic references to droughts due to low Nile floods, dated between 2100 and 1950 B.C., while, according to the ancient records, the flood level had already decreased steadily during Old Kingdom times, implying a declining rainfall south of the Sahara.

From south-west Asia there is also a certain amount of evidence from various sources. Numerous Bronze Age tepehs on the Iranian coast of the Caspian Sea were occupied at a time when the perhumid Hyrcanian forest was replaced in the lowlands by steppe and loess deposition. Similarly the Dead Sea probably stood some 8 m. lower in Bronze Age times (*c.* 2500-1200 B.C.) [26]. As a literary source the biblical references to severe droughts and catastrophic famines probably have a bearing on rainfall conditions in ancient Palestine. Of twelve specific references to such droughts only two belong to the period after 850 B.C.

All in all, the early historical desiccation shortly before 2000 B.C. was quite severe, particularly as conditions were temporarily even more arid than they are today. Possibly the nomadic disturbances at the time were associated with rapidly deteriorating ecological conditions : (a) the Accadian immigration to Sumer before 2600 B.C. (extinction of exotic fauna in Egypt at this time); (b) the Temehu *emigration* out of the Libyan Desert after 2350 B.C.; (c) the Amorite settlement in Mesopotamia (at its height in 2050-2000 B.C.); and (d) the Aramaean migrations between 1200 B.C. and 1000 B.C.

In the course of the last millenium B.C. climatic conditions began to improve again. Although there *is no evidence of precipitation in the Sahara itself*, Ethiopia must have enjoyed a maximum rainfall about 2,000 years ago in order to account for the greater Nile volume and load. In western Middle Egypt the very intensive Nile sedimentation led to the overriding of the valley dunes after about 500 B.C. and Nile flood levels seem to have been increasing already between 870 and 625 B.C.—there are 13 records of exceptionally high floods. In the fifth century B.C. and first century A.D. the mean height of 'strong floods' was 9.54 m., 1 m. higher than it has been since. This seems to explain why 2 m. of mud were deposited between 500 B.C. and A.D. 300—implying a rate of deposition twice as great as during the past century [29, 30]. The entire dune fields, once covering great parts of the valley between the Fayum and Asyut, were drowned in this surge of alluvial material. As a result agriculture prospered as it had not done before, and innumerable towns were built along the margins of the desert gravels (e.g., Tanis). The Bahr Jusef, which now flows from the Nile at Dairut, probably began either at Asyut or Sohag and flowed right along the edge of the Western Desert.

Geological indications from north-eastern Iraq [89] may indicate greater rainfall at the same period. But of a moister climate in Roman or Byzantine times there can be little question.

### PREHISTORIC CLIMATES IN THE AMERICAN DRY LANDS (8000-1000 B.C.)

The study of postglacial climates in South America has hardly begun as yet, but in North America some recent investigations are beginning to throw considerable light on the ecological environment of the last millenia B.C. While in eastern North America pollen profiles point to a similar climatic succession as elsewhere, namely a warm-moist oak-hemlock phase (= Atlantic) followed by warm-dry oak-hickory (= Subboreal) and cool-moist oak-chestnut (= Subatlantic) periods [38], the situation in the Great Basin seems a little different. Here a contemporary maximum of warmth and aridity has been postulated for the whole thermal maximum. Unfortunately most field workers for a long time were Pleistocene geologists but little interested in details of the Holocene. In view of the extensive evidence suggesting climates more arid than today, the postglacial climatic succession has been widely simplified into the following scheme (see also Antevs [3]):

7000-5000 B.C. Climate at first as today, then becoming drier and warmer (Anathermal).

5000-2500 B.C. Warm and arid; disappearance of lakes and glaciers (Altithermal).

2500 B.C. to present. Cooler and moister with rebirth of lakes and glaciers (Medithermal).

The reason for assuming a single warm-arid phase for the thermal maximum is probably twofold: (a) assuming a uniform precipitation since the close of the Pleistocene, greater warmth would imply greater evaporation and therefore aridity; (b) on the basis that pluvials and glacials coincide, interpluvial and interglacial maxima should coincide, so that greatest warmth should imply minimum humidity. For an outline of the evidence on dried-out lakes and disappeared glaciers see [3, 53]. We do not disagree with the evidence, only with its oversimplified interpretation. A good start has been made in the Lake Lahontan area, Nevada, on a more intensive geological study of the Holocene [66]. The profile under the present salt flats shows that lacustrine deposits of the deep Pleistocene lake, dried out before 8000 B.C., lie at the base (see [46]). These are overlain by aeolian and alluvial deposits, a widespread erosional surface and a moderately developed soil 'representing a long interval of complete desiccation'. Then there are sediments of five successive shallow lakes, alternating with subaerial deposits of five desiccation intervals, up to the present day. It is equally possible that the first of these shallow lakes, whose deposits are just as thick as the underlying subaerial sediments, represents a subpluvial phase. Similarly Arnold's work [10], in the Chapala Basin of Baja California, confirms the existence of quite a number of Holocene lakes, the deepest and oldest (15 m.) immediately following a food-producing ('scraper-plane-projectile') culture. Whether this Neolithic culture was roughly contemporary with the Saharan Neolithic is rather questionable however. At any rate a complicated succession of moist and dry phases seems commonplace in the south-west. Of great promise are the recent studies of pollen, sediments and diatoms in Lake Texcoco in the Valley of Mexico and in Lake Patzcuaro, Michoachan [54, 77]. Although the absolute dating is still somewhat problematical the general pollen-climate-culture sequence is as follows:

| | | |
|---|---|---|
| High oak | moist | Nahua, including Aztec |
| High pine | dry | Late Archaic—Early Teotihuacan |
| High oak | moist | Early and Middle Archaic |
| High pine | dry | — |

Summing up then it is not yet possible to give a precise, dated, postglacial climatic succession for the arid zone of North America, although a great many observations speak for an alternation of numerous moist and dry spells of varying duration.

## CLIMATE AND CLIMATIC VARIATION OF THE LAST 2,000 YEARS

The reversal from an arid climate in Subboreal time to more or less contemporary conditions of moisture and temperature took place about midway in the last millenium B.C. Since that time there have only been short-term variations, never exceeding the order of a few hundred years. This and the final section of this chapter on the modification of climate in arid lands is devoted to the question of climatic change in historical times and the short-term variations, of generally limited character, within the last phase of the postglacial climatic succession, corresponding to the Subatlantic. Although there is a great deal of historical, archaelogical and even geological evidence for the focus areas of Near Eastern civilization, the question becomes obscure when we turn to the western Sahara, South Africa, Central Asia or Australia. It is no longer obvious that the general trend of precipitation was at all similar from continent to continent when we come to the examination of first- and second-order climatic fluctuations (measured in terms of $x\ 10^1$ and $x\ 10^2$ years respectively). This will be illustrated from the data available from geological as well as tree-ring analysis in the American South-west.

## THE CHARACTER OF NEAR EASTERN CLIMATE DURING THE CLASSICAL AGE

After the period of strong Nile sedimentation had ended—probably in the second century A.D. if we take as a guide the historical commentaries of Plutarch and Aelius Aristeides on flood levels—aeolian activity was resumed in the Libyan Desert at the latest by the beginning of the Byzantine period (after about 300). In Middle Egypt dunes still intercalated with lenses of Nile mud contain later Roman period pottery [29, 30]. That the Roman and Byzantine period was not moister than today in Egypt can be seen from a lack of local deposits indicating precipitation. The present writer also examined countless Roman sites, without finding a single piece of microstratigraphical evidence to support this. The same conclusion can probably be applied to the Sahara as a whole. Interesting in this connexion is however the so-called weather record of Ptolemy, dating from somewhere between A.D. 127 and 151. Brooks and Sawyer [17], who studied this record, believe that the two entries of rain in July and four entries of thunder for June to August indicate occasional, rare depressions interrupting the normally steady, fine summer weather of the eastern Mediterranean. Notable also are some records of south winds and weather changes during July and August. Dubief [42] has interpreted this as a possible northward and eastward intensification of the Saharo-Sudanese depressions of southerly origin. Possibly Brooks and Dubief were unaware that northward intensification of the 'Sudan monsoon low' leads to summer or early autumn thundershowers or fog in the Red Sea Hills as well as the Suez-Cairo-Delta area even today. Such depressions even bring rainfall to Palestine. Catastrophic rain-showers have been known to occur in August both in the Cairo and Red Sea Hills area even during recent decades. As far as can be ascertained this loosening of a surface minimum from the tongue of low pressure extending northwards up the Red Sea is dynamically induced by upper air troughs situated over the Balkans or Asia Minor, i.e., by circulation features of the middle latitude westerlies. For example, between 29 March and 1 April 1953 such a northward oscillation passed up over the Delta to regenerate as a 'Cyprus low' as it united with an upper air trough moving southwards. Neither is the occurrence of such phenomena unknown today nor do they imply a northward shift of the monsoonal rains. The writer fully agrees with Brooks that the record of Ptolemy is a compilation of meteorological curiosa, abnormal weather features of note.

### *The so-called archaeological evidence of climatic change*

A generation ago it was a common axiom that the Graeco-Roman-Byzantine period, characterized by agricultural expansion into the marginal lands and by great economic prosperity, was a Golden Age blessed with bountiful rainfall, a copious water supply and oases in what is now desert. The abandonment and disappearance of the prosperous cities and flourishing farm lands of the marginal country in North Africa and the Levant in later centuries has been widely appraised as a symptom of climatic deterioration, part of the process of 'progressive desiccation since pluvial times'. Such ancient town sites inspired the publications of Ellsworth Huntington, Leone Caetani and H. C. Butler. but the concept as such was already as historical and classical as the ruins in question. The Greek and later the Arab authors, e.g., Mas'udi writing in A.D. 942, were both of the opinion that the past had been more blessed with rainfall and vegetation. It is true that Roman bridges and piers in 'dry' wadis, large deserted cities once possessing public baths and naucratia and so forth are quite fascinating in the bleak limestone hills of the Levant. But this picture is misleading as most of such ruins still fall within the 200 mm. isohyet and many of them within the 500 mm. isohyet, i.e., even outside of the semi-arid zone. The bleakness and desolation is mostly due to deforestation and a catastrophic soil erosion, particularly after the abandonment of the area. Today the hills are stripped of soil or vegetation and the former lakes of the Orontes Valley have almost filled up with silt. Ancient Antioch is buried by more than 20 m. of silt carried down from the once prosperous uplands of Syria. Reconstructions of the Roman roads and *limes* of desert Syria indicate that the *limes* do not extend outside the zone of permanent wells. E. Kirsten has kindly pointed out to the writer that the appearance of Syrians in great numbers in Western Europe during the sixth century shows that the *villes mortes* were abandoned due to the insecurity resulting from the Byzantine-Sassanid wars—we need only think of the internecine struggles of A.D. 572-591 and 603-628.

An attempt has also been made to show that a similar 'climatic change' occurred in South-west Arabia. The shift of political power and major settlements from the Yamanite interior to the highlands is, however, only due to the destructive wars between Himyar and Hadramaut that led to the gradual beduinization of the oases on the desert margins after A.D. 200 [22]. Furthermore the Romans' horrible descriptions of the incense lands are probably tales spread by the South Arabian merchants and seamen to keep out foreign traders. It is widely held today that Hadramaut was never the chief source of incense, but that the merchants of this area merely played middlemen to Europe with imports from East Africa and the Indies. In short the so-called archaeological evidence does not support a hypothesis of climatic deterioration in the Near East in historical times. The abandonment of wide areas of the Levant, South-west Arabia and North Africa, generally on the interior margins of the settled lands, was a result of increasing economic deterioration and political instability in the disintegrating Roman Empire, the invasion of nomadic tribes and the resulting decline of urban activity. This was the consequence of a transformation of the cultural landscape from agriculture to pastoralism. The decay of artificial terracing hastened a rapid and decisive soil erosion on the already deforested hills. The effect of nomadic invasions, particularly those in the late sixth century, has not been made good even today. Ibn Khaldun gives evidence of the devastations of the banu Hilal and banu Sulaim in the Maghrib during the eleventh and fifteenth centuries, and his comments elucidate the fate of other, once flourishing, provinces. Sedentary agriculture was largely abandoned and most cities were reduced to inconsequence, as nomads have little appreciation for urban commerce and industry [23]. If the soil had not since been swept away, most of these areas could eventually be resettled today under similar conditions. There is simply no foundation in fact for progressive desiccation in the dry zone of the Old World.

### *Fluctuations of the groundwater table*

A second rather different problem is that of the groundwater table. There does appear to be a good deal of evidence from Egypt and the Levant, the Sudan and Arabia that the groundwater table has fallen in historical times, usually 'since Roman times' —merely because we seldom know precisely what happened before that. A general fall of the static groundwater head during the last five thousand years has been proven for the Egyptian deserts. The fossil 'mound-springs' of the Kharga Oasis imply a level some 55-60 m. higher than today [68], and many springs and wells of Uweinat, the Gilf Kebir and the oases Sheb and Tarfawi have dried out since the Dynastic period. The fall of the groundwater table at Bir Misaha amounted to 22 m., at Bir el Atrun and Merga to 10 m.; and for Farafra to 5 m. since Roman times [67]. In the Eastern Desert the groundwater head is 7.5 m. lower than it was in Dynastic times in Wadi el Allaqi, and Roman wells in Wadi Qena are now dry (see [23]). The groundwater level on the Mediterranean coast has not varied appreciably.

In the Levant area reports are more conflicting. Roman wells in the lower Jordan Valley were cleaned out recently but remained dry. At Kasr el Azrak similar conditions indicate a fall of 2 m. At Palmyra the springs supplying the ancient Roman *foggara* have fallen off so strongly that water must now be pumped up from the aquifer through two bore holes. On the other hand Byzantine *foggaras* are in good use again at Ma'an, and cisterns and wells cleared, in the Beersheba-Gaza areas have proved quite usable. A great number of *foggaras*, wells and cisterns were also renovated in the area between Homs, Aleppo and Kdeim in 1937, and there is no question of a falling water table here. But at Dharan in Saudi Arabia a fall of 1 m. is verified while the Sabaean irrigation channels lie 3-4 m. above the groundwater head in the interior of Yaman.[1]

From a good number of other areas it is known that excessive pumping in recent years has strongly depleted groundwater reserves. Several *foggaras* around Selemiya and Aleppo are now dry, the water table has fallen 5 m. in the Bahariya Oasis since 1900, and in Wadi Hanifa, Arabia, by as much as 20 m. Such features are localized however and must be generally attributed to unfavourable hydrogeological conditions. Whether the recent climatic fluctuation may be related in part is rather doubtful.

For some years past many geologists have accepted the opinion that the groundwater reservoir of the Libyan and Arabian deserts is 'fossil', i.e., a relict from the pluvials. Particularly in the Libyan Desert there is no rainfall worth noting today, so that the water must either originate from distant intake beds or be a stay-over from the recent geological past. The scheme first devised by Ball (see [68]), whereby the water source of the artesian basin is localized in Erdi and Ennedi by means of static groundwater head contours, has two flaws. First, it must be asked whether the deeper layers of the water-bearing Nubian sandstone, dipping northwards from the edge of the metamorphic basement in the Sudan, are not interrupted by intrusions of igneous rock. Then again it is most unlikely that Erdi with an annual precipitation today of 20 mm. or Ennedi with 100 mm. can be expected to supply such an immense artesian basin with water [23]. An optimistic estimate would allow, at the very most, 20 per cent of this scanty precipitation to percolate to the groundwater in view of an annual evaporation deficit of 2-3 m. Several authors have estimated that groundwater would require 30,000 to 100,000 years to pass from Ennedi to the Qattara depression, depending upon the fissuring of the sandstone aquifer [68]. Bearing in mind that the last major pluvial dates from perhaps 80,000 to 20,000

1. The writer is greatly indebted to Messrs. D. F. Burdon, L. Dubertret, Ali Shafei and C. Voûte for kindly supplying the above data.

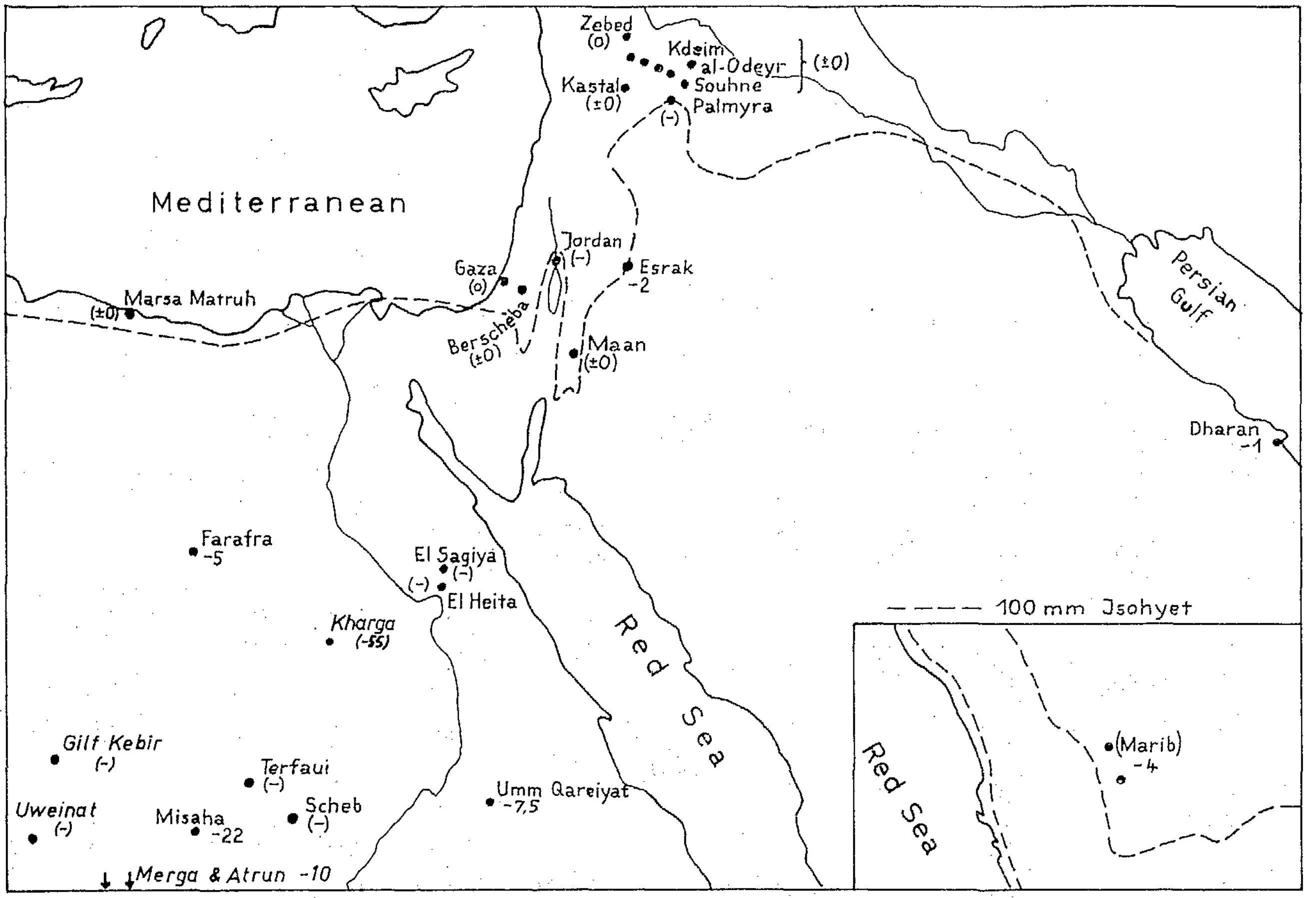



FIG. 4. Changes in groundwater level during historical times. Numbers refer to variations of static head in metres. Dashed line represents modern 100 mm. isohyet. (Modified after Butzer [23, figure 1].)

years before the present, one would rather incline to accept the hypothesis that the desert groundwater reservoir is of pluvial origin.

This also seems to give a clue to the contradictory evidence on groundwater trends since the Neolithic: in areas receiving rainfall today groundwater is being continually recharged, whereas in absolutely arid sections fossil groundwater is gradually being depleted and used up by artificial or natural losses. Here there has been no rain to recharge the water used by man since perhaps the Subpluvial of 5000-2400 B.C. In order to test this hypothesis we have plotted the known groundwater trends against the 100 mm. precipitation contour (Fig. 4). This is not intended to be more than a very rough approximation of the zone without natural recharge today. It is all the more surprising that this line, grossly ignoring the hydrogeological details, nevertheless comes so close to separating those areas with groundwater falls from those with unchanged groundwater levels. This seems to verify that the negative groundwater trends are limited to rainless areas, where fossil reserves are gradually being depleted. This feature is not in the least associated with 'progressive desiccation'.

For the climatic history of short-term fluctuations of precipitation and temperature from the beginning of the Christian era to about 1850, the reader is referred to [22, 23, 26]. Such fluctuations are in the main limited to the usual repetition of dry or moist, cool or warm years re-occurring from time to time since time immemorial. Major features are moist spells A.D. 380-450, 530-590, particularly *c.* 700-1000,

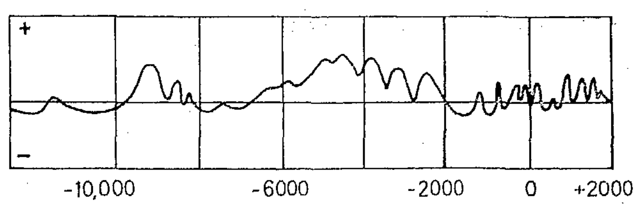



FIG. 5. Main trends of precipitation (hypothetical) in Near East since about 12000 B.C.

during the late thirteenth, early fifteenth, the first half of the seventeenth and the beginning of the nineteenth centuries; dry spells can on the other hand be noted for the years A.D. 450-530, 590-640, the twelfth century and since 1900. A diagrammatic attempt to show the main trend of precipitation in the Near East during the course of the last 14,000 years is given in Fig. 5.

Although little or nothing is known from Central Asia during this period, apart of course from the Caspian Sea area, Schove [75] has compiled a rather impressive climatic history for China from the second century onwards. Salient points are the increased rainfall in the first century B.C., third, fifth, eleventh-twelfth and fourteenth-fifteenth centuries A.D. and the pronounced aridity in the first-second, fourth, sixth, tenth and eighteenth-nineteenth centuries A.D.

### CLIMATIC VARIATION IN NORTH AMERICA FROM 1000 B.C. TO A.D. 1850

The climatic fluctuations of the last phase of the postglacial climatic succession (Subatlantic, Medithermal) have long been dominated by the tree-ring curves of E. Huntington and A. E. Douglass. Based upon the growth-rings of the giant sequoia on the western flank of the Sierra Nevada, it was once thought that the chronology of droughts and wet years could so be accurately dated into the last millenium B.C. In dry areas trees are admittedly most sensitive to moisture fluctuations because drought can actually prevent cambial growth. However Antevs [2] and Schulman [76] have since shown that the sequoia growth-rings are a poor rainfall indicator, recording mainly the length of the growing season. As a result the applicable tree-ring chronology, generally derived from specimens growing at the lower dry limit of forest, has been somewhat shortened. Antevs [2] has carried out a detailed study of rainfall and tree growth in the Great Basin, coming to the following conclusions. Tree growth on the dry limit of the forest corresponded to the water supply available during the growing season in about 75 per cent of the years; groups of especially wide or narrow rings corresponded in a general way to pronounced and extended maxima and minima of rainfall in 90 per cent of the cases observed. However, individual tree-rings matched precipitation in only about 50 per cent of the years. Dendrochronology therefore provides a valuable but not infallible guide, which must be treated with care and preferably supplemented by other types of evidence. It is therefore necessary to employ geological material as well.

A moisture maximum for the last 3,000 years has been localized in the later part of the last millenium B.C. It is associated with large and perennially fresh lakes in the Carson Sink and at Humboldt Lake. This has been indicated by Antevs [3] on the basis of bones of lacustrine fish, now confined to Pyramid Lake, in Humboldt Cave, Nevada. Whether or not this moist spell was contemporary with a re-advance of the Rocky Mountain glaciers, tentatively dated at 2,800 years ago by radiocarbon, remains open. Before the moist interlude however there was a severe dry period shortly before 500 B.C., as is indicated by a cessation of aggradation together with erosion of dry-climate gullies at Fairbank, Arizona. The next dry spell of importance, the 'Whitewater Drought', occurred either from A.D. 162 to 181 or possibly from A.D. 320 to 329. It is witnessed by arroyo cutting and narrow tree-rings in north-eastern Arizona [5]. The third notable dry snap, the 'Great Drought', occurred from 1276 to 1299 according to the tree-ring studies and evidence of arroyo erosion in most parts of the south-west [2, 76]. Since this period there is a reliable tree-ring chronology indicating strong fluctuations of the lower dry limit of tree growth.

Notable have been the serious drought occurring in 1573-1593 in the Colorado Basin, in 1571-1597 in southern California, in 1565-1580 and 1594-1599 in eastern Oregon. It may be noted that the drought corresponded quite well in all three regions. Glacier re-advances occurred somewhere between the sixteenth and nineteenth centuries, but closer dating has not yet been made. There were humid spells about 1526 and 1537-1540 while the period 1670-1717 was generally quite moist, and again in the years 1800-1828. Stronger droughts are further recorded from 1776 to 1789, 1794 to 1798 and 1840 to 1849. After 1850 there are innumerable records and observational accounts of lake levels and precipitation, which will be further discussed below.

## THE RECENT CLIMATIC FLUCTUATION IN ARID REGIONS

In the course of the nineteenth century our technical civilization penetrated into the dry lands of the western Sahara, the Great Basin and Great Plains, the Kalahari and Veld of South Africa and the wide expanse of interior Australia. As a result it is possible for the first time to close the gap in our knowledge of post-Early Holocene climatic variations in most of these areas, while in others many additional details of great value become accessible. Not only were lake levels and river run-off observed and noted, but the practice of direct meteorological observations was extended to the greater part of the semi-arid zone of the world. Meteorological observations of uninterrupted, homogeneous and reliable character have been carried out in various countries of Europe and in the United States since the first half of the eighteenth century. In the semi-arid zone such observations commenced a little later, but their inauguration midway in the nineteenth century is of at least as great interest. Since the 1940s very detailed and refined measurements of upper air data are tending to accumulate a monumental mass of material, which is to a great extent still not generally accessible and of which scientific analyses and evaluations have barely begun.

The interesting feature of climatic observations during the last century is the 'recent climatic fluctuation', well known in higher latitudes, where it has been characterized by a general warm-up of meteorological significance and ecological importance. In lower latitudes there has been a corresponding although somewhat less appreciated fluctuation—not so much to higher temperatures but rather to reduced precipitation. To estimate their significance one need only recall the Dust Bowl years, the advance of the Sahara at the expense of the Sudanese savanna or the appalling catalogue of famines due to drought. The *precipitation anomalies* of the last hundred years are of equally striking nature as the recent temperature changes, and their world-wide character —within the range of observation—lends them an intrinsic value for the reconstruction of past anomalies of the general atmospheric circulation.

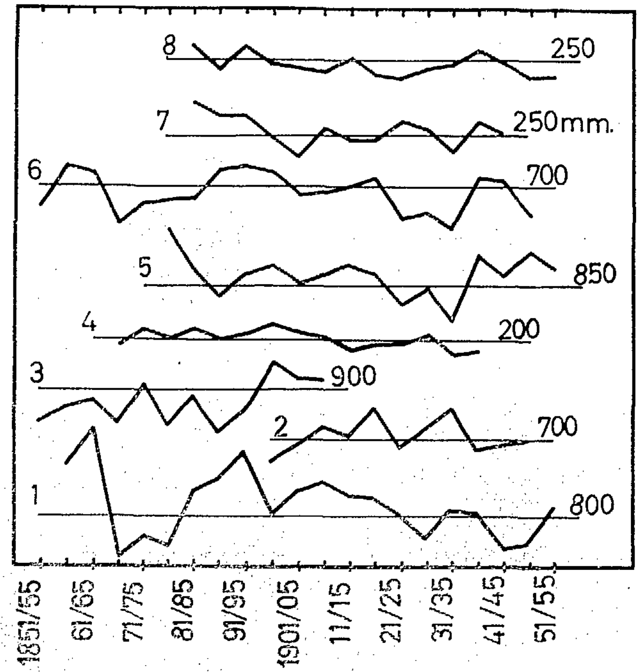



FIG. 6. 5-year precipitation means for Mediterranean and Near Eastern stations, 1851-1855 to 1951-1955. 1. Gibraltar; 2. Bouzaréah (Algiers); 3. Rome; 4. Alexandria; 5. Beirut; 6. Jerusalem; 7. Bushire; 8. Quetta. Vertical scale uniform relative to approximate median value at right (in millimetres).

## RECENT TRENDS OF PRECIPITATION AND TEMPERATURE IN NORTH AFRICA AND WESTERN ASIA

A general re-advance of the montane glaciers occurred not only in the Alps about 1850, but also in the Causasus, the Near East and, in the form of snowfall, also in the Ethiopian highlands. This date also marks the beginnings of meteorological obervations in the southern half of the Mediterranean area. The material employed below for the analysis of the recent climatic trend has been generally derived from the reliable series of the *World Weather Records* [88], with data later than 1940 supplied through the courtesy of the British Meteorological Office, the Institut de Metéorologie et Physique du Globe, Algers, and annual reports of the various stations and agencies in question.

To begin with, Fig. 6 gives 5-year precipitation means for a series of stations going west to east from Gibraltar to Baluchistan. It is immediately apparent that variability is fairly random from place to place while no general trend is noticeable. Closer inspection, however, shows that a series of wet years will affect at least two or more neighbouring stations, gradually tapering out laterally; the same applies for particularly dry years. For example, the years 1856-1865 were moist at all observing stations and the dry years 1931-1935 were distinctly noticeable at Alexandria, Beirut, Jerusalem and Bushire. Proceeding further, these data have been grouped into 15-year means in Table 5 [23], and for the first time it is possible to see a far-reaching correspondence from one area to another. The mean precipitation of 1866-1880 was 15 and 35 per cent lower than that of 1851-1865 at Jerusalem and Gibraltar respectively. About 1878 conditions began to reverse and the means of 1881-1895 are generally higher. Correspondingly the Dead Sea began a long rise which reached some 6 m. by 1910, and the Caspian Sea level of 1882 is the maximum on record since the beginning of reliable gauge readings at Baku in 1877. Nile discharge volumes at Aswan have been measured since 1870, reaching a maximum in 1879. The mean discharge of 1871-1900 is some 17 per cent higher than the mean of 1871-1945. Similarly the Senegal carried a comparatively large amount of water: flood levels reached 15.5 m. in 1870, dropping to 9 m. in 1900 and 5 m. in 1920. Simultaneously the low water period was prolonged from 2 months in 1870 to $5\frac{1}{2}$ in 1900, and to 7 in 1920 (see [23]). The maximum humidity achieved before 1892 marked a climax preceding the all-out climatic deterioration associated with the recent fluctuation in lower latitudes. The trend to greater aridity began first in the western Sahara where the years 1874-1892 had still been particularly moist at Téfédest [41]. But the period 1892-1909 in Ahnet and that of 1893-1900 in Téfédest were exceedingly dry. About 1900

TABLE 5. 15- and 30-year precipitations means

| | Gibraltar | Bouzaréah | Alexandria | Jerusalem | Beirut | Bushire | Quetta | Aden | Nile volume at Aswan |
|---|---|---|---|---|---|---|---|---|---|
| | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | million m.$^3$ |
| 1851-65 | 1 081 | — | — | 723 | — | — | — | — | — |
| 1866-80 | 683 | — | 205 | 600 | — | — | — | — | — |
| 1881-95 | 986 | — | 216 | 737 | 897 | 353 | 277 | 66 | 107.1 |
| 1896-10 | 899 | 683 | 230 | 697 | 922 | 229 | 221 | 43 | 90.4 |
| 1911-25 | 880 | 742 | 180 | 669 | 884 | 264 | 208 | 28 | 81.3 |
| 1926-40 | 798 | 756 | 167 | 618 | 833 | 259 | 253 | 44 | 83.8 |
| 1941-55 | 735 | 739 | | | 940 | — | 209 | 38 | |
| 1851-80 | 882 | — | — | 662 | — | — | — | — | — |
| 1881-10 | 943 | — | 223 | 717 | 910 | 291 | 249 | 55 | 98.7 |
| 1911-40 | 842 | 749 | 173 | 644 | 863 | 261 | 230 | 36 | 82.5 |
| Difference (percentage) | —11 | — | —23 | —11 | —5 | —10 | —8 | —34 | —16 |

this trend became general in the whole Mediterranean basin and throughout the tropics.

Changes between 30-year observational means were defined as 'climatic fluctuations' at the International Meteorological Conference, Warsaw, in 1935. In Fig. 7 the precipitation anomalies associated with the recent fluctuation have been expressed in percentage deviations of the mean 1911-1940 from the mean 1881-1910 [21]. The map is based on some 70 stations with homogeneous records—the obvious gap for the Sahara proper being extrapolated. It is immediately obvious that this climatic fluctuation has been uniform south of a ±0 isoline running from southern France to northwestern India across the Alps,

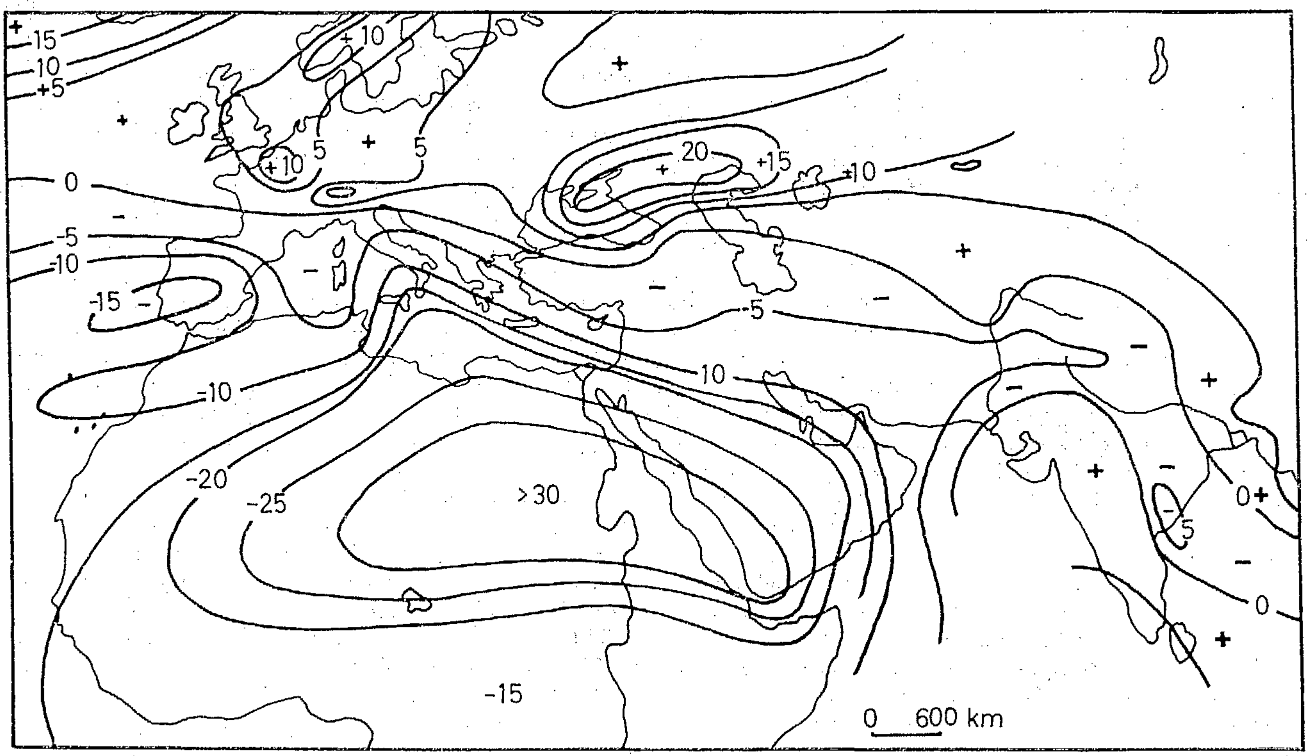



FIG. 7. Precipitation anomalies 1881-1910 to 1911-1940 expressed in percentage deviations from the mean 1881-1910. Annual. (Modified after Butzer [21, figure 3].)

Balkans, Pontic Mountains and Caucasus. North of this line rainfall has generally increased (to over +20 per cent), south of the line it has decreased (to over −30 per cent). North Africa and the whole Mediterranean climatic province, particularly its eastern half, have become very much drier. The greatest decrease occurred on the northern and southern margins of the Sahara-Arabian Deserts. The latter values are not local trends : they are valid for the whole Ethiopian drainage basin of the Nile (a discharge decrease of 16 per cent between the 30-year means before and after 1910—a record of indisputable reliability) and the Senegal basin; they apply to long-term records of Freetown and Aden and are confirmed in the remaining shorter or incomplete records of Bathurst, Accra, Calabar and Khartoum. In this connexion the cumulative graph of Kraus [60] for the Nile discharge is very illuminating. Only in the monsoon area of India has the precipitation anomaly not been uniform. In southern India the autumn and winter rains have increased, while no very significant increases occurred on the west coast and on the Deccan. On the other hand the spring and summer rains of Madras [59] and to a lesser extent the summer monsoon in the Ganges Valley have decreased a little.

Ecologically the record shows 2 m. and 3 m. drops in the level of the Caspian and the Dead Sea respectively since 1910. Lake Jairud in Syria contained several species of freshwater fish during the last century; today there is only a salt pan there that dries out completely in summer. Pasture conditions have deteriorated catastrophically since the 1870s in Tibesti, and since about 1920 the Tibbu of Erdi no longer visit their traditional summer grazing grounds in Uweinat and the Gilf Kebir. Droughts of economic importance plagued the Levantine area in the 1920s and the entire Near East in the 1930s. Lake Aksehir in Central Anatolia dried out entirely in 1933. Similar conditions can be noted for the peripheries of the Sahara. The advance of the desert, especially between the Niger and Lake Chad, cannot be wholly explained by anthropogenic causes, e.g., deforestation. The climatic fluctuation will certainly be involved as well. For example, a decrease in Nile volume by 25.3 million cubic metres annually (between the means of 1871-1900 and of 1901-1945) is no negligible factor for man and vegetation, and without the tempering effect of dams and barrages, agriculture in the Nile Valley would have suffered badly. In other words the recent trend to greater aridity is real and ecologically important.

Temperature changes have been more or less in phase with those of higher latitudes, at least as far as the poleward margins of the trade-wind deserts are concerned. South of the Sahara, and in the equatorial zone generally speaking, there have been tendencies to lower temperatures, at least locally. Five-year temperature means in Fig. 8 again give a cross-section from west to east in the Mediterranean-Near East area, while Table 6 [23] summarizes the significant 15- and 30-year anomalies of the same zone. Generally speaking January temperatures have increased a little throughout this area although a few Asiatic highland stations, such as Quetta (−0.76° C.), show a negative trend. Even the central Asiatic stations show a warm-up (Krasnovodsk +1.46° C.), despite the abnormal westward shift of the Siberian anticyclone in the 1920s and 1930s. Only the mean 1931-1935 is a trifle too cold here (Fig. 8). Within the winter rainfall belt summer temperatures have likewise tended to increase. An exception is Bushire (July −0.16° C.) and, of greater importance, the Iberian Peninsula. The latter condition is due to the intensification of the Azores high whereby cool air-masses are transported north-south on its eastern flank. Nevertheless both winter and summer temperatures in North Africa and the Near East have, broadly speaking, increased a little, in the order of 0.5° C. on the annual mean. The warm-up began earlier than the rainfall decrease, namely after 1850.

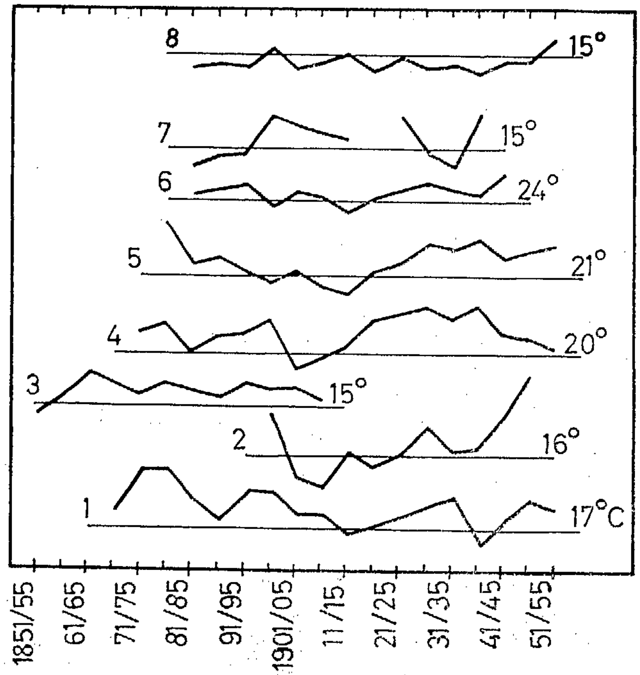


FIG. 8. 5-year temperature means for Mediterranean and Near Eastern stations 1851-1855 to 1951-1955. 1. Gibraltar; 2. Bouzaréah (Algers); 3. Rome; 4. Alexandria; 5. Beirut; 6. Bushire; 7. Krasnovodsk; 8. Quetta. Vertical scale uniform relative to approximate median values at right (in ° C.).

Since 1940, the trend established since the turn of the century has persisted, although, according to available data, in a less pronounced form. Figure 8 shows a continued upward trend of annual temperature at most stations, with the exception of Alexandria,

TABLE 6. 15- and 30-year temperature means in °C.

| | Bouzaréah | Alexandria | | Beirut | | Bushire | | | Quetta | | Krasnovodsk | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | year | Jan. | year | Jan. | year | Jan. | July | year | July | year | Jan. | year |
| 1881-95 | — | 14.08 | 20.29 | 13.87 | 21.25 | 14.72 | 32.12 | 24.15 | 25.87 | 14.85 | 0.61 | 15.35 |
| 1896-10 | 15.95 | 13.47 | 20,09 | 13.21 | 20.96 | 14.04 | 32.03 | 23.95 | 26.05 | 14.98 | 2.47 | 15.99 |
| 1911-25 | 16.01 | 14.21 | 20.53 | 13.83 | 21.01 | 14.16 | 32.03 | 23.90 | 26.65 | 14.95 | 4.06 | 15.85 |
| 1926-40 | 16.30 | 14.72 | 20.99 | 14.08 | 21.67 | 14.04 | 31.80 | 24.20 | 26.61 | 14.81 | 1.93 | 15.61 |
| 1941-55 | | | 20.32 | 13.91 | 21.50 | — | — | — | | 15.43 | | |
| 1881-10 | 16.01[1] | 13.78 | 20.19 | 13.54 | 21.11 | 14.38 | 32.08 | 24.05 | 25.96 | 14.92 | 1.54 | 15.67 |
| 1911-40 | 16.58 | 14.46 | 20.71 | 13.96 | 21.34 | 14.38 | 32.92 | 24.05 | 26.63 | 14.88 | 3.00 | 15.73 |
| Diff. °C. | +0.57 | +0.68 | +0.52 | +0.42 | +0.23 | 0.00 | —0.16 | 0.00 | +0.33 | —0.04 | +1.46 | +0.06 |

1. Means 1894-1923 and 1922-1951.

where the temperature values may be faulty owing to a shift of stations and the computing methods for daily means. The stations in Table 5 and Fig. 6 show further decreases in precipitation, with exception of Beirut (+9 per cent)—where January temperatures have significantly fallen. The mean 1941-1955 was 13 per cent lower than that of 1911-1940 at Gibraltar, 2 per cent at Bouzaréah, and 9 per cent at Quetta. On the southward margins there was a 5 per cent increase at Aden, 15 per cent decrease at Khartoum, 1 per cent decrease at Freetown while the Nile discharge has fallen further. So far as we can tell at the moment, the recent climatic fluctuation is still continuing and so is the newly established trend to greater aridity in North Africa and Western Asia.

## RECENT CLIMATIC FLUCTUATION IN THE SOUTHERN HEMISPHERE AND CENTRAL ASIA

In South Africa, Vorster [82] has carried out a modern analysis of long-term records of precipitation at 17 stations for the period 1881-1950. Of these, 13 show a lower average for the period 1916-1950 compared with 1881-1915. Many of the decreases amount to 10-15 per cent, while the over-all mean decrease according to the semi-total method is 6 per cent. Further, according to the method of least squares, 11 of 17 stations show a downward trend. The 10-year overlapping means show a downward tendency from 1880 to 1930 with a slight increase thereafter. This applies to the Mediterranean-type climate zone of Cape Province, as longer records are not available from the Transvaal, etc. In equatorial Africa the trend has been identical, judging by lake levels in Central and East Africa. Giant Lake Victoria exhibited a net loss of 97 cm. in its hydrological budget from 1896-1920 to 1921-1943. Similarly Lakes Nakuru and Naivasha have fallen steadily during the present century [69] (see also [40]).

In the semi-arid and arid zone of Australia Kraus [58] has given detailed evidence of a sharp reduction of precipitation at interior stations since shortly before 1900—this was exactly the case in the Upper Nile basin. (For further details on the over-all and striking decrease in tropical rainfall see [58, 59, 60].) A few figures for Australia are: Alice Springs, decrease of 22 per cent from 1874-1920 to 1921-1940; Darwin, decrease of 10 per cent from 1870-1920 to 1921-1940. According to Kraus [58], almost all stations on the eastern coast showed steady declines in the amount of rainfall since about 1897.

Lastly a glance at precipitation figures and lake levels in South America conveys the same picture of declining rainfall on both equatorial and poleward margins of the subtropical desert belt. Lake Titicaca displays a net loss of 91 cm. in hydrological budget between the periods 1915-1929 and 1930-1943. Further south Santiago de Chile shows no change between the means of 1867-1920 and 1921-1940. However, Mendoza and San Juan in Argentina show drops of 3 per cent between the means of 1891-1920 and 1897-1920 respectively compared to 1921-1940. Tucuman shows a decrease of as much as 10 per cent from the period 1885-1920 to 1921-1940.

As has been indicated (Fig. 7), the recent climatic fluctuation in Central Asia was associated with increased precipitation at almost all stations. It is therefore curious that lake levels (e.g., Caspian Sea) and river run-offs (e.g., the Volga, Emba, Amu Darya) should have fallen and declined. The matter was investigated by the writer in a recent article [25]. The 2 m. drop of the Caspian Sea between 1881 and 1940 was primarily associated with rising summer temperatures over the Volga drainage basin (75 per cent of Caspian waters are contributed by the Volga) and to a lesser extent over the surface of the great inland sea itself. Temperature trends 1881-1940 yielded a correlation coefficient of 0.60 ±0.12 with Caspian fluctuations, while precipitation only showed a correlation of 0.41 ± 0.14. July temperatures over European Russia were 1.3° C. above the 1931-1940 normal while precipitation was some 8.5 per cent too low. The combined effect was a drop in lake level by 168 cm. This phenomenon was ultimately due to increased continentality in Russia. An axiom to be remembered is that the greater the evaporating surface the greater the effect of rising temperatures, so much so that the latter can at times simulate a decline in precipitation where no absolute decrease has taken place.

In the semi-arid zone of the Far East the recent climatic fluctuation has been little investigated. Most interesting however are the numerous studies of H. Arakawa from Japan, in which he also devotes a little attention to the Yangtze River gauge readings of 1865-1937 [6]. Notable are the low levels of 1876-1881 and 1895-1904, while the average of 1905-1932 is slightly below that of 1865-1894. A glance at the sparse long-term rainfall data shows that the over-all tendency, as in Central Asia, has been variable but tending to positive. The slight decline in river discharge must, as in the Volga basin, be attributed to higher temperatures.

## CLIMATIC VARIABILITY IN THE AMERICAN SOUTH-WEST SINCE 1850

From no other region of the arid zone are observations so complete and detailed as those of the American South-west, particularly the Great Basin area. This material has been worked over by several authors, of which the most complete and accessible study is possibly that of Antevs [2], whose presentation has been largely adopted here. Rainfall measurements have been carried out in California since 1850, in Nevada and Utah since 1870, and run-off measurements have been made on numerous rivers and streams since about 1900. This material has been compared by Antevs with tree-ring curves and lake-level fluctuations. Fluctuations of the Great Salt Lake level have been recorded since 1851 while isolated observations go back to the period before 1845. Regular observations of Pyramid and Winnemucca lakes go back to 1869.

The earliest records about or before 1850 all point to extremely low lake levels or remarkably little run-off. Judging from the tree-ring curves the severity of the drought during the 1840s must have been comparable with that of 1924-1934. After 1850 rainfall increased until 1853-1854, then dropped off until 1860. The over-all trend in the 1860s was positive and all lake levels rose appreciably, and in 1867 the Great Salt Lake reached a stand higher than it had been for perhaps several hundred years. According to Antevs, the lake responds to the cumulative effect of stream run-off over a number of years on account of its size, so providing a good picture of larger fluctuations of climate. However, from the factors involved in recent fluctuations of the Caspian [25], an even larger body of water with a huge drainage basin, it may well be that temperature fluctuations —which Antevs never mentions—can even more logically be suspected to account for such contradictory features as falling lake levels and increasing precipitation. With very much smaller basins and smaller direct evaporating surfaces, smaller lakes such as Tahoe, Winnemucca or Utah will follow the precipitation curve much more faithfully. Therefore only when cool and wet come together can one expect a high water level of the Great Salt Lake. This matter appears to be worth investigating. The long stand at about 4,210 ft. (1869-1878), reaching a record maximum in 1873, certainly indicates optimum moisture conditions—probably high precipitation and lower temperatures—between about 1862 and 1877. This is corroborated by a glance at the temperature record since 1874. In the late 1880s a generally negative trend culminated in the drought of 1889, prior to a new optimum in the earlier 1890s. Precipitation maxima were recorded in north-eastern California while Lakes Winnemucca, Pyramid and Utah achieved high stands. Precipitation remained high in the first years of the present century and reached its highest point in 1907.

Since 1907 the general tendency has been towards a decrease in precipitation and run-off, and a fall in lake levels. This tendency was briefly interrupted by the abnormally moist years of 1921-1922 to achieve a minimum in the Dust Bowl years of the 1930s. In north-eastern California and Nevada rainfall was generally below average between 1915 and 1935, a trend faithfully followed by the tree-rings. The first minimum occurred in the period 1918-1920, the second in the period 1924-1934. Although the years 1925, 1927 and 1932 were relatively moist the remaining period was so droughty that, in combination with the cumulative effect of decreasing precipitation since 1907, a drought of unknown proportions during the period of American settlement brought on a severe economic crisis. Increasing temperatures from about 1910, combined with the low rainfall, made the over-all effect more appreciable. For example, mean temperatures were on the average 0.5-1.0° C. higher than the average during 1931-1940. In parts of the Great Basin the 10-year mean for the period 1921-1930 was lower than the following decennium on account of the strong rise in rainfall after 1935. For example, west of the Rockies, Arizona and south-western New Mexico show positive anomalies of up to 3 per cent for the period 1931-1940. However, together with northern Mexico, this area belongs to the summer rainfall belt.

The greatest aridity of the Dust Bowl years made itself felt on the western Great Plains, particularly in a core area between southern Saskatchewan and Kansas. Temperatures for 1931-1940 were over 0.75° C. too high while precipitation was over 15 per cent too low. For example, in North Dakota rainfall was 14.6 per cent below average, in Montana this figure is 11.5 per cent, in South Dakota 21.5 per cent, in Nebraska 18.2 per cent, in Kansas 13.8 per cent, in Wyoming 9.7 per cent and in Colorado 10.7 per cent. The parched soil, stripped of its natural vegetation by the extension of the cultivated land, was carried away by the wind—the dust clouds still obscure the vision on the Atlantic coast. The meteorological aspects of this agricultural catastrophe are probably as notable as the economic ones.

Since the late 1930s and the 1940s conditions have generally improved. The precipitation anomalies of 1941-1950 were, with the exception of Arizona (—11 per cent), everywhere well above normal. This was particularly so in the chief drought areas : Kansas +13.9 per cent, Utah +13.6 per cent, Oklahoma +11.3 per cent. Simultaneously temperatures somewhat decreased. Rodewald [72] explains the rainfall increase in the interior of the continent by the cooling off in the west, the warming up along the east coast, together with the increasing cold waves of westerly or northerly origin and a greater number of heat waves of southerly or easterly source. The over-all result would be more advective precipitation in the zone of overlap. Since about 1950 the trend has once more reverted to that of lower latitudes elsewhere, namely increased aridity. In 1954 droughty conditions on the Great Plains again approached a serious level.

In review, then, the semi-arid south-west and Great Plains have broadly speaking shown parallel tendencies to the climatic trend on the poleward margins of the trade-wind deserts of the Old World. The over-all tendency since 1907 has been increasing aridity associated with lower precipitation and higher temperatures. As in the Near East, maximum aridity culminated in 1933-1934 and since the late 1930s trends have been somewhat more variable and not infrequently positive.

There is comparatively little information available from the tropical flanks of the North American desert belt. Southern Arizona enjoys a predominantly summer rainfall and in this respect the record of Yuma is of interest : rainfall has increased by 14 per cent between 1870-1920 and 1921-1940. In Mexico itself the situation is identical : Leon +1 per cent from 1881-1920 to 1921-1940, Mazatlan +17 per cent from 1880-1920 to 1921-1940. Wallén [84] has reduced the earlier record of Mexico City giving a corrected record from 1878 onwards. On the basis of 10-year overlapping means the precipitation trend was negative from the period 1878-1887 to the period 1892-1901 followed by an increase until 1925-1934, interrupted for a short period between 1895-1904 and 1908-1917. Rainfall has decreased since the beginning of the 30s up to the period 1942-1951. Since then there has been once more a slight positive tendency. It is to be noted that the dominant upward trend and the maximum about 1930 is solely due to the July rainfall, not to that of the transitional seasons. Here then is the classical exception to the rule, namely a clear increase in rainfall on the tropical margins of the trade-wind desert belt. Wallén assigns it to a strengthening of the moist onshore trades.

## METEOROLOGICAL IMPLICATIONS OF RECENT FLUCTUATION AND PROSPECTS OF FUTURE DEVELOPMENTS

The anomalies of the general circulation associated with the recent climatic fluctuation in lower latitudes are of twofold importance. First they provide the most valuable actualistic experience for a reconstruction of past interpluvial, in particular warm-dry climates. Secondly they at least allow some speculation on the future development of precipitation trends in the arid zone. Based upon the writer's analysis of the related circulation changes in southern Europe, northern Africa and western Asia [21], the salient points can be outlined as follows.

First precipitation anomalies on the north and south flanks of the Saharo-Arabian deserts are clearly in phase, i.e., precipitation increases or decreases in the Mediterranean area and Near East follow parallel with increases or decreases respectively in West Africa, the Sudan and South Arabia (see Fig.7).

Secondly the general rainfall decrease south of the Pyrenees, the Alps, the Balkans and the Caucasus has been associated with notable changes of surface pressure distribution for the periods from 1881-1900 to 1901-1920 to 1921-1940 (see also [21, figures 1-2]). January barometric pressure has risen strongly over the Mediterranean, especially its eastern half, and in the Maghrib. Pressure has also risen in West Africa. In July the picture is similar though less pronounced in the Mediterranean, but more so in West Africa. The general positive trend in the Mediterranean Basin indicates a distinct weakening of the westerly circulation in the lower atmosphere and a considerable northward shift of the jet-stream. The strong pressure rise in the Sudanese belt indicates a southward shift of the trade-wind circulation and the associated dry Harmattan winds. Maximal increase in July (3 mb) indicates simultaneously that the West African monsoon penetrated considerably less inland. This fits in well with the observation of Kraus [57] that the rainy season has been shortened there. The slight negative pressure anomalies over the desert cores strengthen the evidence, provided this is not just a fiction due to extrapolation for the Sahara. In review, the decreased rainfall and ecological extension of the desert zone has been faithfully paralleled by an extension of the trade-wind circulation in both latitudinal directions.

The pressure increase in the Mediterranean together with drops over northern Europe and generally increased precipitation in middle latitudes implies a northward shift of the planetary jetstream. The associated general upper air anomaly has been to an over-all increase of zonal and south meridional circulation patterns, generally with southerly to westerly steering over both the eastern Atlantic and in the Balkans and South Russia. The increase of zonal circulation over Central Europe and Central Asia is obvious from both the intensified pressure gradient between northern and southern Europe as well as from the positive precipitation anomalies there. The statistical examination of Brezowsky [16] fully verifies the increase of zonal components between 1881-1910 and 1911-1940. The strong pressure rise over Cyprus implies a let-off in local frontolysis and cyclogenesis. This is in good part due to fewer cold fronts or upper air troughs penetrating across Asia Minor or the Balkans.

Kraus [57, 58] has come to similar conclusions for Australia, namely, a weakening of the intertropical convergence, an expansion of the subtropical high pressure belt and a wider separation of the tropical and westerly rainfall provinces. He likewise places the ultimate cause in a reduction of direct meridional circulation between the equator and temperate latitudes. In South America and South Africa the situation is again similar; only in North America has there been a poleward shift of the summer rainfall belt, unparalleled elsewhere on the earth. As Wallén [84] has suggested, one must assume a northward shift of the subtropical cells of high pressure—compared with a bilateral expansion in the Saharan area of the Old World, or in Australia.

In this discussion of the recent warm-dry climatic fluctuation it may be attempted to consider the prospects of future developments. It is not here intended to ask or answer the question what is ultimately responsible for climatic changes, although recent investigations [20, 85, 86] underline the probability of an extra-terrestrial, i.e., solar, origin. Whatever the weather significance of sunspot cycles—see the mathematically-founded, sceptical verdict of Berg [11]—the essence of a long-range forecast by Willett [86] in 1951 was a general recession of temperatures and amelioration of moisture conditions in lower latitudes in the period 1950-1970. He based himself upon extrapolation of the character of sunspot activity, forecasting a weak maximum only after 1962. Instead, as Rodewald [72] has already discussed fully in 1956, a record maximum set in very much earlier. This occurred in October 1957 and the $r_M$ for the associated 5-month mean is 222, a maximum of unknown intensity so far. If then at least the association of climate and sunspots as accepted by Willett is tenable, the present tendency of warming-up and drying-out should continue for many years to come. Rodewald is of the opinion that the brief interruption of the recent fluctuation in the 1940s was only an interruption, a minor fluctuation on a long-term trend that began over a century ago and will continue for some decades at least. Recent developments of moisture and temperature unfortunately seem to corroborate this, for lower latitudes, pessimistic prognosis. What supports Rodewald's opinion is that the warm-up has gathered so much 'momentum' that it will be difficult to reverse. Whether this will be the case or not is of course impossible to decide until a statistical basis for possible sunspot-weather correlations has been given. So far all supposed correlations of precipitation, lake-level fluctuations and sunspot cycles are not founded in fact. No correlations between lake levels of the Dead Sea, Caspian Sea, etc., with sunspot relative numbers have proved to be statistically significant—despite many tempting graphical comparisons. Similarly k-tests applied to such fluctuations of terrestrial phenomena themselves show no periodicity.

In retrospect then the ultimate causes of circulation changes are so far beyond the compass of human observation and all attempts to forecast future trends are purely speculative or intuitive as yet. Suffice it to say that the great climatic shifts of the last century indicate the instability of the precipitation-evaporation cycle in the marginal lands of the arid zone. The 'men against the desert' must remain aware of the dynamic character of the general atmospheric circulation, that climatological means cannot express a process such as weather. In the arid zone development or exploitation of water resources of all kinds remains a function of the weather—past, present and future.

# BIBLIOGRAPHY


1. ALIMEN, H. *Préhistoire de l'Afrique*. Paris, Boubée, 1955.
2. ANTEVS, E. *Rainfall and tree growth in the Great Basin*. New York, 1938. (*Amer. Geogr. Soc. Spec. Publ.*, No. 21.)
3. ——. Cenozoic climates of the Great Basin. *Geol. Rdsch.*, 40, 1952. p. 94-108.
4. ——. Valley filling and cutting. *J. Geol.*, 60, 1952. p. 375-385.
5. ——. Geologic-climatic dating in the west. *Amer. Antiq.*, 20, 1955. p. 317-335.
6. ARAKAWA, H. Two minima of the average rainfall at about the turn of the century and at about 1940 in the Far East. *Archiv für Meteorologie, Geophysik und Bioklimatologie*, Series B, 7, 1956. p. 406-412.
7. ARKELL, A. J. *The Old Stone Age in the Anglo-Egyptian Sudan*. 1949. (*Sudan Antiquities Serv. Occ. Papers*, No. 1.)
8. ——. *Early Khartoum*. Oxford, Oxford University Press, 1949.
9. ——. *Shaheinab*. Oxford, Oxford University Press, 1953.
10. ARNOLD, B. A. *Late Pleistocene and Recent changes in land forms, climate, and archaeology in central Baja California*. Berkeley, 1957. p. 201-318. (*Univ. Calif. Publ. Geogr.*, No. 10.)
11. BERG, H. *Solar-terrestrische Beziehungen in Meteorologie und Biologie*. Leipzig, Geest und Portig, 1957.
12. BLACKWELDER, E. Pleistocene glaciation in the Sierra Nevada and Basin Ranges. *Bull. geol. Soc. Amer.*, 42, 1931. p. 865-922.
13. BLAIR, T. A. *Climatology. General and regional*. New York, Prentice Hall, 1942.
14. BRAESTRUP, F. W. Remarks on faunal exchange through the Sahara. *Vidensk. Medd. dansk naturh. Foren. Kbh*, 110. 1947. p. 1-15.
15. BREUIL, H.; VAN RIET LOWE, C.; DU TOIT, A. L. *Early Man in the Vaal River Basin*. Pretoria, 1948. (*S. Afr. Arch. Surv., arch. ser.*, 6.)
16. BREZOWSKY, H. Säkulare Schwankungen der Zirkulation. *Ber. dtsch. Wetterdienstes U.S. Zone*, 35, 1952. p. 35-48.
17. BROOKS, C. E. P.; SAWYER, L. D. Changes in climate in the Old World during historic times. *Q. J. Roy. Met. Soc.*, 57, 1931. p. 13-30.
18. BRUCKNER, W. D. Laterite and bauxite profiles of West Africa as an index of rythmical climatic variations in the tropical belt. *Ecl. geol. Helv.*, 50, 1957. p. 239-256.
19. BRYAN, K. Los suelos complejos y fósiles de la antiplanicie de México. *Bol. Soc. Geol. México*, 13, 1948. p. 1-20.
20. BUTZER, K. W. Mediterranean pluvials and the general circulation of the Pleistocene. *Geogr. Ann.*, 39, 1957. p. 48-53.
21. ——. The recent climatic fluctuation in lower latitudes and the general circulation of the Pleistocene. *Geogr. Ann.*, 39, 1957. p. 105-113.
22. ——. Der Umweltsfaktor der grossen arabischen Expansion. *Saeculum, Jb. f. Universalgeschichte*, 8, 1957. p. 359-371.
23. ——. Die Ursachen des Landschaftswandels der Sahara und Levante seit dem Klassischen Altertum. *Abh. Akad. Wiss. und der Liter., Math.-naturw. Kl.*, 1958. p. 3-19.
24. ——. Das ökologische Problem der Neolithischen Felsbilder der östlichen Sahara. *Abh. Akad. Wiss. und der Liter., Math.-naturw. Kl.*, 1958. p. 20-49.
25. ——. Russian climate and the hydrological budget of the Caspian Sea. *Rev. canad. Géogr.*, 12, 1958.
26. ——. *Quaternary stratigraphy and climate in the Near East*. 1958. (*Bonner Geogr. Abh.* 24.)
27. ——. The Near East during the Last Glaciation. A palaeogeographical sketch. *Geogr. J.*, 124, 1958. p. 367-369.
28. ——. Contributions to the Pleistocene geology of the Nile Valley. *Erdkunde* 13, 1959.
29. ——. Some Recent geological deposits of the Egyptian Nile Valley. *Geogr. J.*, 125, 1959.
30. ——. Die Naturlandschaft Ägyptens während der Vorgeschichte und des Dynastischen Zeitalters. *Abh. Akad. Wiss. und der Liter., Math.-naturw. Kl.*, 1959.
31. CATON-THOMPSON, G.; GARDNER, E. W. Recent work on the problem of Lake Moeris. *Geogr. J.*, 73, 1929. p. 20-60.
32. CLARK, J. D.; DIXEY, F. *The Stone Age in Northern Rhodesia*. Cape Town, 1950. (*S. Afr. Arch. Soc. Handbook*.)
33. CLISBY, K. H.; FOREMAN, F.; SEARS, P. B.; STEARNS, C. E. San Augustin Plains. *Science*, 124, 1956. p. 537-539.
34. COLE, Sonia. *The Prehistory of East Africa*. Harmondsworth, Pelican.
35. COTTON, C. A. The significance of terraces due to climatic oscillations. *Geol. Mag.*, 82, 1945. p. 10-16.
36. CRAMWELL, L. M.; VON POST, L. Post-Pleistocene pollen diagrams from the southern hemisphere. *Geogr. Ann.*, 18, 1936. p. 308-347.
37. DAVID, T. W. E. *The geology of the Commonwealth of Australia*. London, Arnold, 1950. Vol. 1.
38. DEEVEY, E. S. Biogeography of the Pleistocene. *Bull. geol. Soc. Amer.*, 60, 1949. p. 1315-1416.
39. DILLON, L. S. Wisconsin climate and life zones in North America. *Science*, 123, 1956. p. 167-176.
40. DIXEY, F. *Variations in lake levels and sun-spots in Central Africa*. London, 1952.
41. DUBIEF, J. Les pluies au Sahara Central. *Trav. Inst. Rech. sahar.*, 4, 1947. p. 7-23.
42. ——. The evolution of arid zones in the past and today. Unesco NS/AZ/112, Paris 1952. (Mimeographed document.)
43. DUELL, T. and B. The behaviour of barometric pressure during and after solar particle invasions, *Smithson. Misc. Coll.*, 110, 8, 1948. p. 1-34.
44. FIRBAS, F. *Spät- und Nacheiszeitliche Waldgeschichte Mitteleuropas nördlich der Alpen*. Jena, Fischer, 1949. Vol. 1.
45. FLINT, R. F. *Glacial and Pleistocene geology*. New York, Wiley, 1957.
46. ——; GALE, W. A. Stratigraphy and radiocarbon dates at Searles Lake, California. *Amer. J. Sci.*, 256, 1958. p. 689-714.
47. FLOHN, H. Neue Anschauungen über die allgemeine Zirkulation der Atmosphäre und ihre klimatische Bedeutung. *Erdkunde*, 4, 1950. p. 141-162.
48. ——. Allgemeine atmosphärische Zirkulation und Paläoklimatologie. *Geol. Rdsch*, 40, 1952. p. 153-178.

49. Frenzel, B. Die Vegetationszonen Nord-Eurasiens während der postglazialen Wärmezeit. *Erdkunde*, 9, 1955. p. 40-53.
50. ——; Troll, C. Die Vegetationszonen des nördlichen Eurasiens während der letzten Eiszeit. *Eiszeitalter und Gegenw.*, 2, 1952. p. 154-167.
51. Hare, F. K. *The restless atmosphere.* London, Hutchinson, 1953.
52. Haurwitz, B.; Austin, J. A. *Climatology.* New York, McGraw-Hill, 1944.
53. Hinds, N. E. A. Climatic fluctuations in arid regions during late earth history. Unesco NS/AZ/102, Paris 1952. (Mimeographed document).
54. Hutchinson, G. E.; Patrick, R.; Deevey, E. S. Sediments of Lake Patzcuaro, Michoachan, Mexico. *Bull. geol. Soc. Amer.*, 67, 1956. p. 1491-1504.
55. Joleaud, L. Gisements de vertébrés quaternaires du Sahara. *Bull. Soc. Hist. nat. Afr.* No. 26, 1936. p. 23-39.
56. Klebelsberg, R. V. *Handbuch der Gletscherkunde und Glazialgeologie.* Wien, Springer, 1949. Vol. 2.
57. Kraus, E. B. Secular changes of tropical rainfall regimes. *Quart. J. R. met. Soc.*, 81, 1955. p. 198-210.
58. ——. Secular changes of east-coast rainfall regimes. *Quart. J. R. met. Soc.*, 81, 1955. p. 430-439.
59. ——. Secular changes of the standing circulation. *Quart. J. R. met. Soc.*, 82, 1956. p. 289-300.
60. ——. Graphs of cumulative residuals. *Quart. J. R. met. Soc.*, 82, 1956. p. 96-97.
61. Libby, W. F. *Radiocarbon dating.* (2nd edn.) Chicago, University Press, 1955.
62. Manley, G. Climatic Variation, *Quart. J. R. met. Soc.*, 79, 1953, p. 185-209.
63. Martin. H. Südwestafrika. *Geol. Rdsch.*, 38, 1950. p. 6-14.
64. Mauny, R. Préhistoire et zoologie : la grande faune éthiopienne du Nord-Ouest africain du paléolithique à nos jours, *Bull. Inst. franç. Afr. noire*, 18, 1956. p. 246-279.
65. Miller, J. P. Problems of the Pleistocene in Cordilleran North America, as related to reconstruction of environmental changes that affected Early Man. In : T. L. Smiley (ed.) *Climate and man in the Southwest.* Tucson, 1957. p. 19-49. (*University of Arizona Bull.*, 28, no. 4.)
66. Morrison, R. B.; Gilluly, J.; Richmond, G. M.; Hunt, C. B. In behalf of the Recent. *Amer. J. Sci.*, 255, 1957. p. 385-393.
67. Murray, G. W. The Egyptian climate : an historical outline. *Geogr. J.*, 117, 1951. p. 422-434.
68. ——. The artesian water beneath the Libyan Desert. *Bull.* Soc. *Géogr. d'Égypte*, 25, 1953. p. 81-92.
69. Nilsson, E. Ancient changes of climate in British East Africa. *Geogr. Ann.*, 22, 1940. p. 1-79.
70. Picard, L. Zur postmiozänen Entwicklungsgeschichte der Kontinentalbecken Nordpalästinas. *Neues Jb. Mineral., Geol. Paläontol.*, 70b, 1933. p. 93-115.
71. Richmond, G. M. Three pre-Wisconsin glacial stages in the Rocky Mountain region. *Bull. geol. Soc. Amer.*, 66, 1957. p. 239-262.
72. Rodewald, M. Rückgang der Klimaänderung in den Vereinigten Staaten. *Geogr. Ann.*, 34, 1952. p. 159-167.
73. ——. H. C. Willett's Klima-Prognose. *Naturw. Rdsch.*, 1956. p. 142-149.
74. Schoeller, H. Le Quaternaire de la Saoura et du Grand Erg occidental. *Trav. Inst. Rech. sahar.*, 3, 1945. p. 57-71.
75. Schove, D. J. Chinese "raininess" through the centuries. *Met. Mag.*, 78, 1949. p. 11-16.
76. Schulman, E. Tree-ring indices. *Compendium of Meteorology.* Boston, American Meteorological Society, 1951. p. 1024-1029.
77. Sears, P. B. Palynology in southern North America. I. Archeological horizons in the basins of Mexico. *Bull. geol. Soc. Amer.*, 63, 1952. p. 241-254.
78 Suess, H. E. United States Geological Survey radiocarbon dates I. *Science*, 120, 1954. p. 467-473.
79. de Terra, H.; Paterson, T. T. *Studies on the Ice Age in India and associated human cultures.* 1939. (*Carnegie Inst. Washington*, 493.)
80. Trewartha, G. T. *An introduction to climate.* (3rd ed.) New York, McGraw-Hill, 1954.
81. Troll, C. Quartäre Tektonik und Quartärklima der tropischen Anden. *Frankfurter Geogr., Hefte* 11, 1937. p. 64-67.
82. Vorster, J. H. Trends in long range rainfall records in South Africa. *S. Afr. geogr. J.*, 39, 1957. p. 61-66.
83. Wallén, C. C. The variability of summer-temperature in Sweden and its connection with changes in the general circulation. *Tellus*, 5, 1953. p. 157-178.
84. ——. Some characteristics of precipitation in Mexico. *Geogr. Ann.*, 37, 1955. p. 51-85.
85. Willett, H. C. Long-period fluctuations of the general circulation of the atmosphere. *J. Met.*, 6, 1949. p. 34-50.
86. ——. Extrapolation of sunspot-climate relationships. *J. Met.*, 8, 1951. p. 1-17.
87. Woldstedt, P. *Das Eiszeitalter. Grundlinien einer Geologie des Quartärs.* Stuttgart, Enke, 1958. 2 vols.
88. World Weather Records (edited by H. H. Clayton). *Smithson. Misc. Coll.*, 79, 1927; 90, 1934; 105, 1947.
89. Wright, H. E., jr. The geological setting of four prehistoric sites in northeastern Iraq. *Bull. Amer. Schools orient. Res.*, 128, 1952. p. 11-24.
90. Zeuner, F. E. Das Problem der Pluvialzeiten. *Geol. Rdsch.*, 41, 1953. p. 242-253.

# EVOLUTION OF LAND USE IN SOUTH-WESTERN ASIA

*by*

R. O. Whyte

*Chief, Crop Production and Improvement Branch, Food and Agriculture Organization of the United Nations, Rome*

## SCOPE

It is necessary at the outset to define the scope of this chapter in terms of geographical limits, the time period to which most attention is to be given, and the interpretation of the term 'land use'.

The region to be reviewed covers the Arabian desert zone, comprising the present countries of the United Arab Republic (Syrian Zone), Lebanon, Israel, Jordan, Iraq, Saudi Arabia, Yemen and Aden, the Anatolian and Iranian Plateaux comprising Turkey in Asia and Iran, Afghanistan and the Indus Basin (West Pakistan).[1] It may, on occasion, be necessary to extend eastwards beyond these limits into western India, or northwards when we come to refer to Anau, for example, or westwards to the civilizations of Greece and Rome which had such marked effects on the agricultural development of our region of primary study [39, 165, 186, 203, 229].[2] The review has tended to become restricted to those parts of the region from which most of the archaeological data are available. No special study has been possible of Southern Arabia and the Yemen (see however [30, 66, 98]).

As far as the time span is concerned, the review will deal primarily with the millenia following the last Pluvial period, with the Neolithic cultures for which the essential criteria have always been held to be the domestication of stock, the cultivation of cereals, the making of pottery and the manufacture of polished stone celts—some of these achievements had been foreshadowed already in Mesolithic times [43]—and with the subsequent millennia before Christ. It has not been possible to review in similar detail the developments which have occurred in the region from the early centuries A.D. to date. This more recent history would require a separate study and would probably be approached in a different way, using different literature sources. Such work is not made easier by the fact that writers documenting more recent eras tend to concentrate almost exclusively on the pattern of historical events, with little reference to the land and the day-to-day life of the common people. However, some indications of complete or partial historical sequences from the earliest days to date are given with respect to Palestine, Syria, Iraq, Iran and the Indus Valley, but without any attempt to link these into a regional pattern.

The term 'land use' has been interpreted broadly, to include not only the use of land for crop production, pastoralism or forestry, but also the many related aspects which explain how a particular type of utilization arose, how it was and is still related to the type of original vegetation, soil and climate, how the early cultivators and pastoralists found and domesticated their plants and animals, and so on.

This article is to be regarded as a brief contribution to a recent trend whereby archaeological and historical studies are characterized by the interpretation of pre-history and early history—not so much in the conventional or school-book way, but from the point of view of many philosophical, economic and scientific disciplines. It has become the practice of the technician in one particular subject or group of related subjects to look at the available information with a fresh eye, to reassemble the material in his own way, to search for supplementary data hitherto ignored and to present what may amount to a new outlook on past events. This new approach of specialists necessarily involves the application of their own principles and techniques to the wealth of information and material already compiled so meticulously by the practising and synthesizing archaeologists or embodied in historical records, and to the deductions based thereon. Or, in the words of Jacquetta Hawkes (*Observer*, London, 19 April 1959),

1. A map of the sites mentioned in this article will be found on page 61.
2. The figures in brackets refer to the bibliography at the end of the chapter

(but first making the reservation in parenthesis that in the nineteenth century several outstanding archaeologists worked in the Near East and made very accurate descriptions of discoveries and excavations):

For long archaeology was in amateur hands, the pastime of noblemen, squires and diplomats, of parsons, schoolmasters and doctors. Since the first world war it has become increasingly professional, but the professional jobs, in universities, museums and learned societies, have been filled predominantly by men with an arts background. Many of them have been excavators, but essentially they have been scholars and not scientists. Now another revolution is in progress. More and more since the last war the natural sciences have been called in to help archaeology in its tireless efforts to re-create the past.

This is the new science of environmental archaeology (of which there is at least one professorial chair, i.e., in the University of London) or perhaps better, archaeological ecology.

Little attempt has as yet been made to apply to these archaeological or historical data the principles and techniques of ecology in its widest sense, to study the whole or the component parts (climate, soil, flora and fauna) of the habitat or natural environment in which the events recorded by the archaeologist and historian took place. Historical records, as well as the stock-in-trade of the archaeologist—pottery, early metals, human skeletons, animal bones, city and house designs—lend themselves to re-investigation. It then becomes possible to obtain a picture of the habitat of a civilization, to trace those processes which led to its development and generally to its deterioration, and to describe the environmental background of dynasties, secular and religious empires, wars and invasions. With this new approach, it should become possible to obtain a better understanding of the life and struggles of the ordinary people, the hunters, food gatherers, fuel collectors, shepherds, cultivators, tradesmen and craftsmen in relation to the use and misuse of the land.

In discussing before the United States National Academy of Sciences the identification of non-artifactual archaeological materials, Braidwood [23] states that the farther east of western Europe one goes in a study of the animal, vegetable and mineral evidence for the establishment of the village farming community, the worse our understanding becomes. This is true in spite of the most reasonable assumption: that western Asia was the nuclear area for the formation of the village farming community way of life of the western cultural tradition. Braidwood lists the difficulties:

I am not conscious of an extensive literature regarding the moment of disappearance of the larger Pleistocene animals. Observations certainly exist, for example, on the aurochs still being in Poland in the eighteenth century, and on the onager in Iraq until the 1920s. There has been general agreement since the end of the last century that western Asia is the region where domestication of the sheep, goat, pig and cow (plus horse?) took place. However, remarkably little attention has been given to the problem on the spot. Until Reed went into the field on a National Science Foundation grant in 1954-55 no systematic zoological collection, pointed at the problem, had yet been done in the core area. The result is that a corpus of animal bones (both wild and domestic) for purposes of comparative study is now only being collected, unfortunately about twenty-five years too late because of extensive hunting from automobiles and the ubiquitous rifle.

Archaeologically, animal bones have been saved from about one site in twenty—and then, usually only the more rare finds of whole bones or skulls of larger animals. Little or no attention has been given to the smaller fauna, invertebrates, etc., so valuable as clues to the environmental situation. The reports, with very rare exceptions, are restricted to Latin-name lists, done by zoologists of good will, working blindly without a corpus of comparative material and almost invariably without communication with the archaeologist as to context, general problems, etc., save the simple question, 'are these bones of domesticated animals?'. Egypt (with its good preservation and mummification) is somewhat an exception but was evidently outside the core area. The general situation in the Classical lands appears to be about like that for western Asia. The general situation in Europe is many degrees better. Reference to Clark's *Prehistoric Europe: The Economic Basis* indicates a sophisticated and quantitative handling of at least some of the materials, with overtones of interpretation and not simply identification.

In the field of zoology, we have the advice of Reed [160]:

Take the zoologist to the site and let him work with the archaeologists. Let him be a man of varied background, the wider the better; let him not be so young that he has not had training and experience, nor yet so old that he has lost his ability to hunt and dig. Yes, dig. That is the fly-paper that will surely catch him forever. Why are there the absurdly romantic Sunday-supplement articles on archaeologists in wonderfully strange places, why are there pot-hunters, why are there archaeologists at all? Yes, certainly let him dig. Let him discover artifacts and learn about artifacts; let him dig his own bone; *let him excavate his own ideas.* Let him understand anthropological problems, and in turn let him present his to the anthropologist. The fascinating problems are not the purely biological or anthropological ones but are the ecological relationships between changing environments and evolving cultures. And as cultures evolve, environments must change. Once the biologist has caught this point of view, he is doomed to help the anthropologist because none of the trivia he was doing before could possibly have the intellectual delight of these new, interdisciplinary problems. Since the environmental conclusions of the natural scientists are going to be valuable in the interpretation of cultural changes, it is primarily the anthropologists who are interested in acquiring the services of the natural scientists. It is not the latter who have organized excavations to gather late Quaternary environmental data! . . . Once the natural scientists have been members of such an archaeological expedition and have seen the value of the problems presented, perhaps they can get their own grants for subsequent co-operative work or perhaps their own departments will finance their new research interests. However, the intellectual and financial pioneering is going to have to be done by the anthropologists, since they are the ones alert to the needs of such co-operative research. Before long we can expect that, even as anthropology in this century has had its swift growth in American museums and universities, the new science of 'environmental archaeology' or 'Quaternary ecology' will find its natural place in the intellectual life of the nation, with departments of study firmly situated in each of our large universities.

We must deal with several interrelated factors which have influenced each other in varying degrees and directions with the passage of time. Evolving civilizations have imposed their own characteristic mark on the land, again in its widest sense, and the land has in turn had a profound influence on the nature of the civilizations and on the degree of their social, economic and technological advancement. Environmental factors were, for example, probably of the greatest importance in the movements of peoples, such as the spread of the Indo-Europeans, the great Arabian expansions [30, 36] and the Mongol outpourings from Central Asia. Man only rarely understood or fully appreciated the effect he was having on the natural environment in which he lived; the consequences of his use and misuse provided conditions with which later generations and subsequent civilizations have had to deal. *Solidudinem faciunt, pacem appellant* (Tacitus). Mallowan [130] has stated that a new way of life may not necessarily be an advance, perhaps merely an abandonment of an old way of life which was in itself perfected. This is not necessarily progress.

One step forward may often mean two steps back, and the very efficacity of man has often proved his undoing. Great tracts of the world have been exhausted by over-cultivation, by deforestation, and by the improvident activities of mankind. The insatiable desire for immediate material benefits and the complex amenities needed by increasing urban population have inevitably led to periods of mental and physical exhaustion. The ability to think and to feel a generation ahead is, in fact, vital to man's continued prosperity.

Or, in the words of Sir Mortimer Wheeler, in his Marett Memorial Lecture at Oxford, 1952 :

I belong in fact to a generation of students who have learned to make something of a fetish of environment, even at the expense of forgetting occasionally the extent to which we are the authors of that same environment. It is not difficult to think of examples where mankind has created a desert and called it civilization; and when in the long run the desert wins, as is its habit, we once again short-circuit logic and arraign environment. . . . It is a familiar axiom to economic historians that an age of fulfilment, such as is implied by a great civilization, is accomplished by an increase in population which, after a phase of balance, outstrips food-supply and leads to a decline in the standards of living.

Discussing the nature and scope of archaeology in his presidential address to the Anthropology and Archaeology Section of the British Association, 1959, Professor Ian A. Richmond said that archaeology united a very large number of widely differing branches of learning. Some developments had brought about a new understanding of primitive man far outstripping anything possible a generation ago. Perhaps it was not surprising that the outstanding characteristic of the over-all picture of prehistoric man should be its very great unevenness of definition and perspective. Resources, cultural achievement and advancement differed so widely in different regions that the story tended to become not that of the effect of man upon his environment, but that of the effect of the environment upon man.

Toynbee [191] on the other hand, rejects environment *per se*, refers to 'loss of command over the environment' as the determining factor in the breakdown of civilizations, but equates this with 'deterioration of technique'.

Hans Bobek, in reviewing the manuscript of this article, deplored the stress which has been placed on the environmental factors, without taking into account other significant factors, mainly those of social history. Braidwood [26] has stated :

I believe that even if the major theme of all human prehistory were conceded to be primarily an ecological one (which I will *not* concede), three important variations on that ecological theme would appear, which could be paralleled in the history of no other organism. These variations would be additive and much less divisive than their separate listing makes them appear at first sight. A long overview of the details of man's prehistoric past—however incomplete these details may be—would suggest these following as the three variations on an ecological theme :

(*a*) Evolving subsistence patterns showed an increasing extractive efficiency through time, and an increasing ability to 'live into' a given environment.

(*b*) With the passage of time (especially during the last 50,000 years—since the appearance of anatomically modern man), increasing technological complexity made possible adjustments to variable environments and began to free men from painful dependence on one given type of environment. With increased technological complexity, regional ways of doing things came more to the fore.

(*c*) Increasing sociocultural complexity gradually tended to mitigate the necessity for an immediate ecological balance for an increasing number—but not all—people of any given group.

This is a vast subject, deserving of a life-time of study, not the mere fifteen years during which the writer has been concerned with the agricultural development of the countries of the eastern Mediterranean, the Near and Middle East, and the western part of the Indian subcontinent, and only incidentally with the historical background to the present types of land use and agrarian structure. This review, unavoidably written in considerable haste, cannot therefore be more than an introduction to the subject, an indication of the type of information which is available or should be collected, and how it might perhaps be interpreted. It is hoped that it may stimulate further studies in libraries and more team work in the field which will provide data on which to base an authoritative account of the environmental background of the history of civilizations. There is no doubt that historical ecology, with its specialized principles and techniques, should become an important subject in teaching curricula and research, on a team-work basis, in view of the wide variety of disciplines which can contribute to a reconstruction of the evolving environment of history (see, for example, Singer *et al.* [175]).

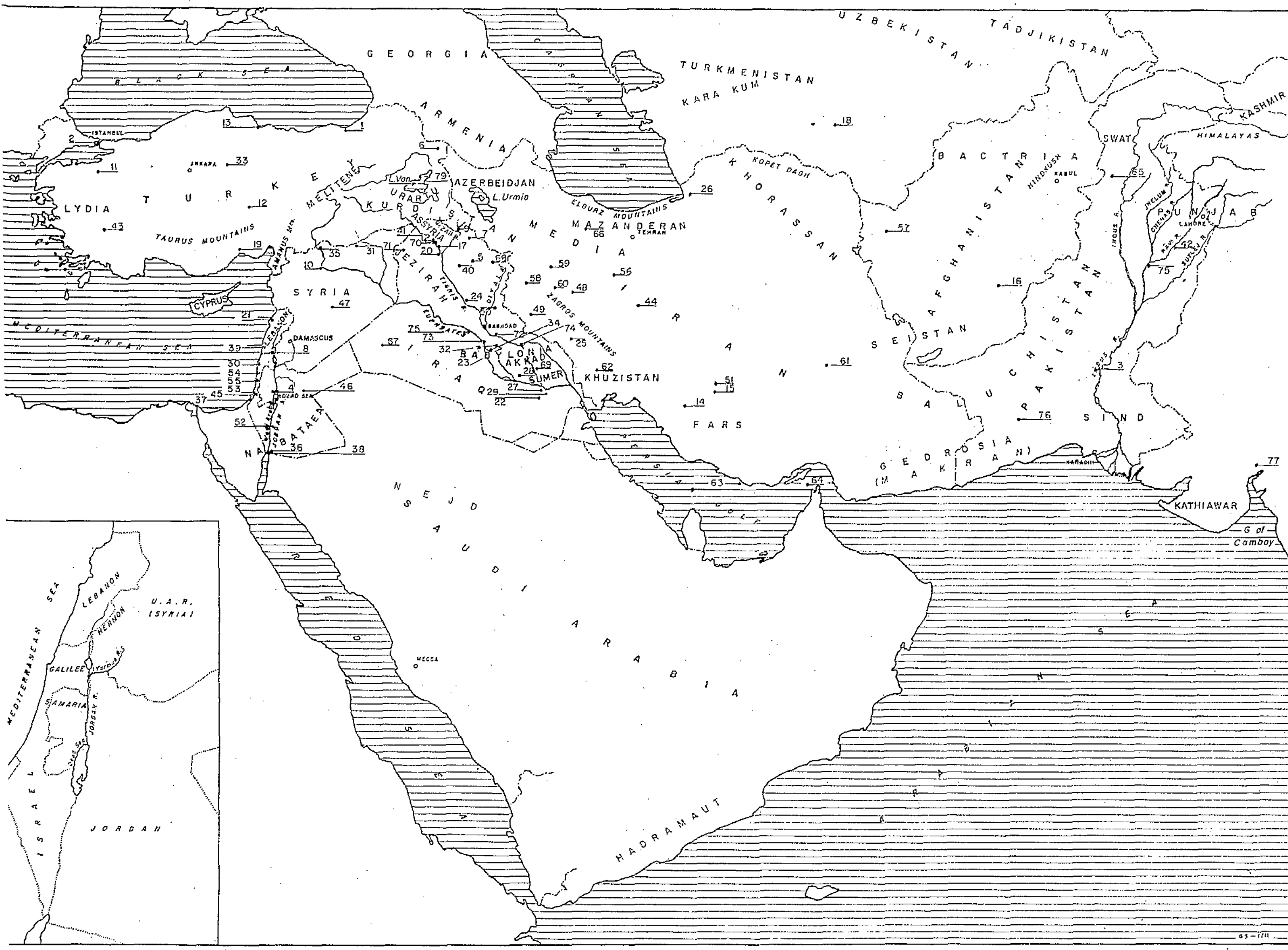
## METHODOLOGY, INTERPRETATION OF INFORMATION AND OBJECTIVES IN RESEARCH

In any study of this kind, a careful appreciation of the quality of the evidence is, of course, of great importance. When one is searching early literature for the generally fragmentary references to agriculture, vegetation, wildlife and related ecological matters, it is found that writers differed widely in their interest in the ecology of the habitat with which they were concerned. For example, Xenophon (see [208]) described the march of the Ten Thousand along a transect from Lydia to Babylonia and then northwards to Trapezus and along the coast of the Pontus Euxinus to Byzantium. There is, however, little indication of the vegetation or agricultural lands which were encountered on the way, although this must surely have been of at least some strategic importance. Herodotus [92] on the other hand, makes many references to agriculture, crops and related matters, perhaps not always on a reliable basis. Theophrastus had a clear view of plant distribution as dependent on soil and climate, and, benefiting by the knowledge available from Alexander's expeditions, came near to a statement of geographical plant regions (Oxford Classical Dictionary [145]). Plato [155] wrote in 'Critias' the following much-quoted passage which, although it refers to Greece, is equally applicable to many parts of south-western Asia :

> At this period, however, with which we are dealing, when Attica was still intact, what are now her mountains were lofty soil-clad hills; her so-called shingle plains of the present day were full of rich soil; and her mountains were heavily afforested—a fact of which there are still visible traces. There are mountains in Attica which can now support nothing but bees, but which were clothed, not so very long ago, with fine trees, producing timber suitable for roofing the largest buildings; the roofs hewn from this timber are still in existence. There were also many lofty cultivated trees, while the country produced boundless pasture for cattle. The annual supply of rainfall was not lost, as it is at present, through being allowed to flow over the denuded surface into the sea, but was received by the country, in all its abundance, into her bosom, where she stored it in her impervious potter's earth, and so was able to discharge the drainage of the heights into the hollows, in the form of springs and rivers with an abundant volume, and a wide territorial distribution. The shrines that survive to the present day on the sites of extinct water-supplies are evidence for the correctness of my present hypothesis.

In reviewing the rapidly increasing modern literature on this subject, it is frequently difficult to distinguish between hypotheses and conclusions based on adequate factual information. One cannot help feeling a little uneasy in quoting statements to the effect that a particular crop or system of tillage first appeared, on the authority of a couple of grain impressions on a piece of pottery or a few specimens of what appears to be a new implement. Actually we must realize that these two examples are quite different. The grain impressions present us with a fact; they definitely prove that a particular cereal was used, and, in so far as the specimens show development from the wild grain, prove crop cultivation. If, however, no development from the wild grain is evident, we may be looking at a residual unpalatable grain which occurred as an admixture in the grain which was actually consumed by the people. The new implement, on the other hand, is indecisive; its actual use is problematical, and it may, even if its use be correctly guessed, imply no more than an improved technique applied to a system of tillage already practised. It would seem to be desirable to apply some type or variation of the statistical sampling method to the study and interpretation of the significance of the residues to be found in the middens of history.

It is necessary to maintain a reasonable balance between the fragmentary, the incidental references by early writers to some biological, ecological or agricultural fact which was not to them of any great significance, and the reliable, the great wealth of data accumulated by archaeologists, anthropologists, historians and geographers. Heating with wood or charcoal; the pottery of the earliest sites inhabited by primitive man, or the mass-produced ware of later days; the beginnings of the heat treatment and use of metals; the change from ordinary mud bricks to the millions of kiln-baked bricks used to build the cities of the Indus and other civilizations; the granaries found among the ruins of the great 'nameless kingdoms of Western Asia'; the use of timber for building the navies of Greece or the Temple of Solomon in Jerusalem; all these can be accepted as authentic features of the history of the civilizations with which we are concerned.




MAP OF SITES REFERRED TO IN THE TEXT

1 Trapezus
2 Byzantium
3 Mohenjo-daro
4 Jericho (Tell-es-Sultan)
5 Jarmo
6 Mt. Ararat
7 Ruwanduz
8 Huleh
9 Shanidar
10 Meskine
11 Ulu-Dag
12 Erciyas-Dag
13 Samsun
14 Kazeroun
15 Shiraz
16 Kandahar
17 Nimrud
18 Anau
19 Mersin
20 Hassuna
21 Byblos
22 Eridu
23 Kish
24 Samarra
25 Susa
26 Gorgan
27 Al'Ubaid
28 Erech
29 Ur
30 Mt. Carmel
31 Tell Halaf
32 Jemdet Nasr
33 Boghazköy
34 Babylon
35 Carchemish
36 Tell-el-Kheleifeh
37 Gaza
38 Elath
39 Tyrus
40 Matarrah
41 Arpachiya
42 Harappā
43 Beyce Sultan
44 Isfahan
45 Lachish
46 Qasr-el-Kharana
47 Palmyra
48 Giyan
49 Elam
50 Tell Asmar
51 Persepolis
52 Petra
53 Ascalon
54 Caesarea
55 Acre
56 Siyalk
57 Herat
58 Kermanesh
59 Hamadan
60 Burujnd
61 Kirman
62 Ahwaz
63 Qais
64 Hormuz
65 Peshawar
66 Qazuim
67 Rutba
68 Suleimaniya
69 Lagash
70 Niniveh
71 Singara
72 Ctesiphon
73 Hindiya Barrage
74 Kut-el-Amara
75 Habbaniya
76 Kulli
77 Lothal
78 Multan

The objective should be not to look so much at the piece of pottery or the metal, brick, granary or building itself, but to try to obtain a picture of the land which supplied the fuel for the kilns, the timber for the building and the cereals which were stored in the granary. In many cases the interest is not so much in the contents of the pottery-bearing strata of ancient sites themselves as in the depth and nature of the material between these strata. It is, for example, important to know whether this is windblown, indicating wind erosion in the vicinity, or water-borne, indicating flooding, perhaps resulting from misuse of natural land resources higher in the same catchment area. Why did the settlements suddenly become abandoned and why did they remain unoccupied for perhaps hundreds of years? To what extent would such events be due either to climatic fluctuations, to hostile invasions, to depletion of soil fertility and increase of salinity, or to the destruction by the inhabitants of the fuel, timber and grazing resources of the nearby vegetation, with resultant erosion and failure of the wells? Was the revival of the settlement due to natural regeneration of these resources?

In general, there is a sequence indicating the increasing intensity of utilization of the natural vegetation for fuel; at an early period, the use of domestic fuel, the burning of charcoal and the low-temperature baking of pottery on a small scale in kilns; later domestic fuel, charcoal, glazed pottery, smelting of metals, and the manufacture of kiln-treated bricks, the actual sequence varying in the different parts of our region [175].

Thus there was a constantly increasing demand for fuel for ever greater production of a wider variety of products requiring progressively higher temperatures. The fuel would come to the centre of settlements from areas within a radius which was safe and practicable for the limited forms of transport, or would be floated down-river from mountainous forested areas farther away. The denudation near the settlement might lead to the destruction of the resource on which it had depended, to wind erosion and the failure of wells; deforestation farther upstream might cause excessive run-off, which would make the flow of the rivers more erratic and expose the centre to the risk of flooding and the deposition of water-borne debris.

One of the major factors in the decline and fall of the Indus civilization is stated by Wheeler [206] in the following terms :

Millions of well-baked bricks went to the building and rebuilding of Mohenjo-daro. Millions of tons of firewood went to the baking of them. With all allowance for the arrival of floating timber from the upper reaches, this implies a widespread deforestation of the surrounding region. This in turn, though partially compensated by growing crops, must have checked the transpiration of moisture and reduced the rainfall. If at the same time, energy and discipline were flagging, and irrigation-channels and bunds inadequately maintained, the total deterioration must have been appreciable. Desert was encroaching on the sown. In rough terms, Mohenjo-daro was *wearing out its landscape*, whether by excessive zeal or by excessive indolence. Over the years it was dying before the final blow.

It may be added that the flood plain of the lower Indus at this time was at least 20 ft. lower than today.

The practising botanical and zoological ecologist can become experienced in the historical interpretation of his field observations, especially when these are made in association with climatic and soil studies. It is possible in certain cases to form a picture of the vegetative cover or faunal population of the past by studying ancient documents and pictorial representations on seals and friezes, by making ecological deductions on the basis of relict vegetation, or by observing the ecological level to which degraded vegetation will regenerate when protected from the influence of the major biotic factors, man with his axe, firestick, plough and grazing animals.

The chorologist, interested in the geographical limits of the present distribution of genera, of plants and animals, can relate his findings to records in rock drawings, tablets, early art and literature [195] and the reports from archaeological investigations; marked changes in the chorology of individual genera will probably be found for which an explanation must be sought.

The application of these disciplines should ultimately make it possible to describe the natural characteristics of the region being studied and in particular its vegetation and fauna (see for example Fig. 1); the former and present extent of deciduous and evergreen broad-leaved and coniferous forests; grasslands and semi-desert scrub; the species of wild plants and animals which occupied them. Archaeology indicates the way in which these natural resources came to be utilized by primitive man, and how there arose the early forms of land use and crop and animal husbandry which later evolved in various and diverse ways through the centuries, yet always necessarily in relation to the basic ecological factors.

Evidence may also be obtained from the art and architecture of these early days, from the representations of crops, domestic livestock or locusts, and from the use of timber for the building of columns or the roofing of temples. Stapleton [179] has used an early frieze to indicate the possible first historical appearance of a short-horned cow, perhaps the prototype of the Danube Valley and Channel Island breeds. In fact, as Alfonso Caso has stated (quoted by Sears [169]) : 'We archaeologists are like detectives, in that we have to make the reconstruction of the drama with only very scanty and poor material evidence. Sometimes, perhaps, like the heroes of

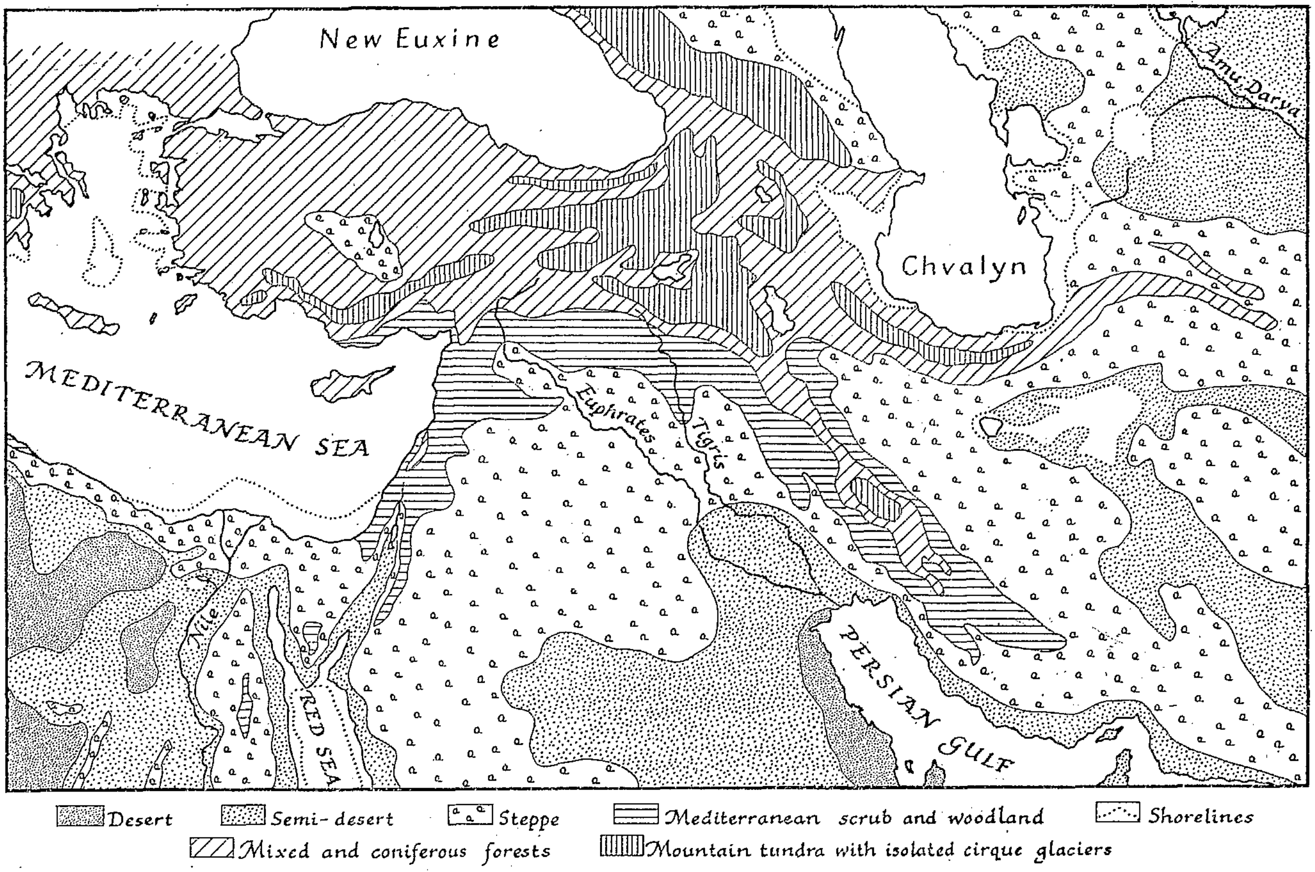



FIG. 1. Climatic vegetational belts of the Near East during the Last Glaciation: generalized after Butzer [36].

detective stories, we go too far in our deductions. But I do not know what is worse—an archaeologist with unrestricted imagination or one with a complete lack of that quality so necessary in life, art and science.'

A number of scientific techniques are used in the study of geochronology to indicate either the relative sequence of a series of events or material residues, or to give a more exact date in terms of years or centuries in the period under review. These include studies of tree-rings of archaeological specimens, palynology or the analysis of stratified deposits of fossil pollen, palaeontology or the study of fossil bones, geochemistry or the study of soluble mineral salts retained in clay sediments (potentially valuable in the study of past climates), geomorphology or the study of the processes governing the formation and change of land surfaces due to new patterns of erosion (natural, not man-made) because of major climatic changes, and variations in storm patterns or tectonic disturbances [176].

The method which has received most attention in recent years is that based on the use of radiocarbon or carbon-14. It was first brought to notice as a widely distributed carbon-element in 1947 by Professor W. F. Libby and his colleagues at the University of Chicago [123]. Since serious doubts have arisen in the minds of archaeologists, such as Professor Milojcic, with regard to the ultimate validity of the method. Barker [8] of the Department of Research Laboratory of the British Museum has recently restated the principles underlying the technique and answered these criticisms and thereby helped to bridge the gap between the archaeologist and the physicist. Since the technique of radiocarbon dating has been in use, several thousand dates have been published, the great majority of which have been accepted as accurate. The method is world-wide in scope, is applicable to a range of commonly recurring materials, and provides for the first time a system of chronology which is independent of hypothetical archaeological and geological considerations.

Steady progress has been made, both in the instrumentation of the method and in the understanding of certain underlying factors which now enable a truer assessment of its capacities to be made. Barker [8] states:

. . . the present state of the method is such that the accuracy of the dates is no longer limited by statistical fluctuations in the measurement of the radioactivity of the sample, but by small perturbations which were previously obscured by the large statistical errors of the original techniques. Of these perturbations, isotopic fractionation effects can be eliminated if the necessary high-precision mass spectrometric techniques are available, but De Vries' recent work indicates that, when all other errors are taken into account and eliminated, there may remain errors of up to 100 years or more which seemingly cannot be reduced by any foreseeable means. Because of the fact that the improvements in instrumentation preceded our knowledge of some of these limiting factors, it is inevitable that the accuracy of some published dates is rather too optimistic, and excepting where it is clear that errors other than the statistical error have been taken into account, one should treat error terms of less than ±100 years with some reserve. In such cases advice should be sought from the laboratory in question. Systematic errors still exist between the various laboratories due to differences in 'modern' reference samples, but measurements are in progress which will result in the publication of accurate correction factors. Consideration of all these facts leads inevitably to the conclusion that the carbon-14 dating method is at its best in fixing the broad outlines of a chronology rather than the fine detail.

An outstanding example of the use of the carbon-14 method in our region is in the dating of the pre-pottery Neolithic site of the *civitas* of Jericho [105, 107]. Zeuner [221] found that two samples from the upper part of the pre-pottery Neolithic complex gave the following results:

GL 28 Site E. phase F. charcoal indet.
Radiocarbon age 8,200 years ±200: *c.* 6250 B.C.
GL 38 Square Fl, layer Y. tamarisk charcoal
Radiocarbon age 7,800 years ±160: *c.* 5850 B.C.

These dates are considered by Zeuner to be perhaps on the young side, since to some extent washing of the material (charred date palm, furniture wood, remains of flesh, and charcoal) to remove the effect of any organic substances carried down in solution would appear to result in radiocarbon dates about 10 to 15 per cent higher than those quoted above. Braidwood [25] quotes radiocarbon determinations for a great many sites in the Near East, with special reference to Jarmo, Tell-es-Sultan and the caves of the Caspian foreshore. In figure 5 of the same article is a diagrammatic summary of the positions, in time and general geographical region, of the available radiocarbon dates in the Near East for the range from about 5,000 to 12,000 years ago; on this figure are inserted curves to suggest levels or eras of food-getting practices.

A desirable objective for special study would be the piecing together of all available bits of evidence from all possible sources, to obtain a picture of the original vegetative cover, to map this and delimit the major phytogeographical zones, the types of vegetation within these and the nature of their ecological succession. Any such study would be of great scientific interest and would also have a wide practical application of a deductive nature for present-day land-use planning. A promising start in this direction is being made in the preparation by L. Emberger and H. Gaussen of maps of the bioclimatology and the climax vegetation types of the Mediterranean and Near Eastern regions, under the auspices of FAO and Unesco. It would, however, be desirable to carry this work further, by giving not only the macro-types of vegetation, but also their detailed botanical composition. Such a project might be undertaken by a combination of methods:

1. It would be possible to collect the many references in published literature, ancient and modern, to the occurrence of this or that species of tree, shrub or herb in some particular locality. While recognizing the frequently circumstantial and unreliable nature of such evidence, it should nevertheless be possible to make a useful contribution to the over-all picture.
2. One should consider the subdivision of this and adjacent regions into major phytogeographical zones, such as has been done by the botanists Engler, Eig, Zohary and others and is now being done by Emberger and by Gaussen.
3. There is the possibility of making ecological studies of the present vegetation, in which one is concerned with regressive stages, sometimes very low in the ecological scale, and in which one would compare the degraded sites with relatively protected sites, using such climatic and soil data as may be available, to produce a reasonably accurate indication of the original climax. Boyko [17] has reviewed the problems of regeneration in arid zones.
4. One may use pollen analysis or palynology, the study of fossil pollen, a method useful in making correlations between deposits and in the relative placing of these deposits in a stratigraphical column. If detailed studies are made of soils and their associated microclimates, it may be possible to make deductions about fossil soils and the climate at the time of their formation. Dating these deposits by other means will make it possible to determine the pollen chronology for a particular area. It is, however, difficult to apply this technique in the Near East, because the high salt content of the lakes leads to the destruction of the pollen. Erdtman [63] states that little is known about pollen grains and spores in the sediments of the Dead Sea, Lake Van and Lake Urmia. If this gap in our knowledge could be filled, data of importance in studying the history of climate and vegetation in the arid zones would be obtained. Erdtman has investigated a few samples of marine sediments from the vicinity of Basrah and some samples from the Shanidar Cave in northern Iraq [178], but the pollen grains are in general few and not well preserved. Lorch [230] investigated pollen from cores taken from the Huleh swamps in Israel, in an attempt to throw more light on the Quaternary

climate in the south-eastern Mediterranean area.

5. It is perhaps possible to consider using archaeomagnetism to date biological material, as well as the clays and stones of ancient Greece, as described in *The Times* of 7 May 1959. This method, worked out by R. M. Cook and J. C. Belshé of the Department of Geodesy and Geophysics in Cambridge University, is based on the principle that many clays and stones, if heated beyond a certain point (about 500°-600° C.), tend to get a fixed magnetism in the direction of the earth's magnetic north at the time they cooled after firing. The earth's magnetic field varies with time in direction, so that the remanent magnetization of a piece of fired clay or stone should be characteristic of some particular time in the earth's history at that place.

Air archaeology is valuable in studying ancient patterns of land use [227], for example, the Neolithic land use and cropping systems in the Tavoliere di Foggia, the remains of cultivation systems of the Classical period in Attica, Roman centuriation around the central Mediterranean, and its absence in Roman landscapes in Syria (see also [231, 232]). By using vertical air photos possibly supplemented by obliques, and noting vegetation markings, ancient crops sites, grass, weed and soil marks, valuable information can be obtained.

It is desirable to discuss some of these approaches at greater length. First, with regard to bibliographical sources, many would expect that the Bible might give some indication of the floristics of the present country of Israel and adjacent lands in the centuries before Christ, and that from these floristic data we could, with our modern knowledge, formulate a picture of the types of vegetation which existed in the various parts of this region. Moldenke and Moldenke [134] state, however, that:

> . . . anyone delving even very superficially into the literature of Bible plants will be impressed at once by the amazing discrepancies, contradictions, palpable misidentifications, erroneous statements and general confusion which exist there. The reasons for this lamentable confusion are several. First it must be remembered that the exact science of botany, as such, is a very recent development in human knowledge. . . certainly during the days when the books of the Bible, especially those of the Old Testament, were composed and later recorded, there was no such thing as an exact science of botany or botanical nomenclature. . . . Secondly, the writers of the books of the Bible were not botanists or even 'natural historians' (with perhaps one possible exception). Mostly they were very plain men with a limited vocabulary. . . . Thirdly one must keep in mind the history of the Scriptures. It is generally agreed. . . . that much of the material of the Old Testament originated in the form of poetry—songs or ballads or what we now call folk songs—handed down from generation to generation of bards and singers for many hundreds of years before ever they were written down. . . . Fourthly one must remember that even after the books of the Bible were once recorded in written form, they were still subject to much possible change. . . during the translation by many different people at many different periods.

For example, it is most unfortunate that botanical knowledge was not in a more advanced stage at the time when the preparation of the Authorized Version of King James I was undertaken, for in this version used almost universally among English-speaking Protestants for the past 350 years or so 'aspens are called mullberries, mullberries are called sycamine, a species of fig is called sycamore, the eaglewood is called aloes, the acanthus is referred to as a nettle, the almond becomes a hazel, the juniper is called a heath, the dill is called anise, the apricot becomes an apple, the box is called ivory, the cypress is called box, the saltwort is referred to as mallows, the terebinth becomes an elm, and the plane tree becomes a chestnut'.

It may be felt that this criticism of the accuracy of plant names in the Bible is a little exaggerated, since perhaps new translations such as the Revised Standard Version may be more accurate than the King James' Version. Biblical translation out of original text is the painstaking lifetime work of scholars. Some of the newly discovered original scrolls appear to show that the copied scrolls which formed a basis for translations were often very accurate. There are recordings, for example, in cuneiform, which are much older and contain many more names of plants and animals of those times (3000-2000 B.C.) than the Bible. In this connexion the Oxford Classical Dictionary [145] states:

> The question of the identification of plants mentioned by classical writers frequently arises and can be answered for certain distinctive or economically important species. The question, however, ignores the semantics of plant names. A modern plant-name—even a 'popular' one—presupposes a conception of species and of their constancy and limitations and an idea of classification that was absent in antiquity. Greek and Latin writers, like modern unlettered peasants, constantly called the same plant by different names and different plants by the same name. The question as to what a particular writer meant by a particular plant name is therefore, with the exceptions mentioned above, normally unanswerable.

There is also the methodology adopted by the plant geographer concerned with the delineation of either the major vegetation regions of the world, or the zones of the major types of vegetation. Since the types of land use which have developed in our region over the millennia are closely related to the environment and since the natural climax vegetation is at least a reasonably accurate indicator of that environment, it is essential that studies such as those described below on Israel and the adjacent parts of Jordan, and other observations and maps of Turkey, Lebanon, Syria, Iraq and Iran should be combined into a synthetic whole for the region. Uniformity of nomenclature for zones and types of vegetation is highly desirable. There is a need to define the major bioecological or bioclimatic or phytogeographical zones within the region as a whole, and to reconcile and place in their correct perspective the Mediterranean, Irano-Turanian, Saharo-Sindian and Sudano-Deccanian zones of the Jewish botanists, used also by Regel [162] for Iraq; the Mediterranean Alpine, Syrian and Steppe zones used by Pabot and Mouterde for the Lebanon and Syria, with their eastward extensions into Iraq and Khuzistan; and the forest, shrub and steppe zones of Iran and Turkey-in-Asia recognized by Bobek and Birand respectively. If we could bring some degree of order into this situation for the whole of our region, it might even be possible by observation, deduction and inspired guesswork ultimately to reconstruct the original plant communities.

Then it would be desirable to attempt to show the geographical distribution of the key genera of our region, such as *Triticum*, *Hordeum* and *Aegilops*, not as weeds of cultivation as they occur today, but as components of specific plant communities in the days before cultivation. By following these various steps, one might ultimately be able to relate this natural and original distribution to the location of some of the earliest archaeological sites.

In producing a bio-ecological map or maps it would probably be essential to attempt to map and describe the original vegetation climax, but this is sometimes very difficult to achieve. Although it may well be possible to use relict trees to indicate the original type of forest cover, centuries of overgrazing and in many cases also cultivation have reduced the original herbaceous cover to a stand of annuals or unpalatable perennials and eliminated the key genera which played such an important role in the change from food collecting to cultivation. The person responsible should have a well-trained critical ecological eye which never accepts vegetation at its face value, and a long and thorough knowledge of the flora, and of the biotic factors to which it has been exposed. One must consider the actual or possible irreversibility of certain successions. The *Carex stenophylla* community which now covers such a vast area of the grazing lands of the Near East is apparently a stable subclimax, which cannot be induced to progress to higher ecological levels without perhaps some type of scarification of the soil. The *terra rossa* of the Mediterranean region, formed during the last pluvial, has now been eroded off much of the hill country and cannot be re-formed under present conditions. The original characteristic climax vegetation of that soil type, whatever it may have been, cannot reappear, but instead one finds a permanent subclimax or a new type of succession on the subsoils of schist or other materials. Again, certain species are indicators of earlier cultivation in areas where little other evidence remains; for example, the presence over extensive areas in northern Afghanistan of *Peganum harmala* and *Alhagi camelorum* indicates earlier cultivation under low rainfall conditions.

If it were possible to map the zones of original distribution of the various types of game animals on the same lines, as is gradually becoming possible and reliable for the zones of vegetation (not quite so simple, since animals are mobile, plants are not), it would perhaps be possible to state that a particular type or group of wild animals was characteristic of one of our major or minor bio-ecological or vegetation zones or types, perhaps depending on it for food and cover. From this it might in turn be possible to deduce that it would be in these floral and faunal zones that primitive man, at a stage so little removed from dependence on nature, largely found his food and living. The vegetation types concerned would be the first to suffer from the fires employed by the hunter in his concentration of the game for slaughter.

## THE ENVIRONMENT

### CLIMATE

The main relevant conclusions drawn by Karl Butzer in the preceding in chapter are:

That from the close of the sixth to the close of the third millennium B.C. there was a markedly greater humidity and rainfall throughout the dry zone of Africa and western Asia enabling a more exuberant fauna and flora to thrive in areas climatically unsuitable today.

That the early historical desiccation shortly before 2000 B.C. was quite severe, particularly as conditions were temporarily even more arid than at the present time.

That towards the end of the last millennium B.C. (Roman and Byzantine times) climatic conditions began to improve again.

That since that time there have been only short-term variations, never exceeding the order of a few hundred years.

That the so-called archaeological evidence does not support a hypothesis of climatic deterioration in the Near East in historical times, but indicates rather the abandonment of wide areas as a result of the economic deterioration and political instability of the Roman Empire, nomadic incursions and decline of urban activity.

Butzer's conclusions are based on climatological data and calculations supported by the evidence from rock drawings of fauna, flood sequences, the structure and location of sand dunes, and from other historical, archaeological and geological evidence. His chapter must be considered carefully in connexion with the frequent references in subsequent passages of this section (written before Professor Butzer's contribution was received) to the relation between the climatic characteristics and zones of south-western Asia and the types of vegetation, agrarian structure, types of farming, crop plants and domestic animals which have existed since earliest times or have developed in the region. It would, for example, be desirable to attempt to map the bioclimatic or bio-ecological zones within our region, as is now being done by L. Emberger and H. Gaussen, using perhaps the terms employed by some of the phyto-geographers, i.e., Mediterranean, Irano-Turanian, Saharo-Sindian and Sudano-Deccanian. The major factor influencing human behaviour in relation to the environment has, of course, been desiccation. Throughout this study of the ecological background of land use, we have to attempt to distinguish between the major desiccations and the long rhythmic fluctuations between relatively wet and relatively dry periods, described by Butzer on the one hand, and the variable intensities of local desiccation produced by man's misuse of the land and its protective vegetative cover in what is already a critical environment for plant growth and survival.

It may be appropriate for the sake of argument to refer to some doubts in the minds of those concerned with the history of agriculture and palaeobotany. Robert Braidwood and Robert M. Adams, for example, remain extremely sceptical of Butzer's earlier formulations of post-pluvial climatic fluctuations in the Near East. In addition to the hazards of the deductions noted below, there are additional difficulties that appear to arise from a too-literal reading of 'historical' accounts. It is, for example, doubtful whether it can be proved that there was a markedly greater humidity and rainfall throughout the dry zone of western Asia from the close of the sixth to the close of the third millennium B.C.

It is generally believed (following Brooks, [31]) that the last major desiccation began in North Africa and the Near East when the climatic belts shifted north at the end of the last Pluvial. Peake and Fleure [151] for example have described the situation as follows. About 7000 B.C. the storm zone which had for many centuries traversed the Mediterranean began to shift further north. As long as this storm zone had traversed the Mediterranean, the Sahara and Arabia had experienced a light but regular rainfall, more intense in the west but not negligible in the east. These regions, which perhaps had been partly wooded in the Würm glaciation, had been grassy steppes for many centuries, The game which abounds on such steppes probably sustained a fairly large population. The gradual northward shifting of the storm zone caused a progressive reduction in this rainfall, until eventually these regions became the deserts we know today.

It appears, however, according to Braidwood [24], that his meteorological colleagues at the University of Chicago do not believe that the climatic picture is quite as simple as Brooks suggests. Bobek's recent survey of the evidence [14] leads him to suspect that a uniform 'pluvial girdle' of the subtropical latitudes did not exist in the Pleistocene. It is, according to Braidwood, very difficult to find clear and significant evidence of desiccation within the period when agriculture based on wheat or barley, or stock husbandry based on the sheep, goat, pig and cattle, began. Stekelis and Haas [181] show that 'the biotype of layer B of Abu Usba was not essentially different from that found on the spot today, except for a somewhat denser vegetation of the forest, correlated with a somewhat larger quantity of rain'. Braidwood states that the evidence from Jarmo is exactly parallel, except that the vegetational cover of the Chemchemal valley was evidently a parkland of scattered oak, the destruction of which he puts down somewhat unjustly merely to overgrazing. Braidwood continues :

The field research necessary for a meaningful palaeoclimatological, palaeobotanical and palaezoological history of post-glacial south-western Asia is only beginning. We have a long way to go. But for some years I have taken my own clue from hints such as those suggested above, which point to no great or significant environmental difference in the time range of *c.* 10000 to 5000 B.C., from that of today in south-western Asia. Hence I have focused my own attention on the hillflanks and intermontane walleys of the 'Crescent' and away from the more arid environs of the riverlands and oases. I feel justified in letting my thinking proceed from present-day rainfall and vegetation maps. I have my eye particularly on the flanks of the Amanus and in north-west Syria, on the Anatolian plateau flanks which lie about the great bend of the Euphrates, and on the western flanks of the Zagros with a possible fingering up towards Lake Urmia. I am, as yet, non-committal about the rain-watered Jordanian uplands. It is not, however, my understanding that clinching arguments can yet be offered for either an 'oasis' or 'hilly-flanks' theory for the origins of the effective village-farming community way of life in western Asia. A great deal more must yet be learned by archaeologists and natural scientists working in the field together and in easy communication.

Braidwood's reconstruction of the climate for the region and time of Jarmo is based upon intensive, integrated studies of the woody genera, mollusca and vertebrate fauna, all obtained in an archaeological context, and is believed to provide the only really reliable instance of climatic reconstruction that is currently possible in the Near East. This reconstruction is an important part of a volume by Braidwood and his associates which is now in the press.

It will certainly be desirable in further studies to consider the views regarding the origins of agriculture in oases *versus* hilly flanks, to present them more clearly and to balance them one against the other [216]. For this purpose, the term 'oasis' should be better defined as including, for example, watered areas surrounded by semi-fertile but not necessarily desert land. We referred above to Braidwood's mention of his lesser interest in the more arid environments of the river lands and oases. Woolley [216] reminds us that in and after the fifteenth century B.C. the land of Niya near Meskine on the middle Euphrates was jungle harbouring herds of elephants. It would appear that 'here Braidwood bases himself on a rather arbitrary assumption which colours his arguments throughout'. One should also consider the possibility that the (few) early sites discovered, such as Jarmo, may really be backwaters, preserving primitive techniques long after further developments had occurred elsewhere.

From the plant ecological point of view, it would appear that insufficient attention has been given to the effect of clearance of the vegetative cover in a critical environment, on the microclimate in which natural vegetation, crops and domestic livestock have to exist. Reduction of vegetation to a lower stage of succession always means greater exposure to the sun's rays, a higher temperature and reduced humidity at the soil surface, and the exposure of plants and crops to the physical effects of the sand-laden, searing hot winds out of the desert. It might even be possible that the severity of these man-made conditions around the desert fringe would be greater and affect a larger area than the fluctuations in macroclimate referred to above.

The use of evidence of floods to prove the existence of more humid conditions in the mountains from which great rivers flow is perhaps a little dangerous. For a time during the removal of vegetation from headwaters, the capacity of that vegetative cover to hold back the rainfall from the rivers may be retained, but perhaps there comes a critical period when the percentage run-off increases suddenly and greatly, and floods occur. It may also be that after a succession of flood years, some degree of stability would again be achieved, through the regeneration of secondary growth, and the flood level and frequency would be reduced.

## GEOMORPHOLOGY, GEOLOGY, SOILS AND HYDROLOGY

These basic factors of the environment have governed the types of land use which have developed in our region of study; changes in their characteristics have influenced, sometimes drastically, the history of the land, its vegetative cover, crops and livestock on which successive civilizations and people have had to depend, most generally on a declining scale of productivity. It does not appear that there have been any major geomorphological or geological changes or trends which should be taken into consideration in reviewing the history of land use by man. Relevant papers include that of Miller and Leopold [133] on the use of soils and paleosols for interpreting geomorphic and climatic history of arid regions, and that of Buringh [33] on pluvial phases in the Pleistocene and their influence on present soil conditions in Iraq. The evidence which exists of what Birot and Dresch [11] call an earlier humid geomorphology in the now arid mountains along the Red Sea coast of Arabia and in other parts of the region does not appear to be relevant in our period. The position is, however, quite otherwise when one comes to consider soils and hydrology.

There is no doubt that man-made erosion following devegetation and excessive cultivation has played havoc with the original soil cover on hill and mountain lands. The dryland cultivators of our region are subsoil farmers. Plant communities and crops in these areas are now growing on B or C horizons, a condition which they express in a stage of ecological succession or nature and yield of crops. The original soils in the mountains of the Eastern Mediterranean and in Turkey, Iran and Afghanistan have either been lost to the sea or have contributed to the new alluvial areas, of which the Tigris-Euphrates and Indus valleys are the outstanding example. It appears to be doubtful whether wind and water erosion has been so serious in the semi-desert areas, since old roads between centres of habitation may still be traced in aerial photographs.

Karatekin [102] has reviewed the hydrology of the Near East and the research in progress in various aspects, but makes little reference to the factors and conditions of major importance in the changing and generally deteriorating use of the land. These include changes in the flow of major rivers, from year-round to seasonal due to devegetation in the upper reaches; the history of floods and siltation of river beds and irrigation works; the lowering or raising of water tables; and the failure of wells. Butzer in the preceding chapter has reviewed the fluctuations which have occurred in the groundwater table, fossil and otherwise, from Neolithic times onwards.

The amount of rainwater which now runs amok over the lands of the Near East must reach fabulous proportions. There is not the slightest doubt that devegetation has been of major dimensions throughout the mountain areas of the Near East. It is probable that before the cover of forest and ground vegetation was removed, only about 20 per cent of the total rainfall could be measured as surface run-off. In the absence of accurate data from the region on run-off in relation to vegetative cover and soil type, one may assume on the basis of data from other regions that the present figure in, say, the Zagros Mountains, would be nearer 70 or 80 per cent in many slopes. If one realizes that an inch of rainfall represents 100 tons of water per acre, it can be seen that the amount of water flowing at dangerous velocities down the mountain valleys to the valuable land in the plains beneath is a major factor in the over-all picture of disequilibrium of land use in our region.

## HISTORY OF THE VEGETATION

The use, and in most cases the misuse of the land in south-western Asia has had a great, indeed an ecologically catastrophic effect on the natural vegetation. We must, at the outset, state that no idealistic claim is made that the vegetation should have remained as it was before man began his depredations. Timber and fuel had to be provided, cereals and other crops had to be grown on cleared land, and free-ranging animals had to find feed. Yet the botanist and plant ecologist cannot but be exasperated, if not actually angered, by the utterly careless way in which the vegetative cover has been and is still being slaughtered in man's anxiety to provide for his needs in terms of timber, fuel, land for cultivation and grazing resources for his livestock.

Almost without exception the areas still covered by anything in the way of vegetation have been characterized by ecological regression for thousands of years. The effects have been of a biotic nature, the influence of man and his grazing and browsing animals [208]. This regression is probably due only slightly, if at all, to any major or local climatic change, although it has had great effect on the microclimate around and within the plant communities and thus has led to greatly increased desiccation. We should mention the studies of Oppenheimer and Boyko [143] on ecological relationships and water expenses of Mediterranean forest vegetation. The influence of the progressive desiccation of rocky soil, which occurs between April and October, is very pronounced on the transpiration of *Quercus calliprinos* and *Laurus nobilis*. In *Phyllyrea media* and *Pistacia palestina*, however, the stomata remain fully or partially open throughout the summer. Differential exposure to the sun's rays produces large differences in microclimatic conditions for plant life on northern as compared with southern slopes [16]. In the sun, heating of the surface is greater in dry grass (Stipetum) covering shallow soil than in calcareous rock, due to the higher evaporation above the grass and the better heat conductivity of the rock.

The approach of the phytogeographer may be exemplified by Engler [62], who recognized five major plant kingdoms of the world, the first of which, the northern extra-tropical or boreal, included the Mediterranean region as a subdivision. In the Mediterranean region, Engler recognized the well-known sclerophyllous evergreen forms that no longer belong to the arctotertiary element, since they are not found in the Tertiary deposits of the present Arctic region. As, however, several of these forms existed at one time in the region in which the boreal flora is now dominant, Engler called the element which distinguishes the Mediterranean flora 'tertiary-boreal'. He states that the Mediterranean flora must have lost some of its original character because of progressive extension of the xerophytic area. In the south-west of the Mediterranean region, more of the original character is retained, but in the east, the region with which we are concerned, the steppe element has so gained the upper hand that the plant cover has acquired a habit very similar to that of the Central Asian and southern steppe lands.

Within the Mediterranean region, Engler recognized six provinces; South-west Mediterranean, Iberian, Ligurian-Tyrrhenian, Central Mediterranean, Armenian-Iranian Mediterranean and Southern Mediterranean. He classified Syria, the Lebanon and former Palestine as the Central Mediterranean Province.

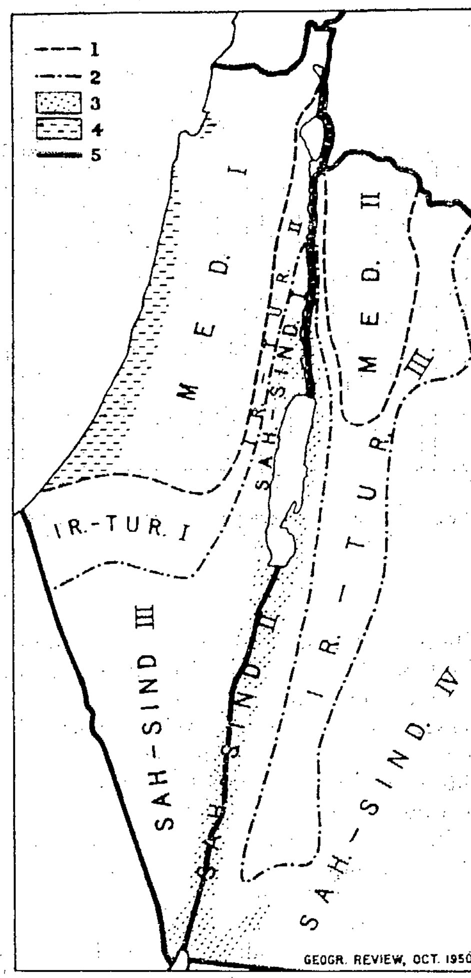



FIG. 2. Phytogeographical zones of Palestine (after Eig): Mediterranean (I. Cisjordan; II. Transjordan); Irano-Turanian (I. Judean Desert; II. Near Negeb; III. Transjordan); and Saharo-Sindian (I. Lower Jordan Valley; II. Wadi 'Araba; III. Far Negeb; IV. Transjordan).

Key: 1, boundary between Mediterranean and Irano-Turanian zones; 2, boundary between Irano-Turanian and Saharo-Sindian zones; 3, principal area of occurrence of Sudano-Deccanian enclaves; 4, area of Saharo-Sindian penetrations; 5, pre-partition international boundaries.

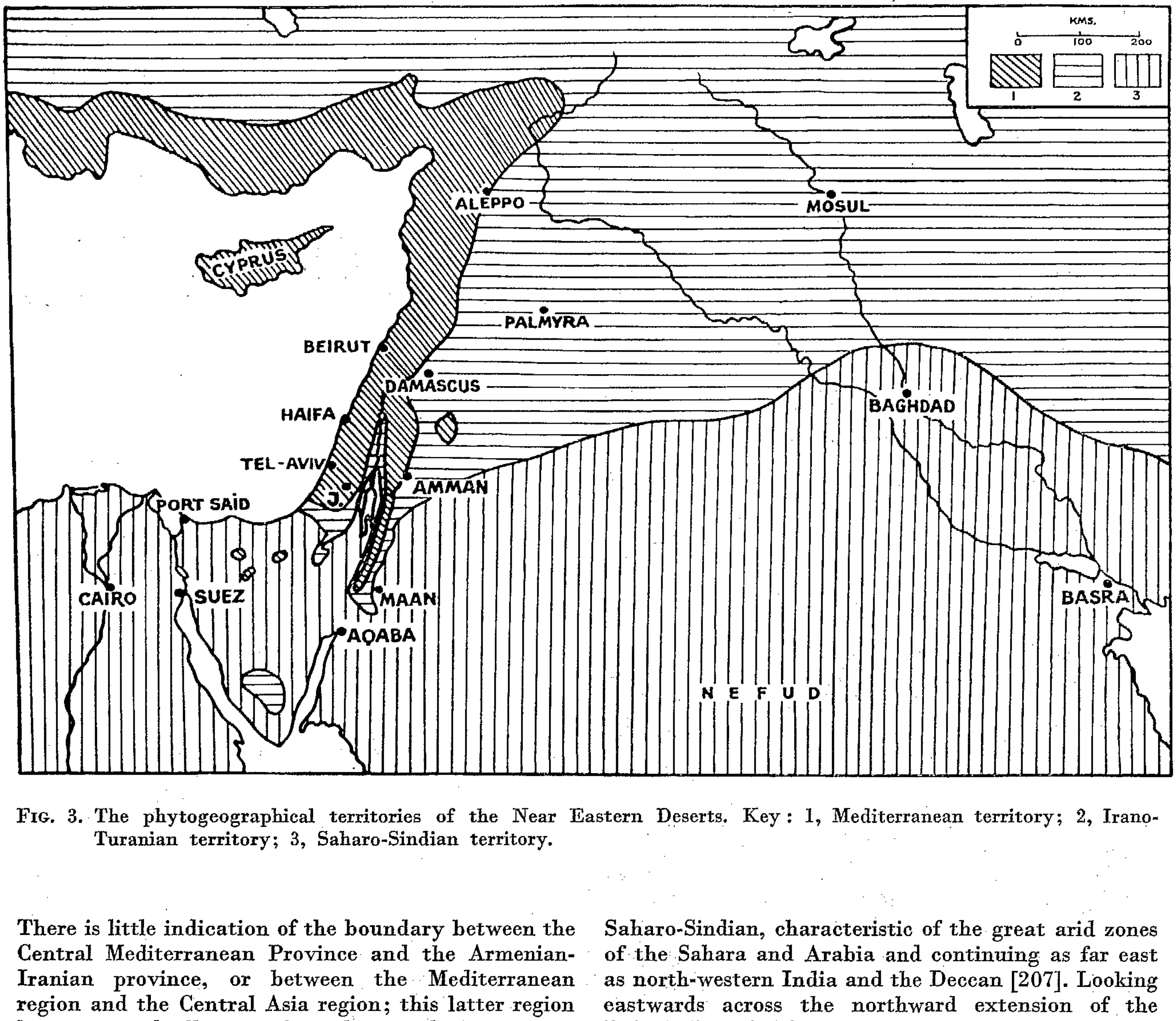



FIG. 3. The phytogeographical territories of the Near Eastern Deserts. Key: 1, Mediterranean territory; 2, Irano-Turanian territory; 3, Saharo-Sindian territory.

There is little indication of the boundary between the Central Mediterranean Province and the Armenian-Iranian province, or between the Mediterranean region and the Central Asia region; this latter region becomes gradually transformed towards its western side into the Armenian-Iranian province of the Mediterranean region.

In his first published work entitled 'Les éléments et les groupes phytogéographiques auxiliaires dans la flore palestinienne', Eig [60] presented a map showing the extent within pre-partition Palestine of three main subdivisions, which he recognized as Mediterranean, Irano-Turanian and Saharo-Sindian. A revised version of this map was produced later by Eig [61] (see Fig. 2) and a more extensive one by Zohary [222] (see Fig. 3).

The plant geographers of the Hebrew University in Jerusalem assert that Palestine is the only country in which outliers of the three major types of vegetation of our region of study can be found: (a) the Mediterranean; (b) the Irano-Turanian, characteristic of Iran, Turkey and adjacent lands; and (c) the Saharo-Sindian, characteristic of the great arid zones of the Sahara and Arabia and continuing as far east as north-western India and the Deccan [207]. Looking eastwards across the northward extension of the Rift Valley of Africa, which is represented by the Jordan Valley and the Dead Sea, it is said that one can see these types in reverse, Saharo-Sindian on the lower slopes, then a mixed vegetation in which the Irano-Turanian element is well represented, and above that the characteristic oak forests of the Mediterranean type.

By ecological deduction combined with the use of historical records, it would be possible, as Eig does, to say that the climax but now largely vanished vegetation of these zones contained:

Mediterranean: *Pinus halepensis*, *Ceratonia siliqua*, *Pistacia lentiscus*, and *Quercus aegilops* ssp. *ithaburensis*. 'Open thy doors, O Lebanon, that the fire may devour thy cedars. Howl, fir tree; for the cedar is fallen; because the mighty are spoiled; howl, O ye oaks of Bashan; for the forest of the vintage is come down.' (Zachariah, XI. 1-2.)

Irano-Turanian : open forest of *Pistacia atlantica*, or of *Juniperus phoenicea*, both associated with *Artemisias herba-alba* and species of *Astragalus*.

Saharo-Sindian : with, in Palestine, riparian forest along the Jordan of *Populus euphratica* with valley plains associations of *Suaeda palaestina* and *Salsola tetranda;* in the nearby mountains *Suaeda asphaltica* and other species.

Zohary [222] recognizes a further type, the Sudano-Deccanian, represented by 30 species, mostly shrubs and trees, constituting a few associations which he classes under *Zizyphus spina-christi*, mainly limited to the cases around the Dead Sea and along the lower Jordan Valley. *Zizyphus spina-christi* is undoubtedly primary; the species seems to be secondary in almost all the alluvial plains of former Palestine. Remnants of *Acacietum albidae* form pure stands in some localities. Zohary believes that its discontinuous distribution and its occurrence in strikingly diverse habitats point to the assumption that these stands are relicts of ancient tropical vegetation which at one time covered various parts of Palestine. If this means that tropical vegetation of a semi-desert type was once more extensive in Palestine, it must have become of a relict nature owing to a change to the Saharo-Sindian under more arid conditions, or owing to man-induced desiccation.

Mouterde [138] has recognized five plant geographical zones in Lebanon and Syria :

Coastal zones from sea level to about 1,400 m. : typical Mediterranean vegetation without xerophytic plants, probably climax woods of *Pinus brutia*, alternating with *Quercus calliprinos*, *Q. infectoria*, *Arbutus andrachne*, *Pistacia palaestina* and *P. lentiscus*.

Mountainous zone, from 1,400 to about 2,000 m. : climax in certain well-watered areas is *Abies cilicia*, in other parts *Cedrus libani*, *Pinus brutia*, *Cupressus sempervirens*, *Juniperus excelsa* and several *Quercus* species.

Summit zone, above 2,000 m. : a few species of *Noaea* and *Allium* are common to these high regions and to the desert or at least to the sub-arid parts of the ante-Lebanon.

Zone of the interior plains (Continental, Mediterranean or Syrian) : this zone commences immediately after the crest of the coastal ranges; the vegetation is Mediterranean mixed with many Irano-Turanian forms; the probable climax is an open woodland of *Quercus calliprinos* and *Q. infectoria*.

Steppe zone : very dry climate with intense variations in temperature and low rainfall; flora of the Irano-Turanian types with *Artemisia herba-alba*, and species of the Salsolaceae.

Pabot [148] has been able to classify the vegetation of the Lebanon in greater detail than that adopted by Père Mouterde and has recognized some twenty zones; those on the western slopes are called : Lower Mediterranean, Mid-Mediterranean, Higher Mediterranean, Cedar Zone, Sub-Alpine (Lebanon) and Alpine Zone (Lebanon). In Syria, Pabot [146] recognizes three main zones : Mediterranean, Syrian Mountain and Steppe. In Anatolia during the Ice Age, glaciation occurred only on the highest mountains (Ulu-Dag and Erciyas-Dag); however, Louis [127] believes that this period was characterized by a much higher rainfall in the mountains but not in the steppes of Central Anatolia (see Walter [199]). Practically nothing is known about the floral history of Anatolia; Birand [9, 10] has described the present zones of vegetation, and has indicated in his paper to the International Union for the Conservation of Nature and Natural Resources (in Athens, 1958) the extent to which the vegetative cover has suffered at the hand of man. The occurrence of a cedar forest near Samsun on the Black Sea and of the forests of *Fagus orientalis* in the Taurus and Amanus Mountains would seem to indicate a different distribution of vegetation types in prehistoric times. It is, however, more important to trace changes in vegetation in historical times based on relicts of *Juniperus*, *Quercus* and *Berberis crataegina* found in the mountains of Central Anatolia and on the inside of the mountain rim. The occurrence of these relicts indicates former forest, and leads Birand to conclude that the forest area has been reduced from 70 to 13 per cent of the total area of the country. In the transition zone between forest and steppe, the delicate biological balance can readily swing in favour of steppe conditions, as a result of the operation of the usual factors of deforestation, burning, cultivation, grazing, etc., leading ultimately to erosion and the impossibility of reforestation.

Hans Bobek (quoted by Monod [135], see also Bobek [13]) has evaluated and mapped the extent of distribution of the forest types of Iran as compared with the original condition, defined as being that at the end of the Neolithic (*c.* 5000 B.C.) and the beginning of the period when vegetation has been less influenced by climatic variations than by human activities. He estimates that there remain : one-quarter of the Caspian coast humid forest; one-half of the Caspian mountain humid forest (much of it severely degraded); one-fifth to one-sixth of the oak and oak/juniper forests of the Zagros; and hardly one-twentieth of the juniper forest of the Elburz and Khorassan, the stand being almost completely destroyed.

The open *Pistacia amygdalus* stands which once covered almost the entire central plateau, apart from the true desert areas, have also been heavily depleted, with a consequent expansion of the desert steppe.

The regions in Iran which have suffered most from the destruction of plant cover are those inhabited by nomads or semi-nomads and are therefore exposed

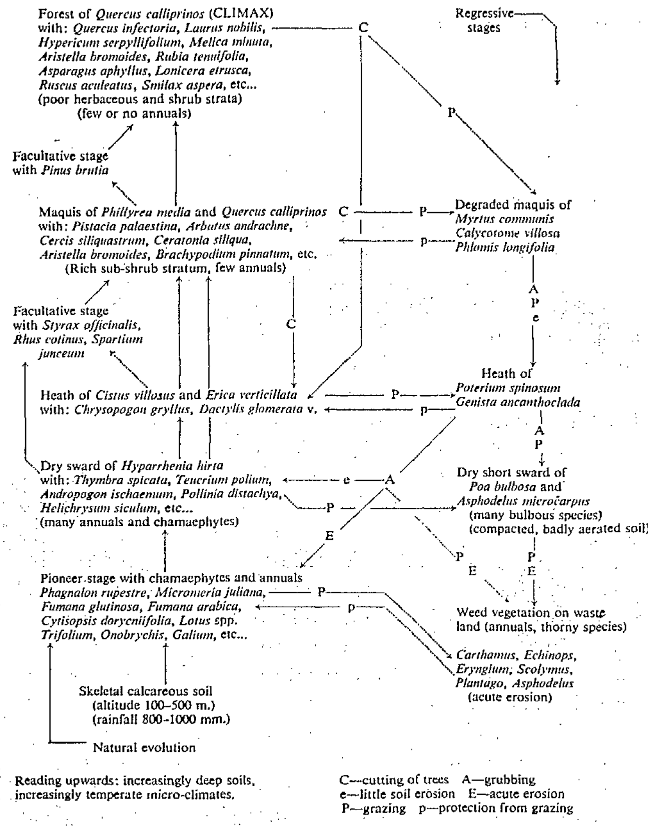



DIAGRAM 1. Example of a plant succession in the Mediterranean zone.

to extensive grazing, dry farming and charcoal burning. The highly developed civilizations which have been based on irrigation ever since the Neolithic are only indirectly affected by increased run-off from water supply areas outside their control, and the increased pressure of nomads on the settled population.

Pabot [146] has attempted to indicate the original vegetation of Syria, by reconstructing in Diagrams 1-3 three hypothetical but reasonably well-founded successions, showing how he believes the vegetation may have regressed from and how it might progress back to actual or theoretical climaxes of Mediterranean *(Quercus calliprinos)*, Syrian mountain *(Juniperus excelsa)* and steppe *(Pistacia atlantica)*. It is difficult sometimes to believe that the vast expanses of overgrazed steppe of *Carex stenophylla* are related in any way to the second and third of these climax types, but this is now firmly believed to be so.

Preliminary indications of original climax vegetation have been obtained from the Khuzistan plains and the adjacent parts of the Zagros Mountains in Southern Iran. Here, up to about 1,000 m. practically no natural forest remains, with the exception of some reduced thin forest of *Populus euphratica* along the River Dez. Assuming that the climate in prehistoric and early historic times was little different from the present, it is possible to conclude that this region was covered with more or less dense forests, except for the mountains above 3,400 m. and the normal zones of erosion [160a]. The great forest zones must thus have been as follows :

1. From 0 to 300 m. approx. : *Tamarix* spp., *Populus euphratica, Phœnix dactylifera* (date palm) in the more humid parts; and, in the dry parts, *Zizyphus spina-christi, Pistacia khinjuk, Ficus carica* (2 subspecies), *Tamarix stricta* (sands).
2. From 300 to 800 m. approx. : *Pistacia khinjuk, Ficus carica, Ziziphus spina-christi, Amygdalus scoparia, Pistacia atlantica;* in the valleys, *Tamarix* spp. *Populus euphratica, Salix* spp.
3. From 800 to 1500 m. approx. : *Quercus persica* (prevailing), *Pistacia khinjuk, P. atlantica, Celtis* sp., *Acer cinerascens, Amygdalus* spp., *Prunus* sp. etc.; in the valleys, same species as in lower altitude, with in addition *Platanus orientalis* (probably the forest type on the hills around Jarmo further to the north-west).
4. From 1500 to 2500 m. approx.: *Quercus persica, Pistacia atlantica, Acer cinerascens, Fraxinus syriaca,*

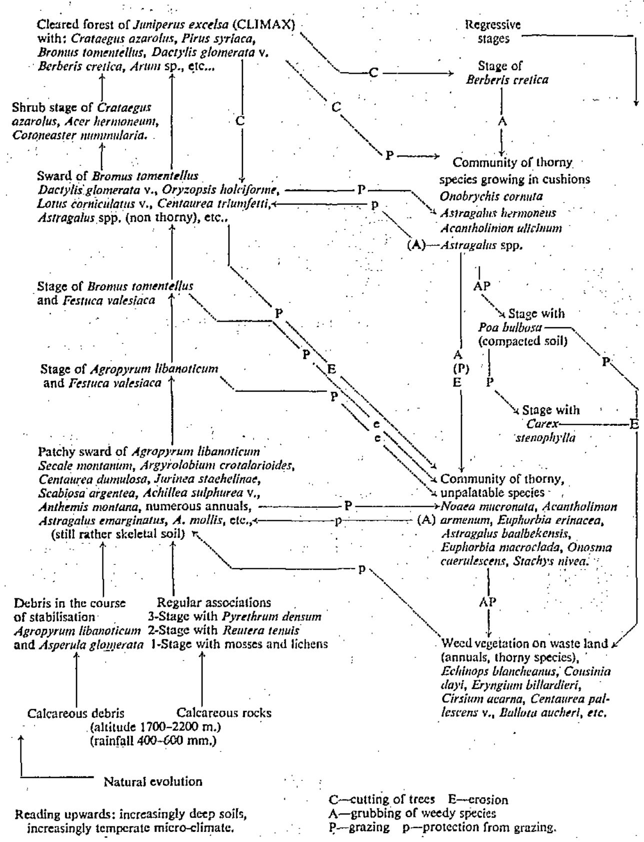



DIAGRAM 2. Example of a plant succession in the Syrian mountainous zone.

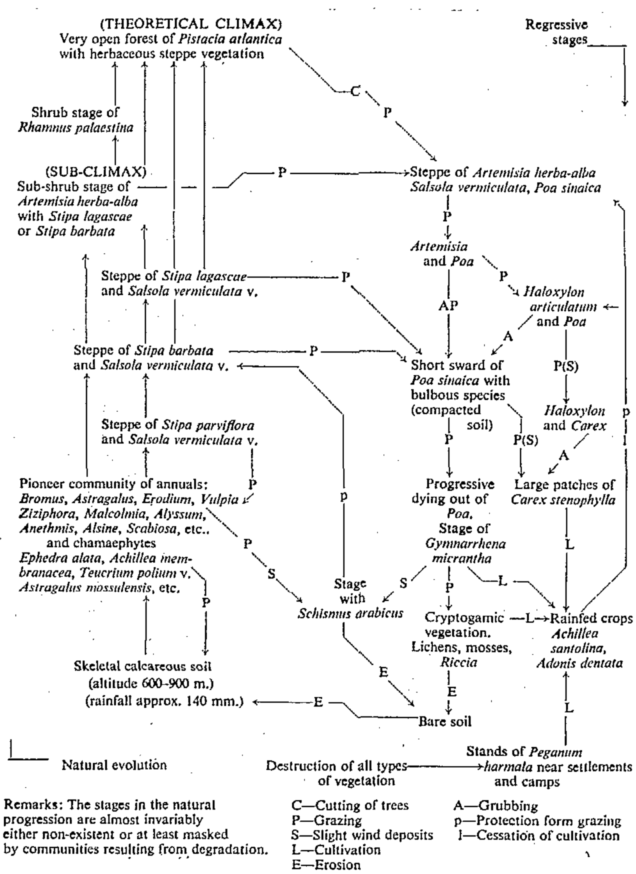



DIAGRAM 3. Example of a plant succession in the steppe zone.

*Crataegus* spp., *Pirus syriaca*, *Celtis* sp., *Juglans regia*, *Amygdalus* spp., *Juniperus excelsa*, *Prunus mahaleb*, *Lonicera nummularifolia*, etc., in the valleys, *Platanus orientalis*, *Salix* spp., *Fraxinus* sp.

5. From 2500 to 3400 m. approx. : *Juniperus excelsa*, *Lonicera nummularifolia*.

Pabot [147] believes that in Afghanistan in antiquity there existed (a) in the less arid parts of the northern plains open forests of *Pistacia khinjuk*, *P. atlantica* and *P. vera;* (b) in the mountains bordering these plains *Juniperus excelsa;* (c) in the mountains to the east of Kabul forest of *Quercus ballout* with *Pistacia atlantica* and *Cercis griffithii*, of which relicts still exist; and (d) in the mountains near Kandahar forest of *Pistacia atlantica*, some specimens of which are still to be found.

Hans Helbaek has adopted a somewhat different technique in his studies of the wild, and particularly the weed, flora around Jarmo and Nimrud, and at other sites in northern Iraq. A herbarium collection has been assembled and is being identified. Braidwood [18] writes :

Having seen for himself the nature of this upland region of Kurdistan, Helbaek is convinced of the soundness of the suggestion that Jarmo and other ecologically similar localities witnessed the first attempts at agriculture. In the region about Jarmo the present-day botanical evidence strongly substantiates the idea, in that here are found the wild wheat, the wild barley, lentil, pea, flax, fig, almond—all species which are potentially domesticable in their present forms, or are potential factors in hybridization. All are found in a definitely wild state, that is in uncultivatable stations, so that they must be considered as indigenous and not as later introductions.

Helbaek's systematic botanical collections about the site of Jarmo are the first case, in the Near East, where a professional attempt has been made to co-ordinate archaeological and botanical investigations, and one of the very few cases in the general area where an intensive systematic collection has been made at all. The results, when digested, will contribute not only to the increase in general botanical knowledge of the area, but will also bear on understanding the transition from cave-dwelling savagery to the establishment of the village farming community.

It appears that we have a basis on which to begin to apply modern botanical and ecological knowledge and techniques to the preparation of our picture of the major plant geographical zones of the Near East, of the many types of vegetation or plant communities which occur within them, and of the nature of ecological regression and progression to be found within the vegetative types. In which of the major plant geographical zones and in which of the communities within these zones, pre- and post-desication, would one expect to find the important species of *Triticum*, *Aegilops*, *Hordeum*, *Medicago* and the many other economic plants which were originally members of the wild flora of the region and now occur in the non-cultivated state almost entirely as weeds in crops and the borders between fields? Knowledge of this nature would be of great value, when combined with that obtained from studies on climate, geomorphology, geology and soils, in delimiting the major and minor land systems and units into which it is highly desirable, if not essential, to subdivide the area before attempting any integrated planning at the present day.

Closely connected with the deterioration of the vegetative cover of south-western Asia, as in other parts of the arid zone, are the location and degree of infestations of locusts, in our region the Desert Locust *(Schistocerca gregaria)* and the Moroccan Locust *(Dociostaurus maroccanus)*. According to Uvarov [194] the latter offers probably the best example of the effects of land use in a semi-arid climate on the population of an injurious insect, through changes in vegetation structure and microclimate. In discussing the development of arid and semi-arid lands Uvarov [193] states :

. . . my object is merely to draw attention to the need for taking into account its possible hazards among which locusts and grasshoppers have already proved to be outstanding. These particular hazards can be avoided if they are carefully studied before it is too late. . . . In the typical semi-arid country of North Africa, the Moroccan Locust is called in Arabic 'Djerad-el-Adami'—man's locust. This name is appropriate to most locusts and grasshoppers, as it has been man who has encouraged and continues to encourage them by short-sighted land usage.

As might be expected, the Desert and Moroccan Locusts have for a long time found in south-western Asia the patchy, mosaic type of vegetative cover which provides the ideal dual-purpose habitat, for oviposition and food/shelter. For example, Thompson [190] has noted that Egyptian artists depicted locusts attacking various plants including the grapevine, a relief depicting Assurbanipal and his queen feasting to celebrate the victory over the Elamites shows a locust on a palm, an enamelled orthostate from Assur at the time of Sargon II shows a dignitary with a locust above his head before the God Shamash, presumably praying for the removal of the plague, Assurbanipal's library had a text of a prayer for keeping them away, and Babylonians used incantations against them. Thus not only do we find evidence of the destruction of vegetation at a very early date in a time sequence, but also of one of the hazards which accompanied that destruction.

## THE BEGINNINGS OF LAND USE

It may be possible to synthesize information and deductions from a number of related disciplines in such a way as to define the reasonable state of equilibrium which existed between vegetation, fauna and man in the days of the hunters and food-gatherers [71, 151]. Into this primitive environment came what Gordon Childe [41] has called the economic revolution of food production, 'the deliberate cultivation of food-plants, especially cereals, and the taming, breeding and selection of animals', the greatest economic revolution in human history after the mastery of fire, or what Braidwood has called the swing from food-collecting cultures to village-farming communities [20, 27, 28].

The great question is when and where this revolution took place, and agriculture and pastoralism began [151]. What type of crop cultivation was the first to appear, the planting type which Sauer [167] believes to have been the original type and to have arisen to provide carbohydrate foods for the fish-eating coastal communities of south-eastern Asia (Bengal and Burma), or the sowing type with which we are primarily concerned in our region of study and which many regard as the original type, but which Sauer believes developed later in climates marginal for vegetative planting, i.e., (a) North China, (b) from western India and West Pakistan to the eastern Mediterranean and involving passage from a summer rain to a winter rain environment, and (c) the highlands of Ethiopia. One may mention in passing the case made by Murdock [139] for an early centre of cultivation in the great bend of the Niger River in West Africa. Braidwood [26] finds both the south-east Asian and West African cases quite reasonable, but reminds us that there is neither archaeological nor palaeo-environmental documentation for their great antiquity.

Sauer has postulated that neither heavy forest nor open grassland was suited to man's earliest state, that his water needs were high and frequent, and that he required certain cultural skills before he could cope with drought-affected regions.

The earliest homes of our kind are to be sought in tempered climes, not heavily forested places, either on the outer margins of the tropics or elevated above the rain forests. Such mesothermal climates have opposed rainy and dry seasons, with growing and resting periods of vegetation, and with times of greater or less abundance of food. . . . pleasant places, of mild weather with alternating rainy and dry seasons, of varied woodland, shrub and herbs, a land of hills and valleys, of streams and springs, with alluvial reaches and rock shelters in the cliffs. . . .

Apparently, in fact, as far as our region is concerned, within or on the fringes of the Mediterranean environment. If this assumption is true, the first plants and possibly also the first animals to be domesticated would be those which belonged to that particular ecological complex or biome.

In presenting his basic premises for the origin of primitive agriculture, Sauer believes that the 'basic invention of agriculture' must have been made during the last deglaciation, and that: (a) agriculture did not originate from a growing or chronic shortage of food; (b) the hearths of domestication are to be sought in areas of marked diversity of plants or animals where there was a large reservoir of genes to be sorted out and recombined; (c) primitive cultivators could not establish themselves in large river valleys subject to lengthy floods and requiring protective dams, drainage or irrigation; (d) agriculture began in wooded lands; (e) the inventors of agriculture had previously acquired special skills in other directions that predisposed them to agricultural experiments; and (f) above all, the founders of agriculture were sedentary folk (Sauer's belief that mobility is incompatible with crop cultivation and maintenance does not consider the special desert form of shifting cultivation practised by migratory grazing communities who sow their barley on the way to the grazing grounds and harvest the crop on the way back to their based).

Childe [41] refers to Menghin [132] as representing the school which holds that domestication of animals and cultivation of plants were initiated by distinct groups.

Domestication would arise among hunting peoples, agriculture among those already devoted to the collection of roots, seeds and berries. Mixed farming would only result from the fusion of pastoralists and cultivators. Others assign the primacy to agriculture; the cultivator could induce wild animals to submit to domestication by the food his operations guaranteed. The nature of the archaeological record is liable to favour the latter view unduly; herdsmen living in tents and using bone tools and leather vessels are less likely to leave recognizable traces than cultivators who will leave about sickle-flints and querns and very likely pot-sherds. (Childe [41].)

As Wheeler has said 'many of us were brought up to the simple economic succession: hunting—pastoralism—agriculture—civilization . . . but today, with accumulating knowledge, the problem is less easily solved'.

Conditions of incipient desiccation are introduced as providing a stimulus towards the adoption of a food-producing economy. 'Enforced concentration by the banks of streams and shrinking springs would entail a more intensive search for means of nourishment. Animals and man would be herded together in oases that were becoming increasingly isolated by desert tracts. Such enforced juxtaposition might promote that sort of symbiosis between man and beast implied in the word "domestication" [41].' One cannot help wondering whether the desiccation which is produced by many archaeologists to explain various phenomena was real climatic desiccation or may not have been an outcome of the excessive disturbance of the delicate equilibrium which exists in arid zones between climate, vegetation and soil by hunters using fire, fuel cutters or primitive grazers with their flocks and herds.

Toynbee [191] has also introduced desiccation into his interpretation of the results of the Pumpelly expedition of 1903 and 1904 to the Trans-Caspian oasis of Anau, the site in the extreme south-western corner of the Eurasian Steppe, at the foot of the north-eastern escarpment of the Iranian Plateau. Here Toynbee finds 'the challenge of desiccation stimulating certain communities which had formerly lived entirely by hunting to eke out their livelihood under less favourable conditions by taking to a rudimentary form of agriculture'. The report of the 1904 Pumpelly expedition states that 'with the gradual shrinking in dimensions of habitable areas and the disappearance of herds of wild animals, Man, concentrating on the oases and forced to conquer new means of support, began to utilize the native plants; and from among these he learned to use seeds of different grasses growing on the dry land and in marshes at the mouths of larger streams on the desert. With the increase of population and its necessities, he learned to plant the seeds, thus making, by conscious or unconscious selection, the first step in the evolution of the whole series of cereals'. The report also states that the agricultural stage preceded domestication of animals and thus preceded the nomadic shepherd stage of civilization. 'It is not the hunter with his hound but the ci-devant hunter, transformed into an agriculturist with his watchdog, who has it in his power to accomplish the further transformation which brings into existence the shepherd with his sheep-dog.' (Toynbee [191].)

Rivals to Anau as possible near-eastern centres for the origins of agriculture are Jericho, certain sites in the Tigris-Euphrates valley and surrounding foothills (hilly flanks), and the Caspian foreshore. We do not wish to become involved in the discussions between archaeologists as to the merits and particularly the relative ages of their own 'pet site' or of the meaning of terms such as urbanization and civilization, village, city and town [42, 205, 214], or on the relative merits of oases, river lands, hilly flanks or coastal sites as the probable place of origin of early towns [24]. This review will be confined to the various ways and sequences in which agriculture and pastoralism are supposed to have originated and to the environment in which this revolution may have taken place.

The excavations at Jericho by Professor John Garstang between 1930 and 1935 and the subsequent work on the same site by Kathleen M. Kenyon [105, 106, 107] have produced evidence which, in the latter's words, have disturbed the neat and tidy scheme that existed up to that time of man's emergence from Palaeolithic and Mesolithic savagery through Neolithic barbarism to the civilization of the metal ages. Kenyon refers to the nomadic hunters of the first stage (somehow the use of the term nomadic for these pre-grazing days is a little confusing, as one usually now associates nomadism with stock-grazing communities with no settled home), who

. . . discovered agriculture and stock-breeding and were thus assured of enough subsistence to become settled villagers, self-sufficient and unprogressive, but at least no longer savages. After long years of this unprogressiveness, the eventual discovery of the use of metal led to trade, specialization, the need for surplus food to feed the traders and specialists, the growth in importance of favoured areas such as the great river valleys and the development of the villages there into towns through the accumulation of surpluses and the consequent need for organized rule to control them. The theory was reasonable, and what was then known about the early village settlements in western Asia and the rise of towns and states in the river valleys of Egypt and Mesopotamia seemed to fit the facts. A chronology of early villages in the later fifth millennium and the growth of towns in the later fourth, leading to states in the third, seemed to cover what was known.

The geographical environment of Tell-es-Sultan at Jericho must have played a major part in these developments in the sixth or early seventh millennium. The perennial and copious spring which still rises at the foot of the *tell* would have been a principal factor. The present-day contrast between the luxuriant oasis and the surrounding country is believed to have existed at the time of the first settlement, that wild grains are indigenous to the area, that game would have been abundant on the plain, and that the hill country on both sides of the valley would probably have been rather heavily wooded, since upland occupation does not become widespread until the urban development of the third millennium. We must await the reports of the botanists and zöologists with regard to the grains and grain-impressions and the bones of wild and perhaps domestic animals before reaching any final conclusion on the environmental background. If, however, there were large enough stands of wild, large-seeded Gramineae within easy access of a town with an estimated population of 3,000 people (a very large acreage of natural stands would have to be involved, with a probable average grain yield of less than 500 kg. per hectare), it is unlikely that the Jordan Valley could then have been the Saharo-Sindian ecotone which it is today. If it were Saharo-Sindian at that time, it would be likely that grains of the large-seeded Gramineae would have been collected, possibly during an earlier food-gathering phase of human development, at higher elevations of the Jordan Valley, in the plant communities of the Irano-Turanian environment, and domesticated and cultivated by later generations under irrigation in the valley itself in an environment to which they were not naturally adapted.

The evidence obtained of two successive pre-pottery Neolithic towns of Jericho is regarded as indicating:

... a very much earlier and very much more rapid development of urban civilization than had previously been suspected, and this is unlikely to have been confined to Jericho. At a time when new knowledge is gained almost every year (the evidence of Jericho, Mersin, Hassuna, Jarmo and Byblos all dates from the last twenty years, and much of it from the last ten), there is no reason to suppose that new finds do not await us still. I therefore put it before you, as a pure hypothesis, that in western Asia there was, in the relatively favourable climate at the end of the Pluvials, a period of much more rapid development towards settled life and the Neolithic stage than has hitherto been suspected. The area covered by this may have been small, but I shall be surprised if it is limited to the Jordan Valley. What secrets are hidden in the cores of the unnumerable *tells* of Syria? Thereafter, increasing desiccation may have given an advantage to these groups which had developed a less specialized economy; and it is their villages, certainly at Jericho, superseding the town, which have hitherto been regarded as representing the first beginnings of the Neolithic way of life. . . . It is a commonplace that by historical times the great Fertile Crescent, stretching from Egypt to Mesopotamia via the Mediterranean coast and the Anatolian foothills, is the area of settled populations and growing civilizations, encircling a semi-desert and desert core occupied by nomads. From the dawn of history and no doubt long before, these nomads erupted at intervals into the fertile lands. Jericho guards one of the principal routes by which the Palestine coast-lands may be reached from the east. The arrival of new groups there reflects the process of penetration into Palestine as a whole.

Let us turn to what Gordon Childe calls the colonization of Mesopotamia, a region much less homogeneous geographically than Egypt and which was much more exposed to invaders from the surrounding areas in the Zagros Mountains and Iranian Plateau, north Kurdistan and Armenia, and the Arabian Desert. The alluvial stretches on either side of the great rivers of Babylonia were, according to Childe [41], even less self-sufficing than Egypt. The timber and stone for building and even the material for the simplest tools had to be imported.

The prehistoric settlements in northern Syria and Iraq outnumber historic settlements by five to one, and there was a decline in population from 2500 B.C. onwards until irrigation had become a common practice [130]. Childe states, however, that since the flora and fauna depicted on the earliest pictures and monuments are those appropriate to an arid climate such as exists today, we may safely disregard any claims that there is archaeological evidence of climatic change. The land has, however, changed considerably even in historical times.

The deposit from the two rivers is still silting up the head of the Persian Gulf so rapidly that on one estimate the coastline advances about 1½ miles a century. In the seventh century B.C. the Kerkha, which now loses itself in the sands and marshes above Basra, debouched directly into the Persian Gulf; Sennacherib had to sail 160 km. from the mouth of the Euphrates to reach its estuary. At the beginnings of historical times a series of tidal lagoons extended inland almost to the foot of the limestone ridge on which stand the ruins of Eridu, the first royal city of Sumerian tradition. The land of Sumer must have been a region of swamps such as subsists today around Basra, where date palms grow wild. Since then the deposit left by the inundation has been steadily raising the level of the land till today, even at Kish, the surface of the plain lies 25 feet above 'virgin soil'.

Account must, however, be taken of the subsidence of the delta floor, which is almost exactly equivalent to the rise in surface level. The earliest settlement is just at sea level—the plain today is 14 feet above sea level.

This colossal silt load of the Tigris and Euphrates deserves critical consideration. How long has it been a characteristic of these rivers, and has there been a progressive increase or a periodical fluctuation in the load? To what extent does or did it represent the effect of rainfall of high precipitation/frequency on very erodible soil types, or the effect of the clearance of forests and the cultivation of the soil in the upper reaches of the catchment area, or a combination of both? The relative importance in this respect of the Tigris and Euphrates and their tributaries on the one hand, and the Kerkha and Karoun is indicated in figure 9 from Birot and Dresch [11] (but see below, page 92).

Sumer cannot have been, according to Childe, the scene of the 'Neolithic Revolution'; links with the Old Stone Age cannot be expected in this new land.

Its first inhabitants must have come from elsewhere, from older land, perhaps the steppe zone to the north-west or the mountains to the east, where urial, mouflon and goat roam wild and where cereals reputedly grow spontaneously. Now the culture of the earliest agricultural colonists of Sumer is, in fact, duplicated in many farming villages from the foothills of Assyria westward across the Steppe to the Euphrates. But in the north these villages occupy the sites of earlier settlements, disclosing a culture that is presumably prior in time, if not ancestral, to the oldest culture of Sumer. It is accordingly legitimate to begin our survey of Mesopotamian origins in Assyria and Syria. That region is at least a possible cradle for stock-breeding and agriculture. In the fifth and fourth millennia it was certainly no desert nor treeless steppe but rather a parkland; even in the second millennium plenty of trees grew there. Perennial streams and springs were relatively abundant, but not unlimited as in temperate Europe. So permanent settlements were restricted and remained continuously occupied from prehistoric to historic times.

So we come to the excavation by Braidwood [25, 27, 40], in the upper reaches of our catchment area, of a series of superimposed hamlets at Jarmo in the intermontane valley of Chemchemal in Iraqi Kurdistan, which would appear to be very near the beginning of food production. Agriculture is proved by the occurrence of grains of wheat or barley, querns and sickle-teeth, while most of the animal bones are of sheep or goats, oxen, pig and dog. Braidwood [25, 228] has presented a review of the evidence relating to the change from the food-gathering to the food-producing stage, and describes the nature of the incipient cultivation found at Jarmo, with radiocarbon ages ranging from 6,606 ±330 years to 11,240 ±300 years.

Childe [41] states, however, that no archaeologist can say that Jarmo reveals the starting point of the established sequence of Mesopotamian cultures, nor even that it is earlier than Hassuna or Samarra. He therefore concluded that the Hassuna site in Assyria west of the Tigris (see [125]) may not illustrate the very first steps in food production, but that it is certainly nearer thereto than anything yet known in the Tigris-Euphrates valley. The developmental stages in ancient Mesopotamia and the relation between agricultural and other historical events have been summarized by Adams [1] as follows:

*Developmental eras in Ancient Mesopotamia*

*Terminal food-gathering:* A hunting gathering adaptation based on small, non-sedentary groups. Known mainly from caves in foothills, but may have occupied open sites as well.

*Incipient agriculture:* Small semi-sedentary communities in hilly uplands acquired basic agricultural techniques for settled life.

*Formative:* Adoption and spread of typical upland village subsistence pattern, and perhaps also of its corresponding forms of social organization. Sedentary agriculture with digging-stick and hoe cultivation of wheat and barley, domestication of sheep, goats and probably cattle, ceramics. Communities remained small and relatively uniform in size and composition, but increased in number, spreading into the alluvium with the introduction of irrigation techniques. 'Fertility cult', small shrines.

*Florescent:* Emphasis shifted to the lowlands with the development of plow-irrigation agriculture. Expansion of technology and appearance of full-time craft specialization; introduction of potter's wheel, cart and chariot, sail, copper metallurgy, early phases in the development of writing. Rapid growth in concentration of surpluses, largely in hands of priestly hierarchies, with consequent building of monumental religious structures in town-urban centres. Beginnings of warfare.

*Dynastic:* Separation and institutionalization of secular-political and religious economic controls in true urban centers . . . the appearance of kingship and the city-state. Emphasis on fortifications and growing importance of warfare, culminating in Sargonic conquests. Slow growth of private capital in trading and manufacturing, but at the end of the era temples probably still dominated the economic life. Rationalization and expansion of handicraft production; bronze metallurgy, refinement of cuneiform script.

Having dealt on the one hand with Mesopotamia and on the other with Palestine and its Tell-es-Sultan at Jericho and its many caves in which primitive and not yet settled farmers could shelter and store their food, there remain the intervening areas, the parkland steppe of northern Mesopotamia comprising Assyria and North Syria and the hill country immediately to the west of the Euphrates, including the Orontes Valley and the Phoenician coastlands.

The steppe zone north of the Sinjar range was a main artery of communication between east and west. However, a relatively reliable rainfall, adequate supplies, permanent water, stone and timber and proximity to deposits of obsidian and ores permitted the survival of small but viable economic units with little pressure to concentration of population and economic consolidation. The written record begins here seven centuries later than in Egypt or Sumer.

Over the narrow belt of high ground that divides the Euphrates from the Mediterranian drainage, we find that the Amanus and Lebanon ranges tap the moisture-laden depressions from the west. So with winter cereals, fruit trees and vines, the Orontes valley and coastal plains could support a substantial population based on fishing, cereal growing and stock breeding, combined where appropriate with orchard cultivation. Again the beneficial conditions would not demand any concentration of the population. Judging by the great depth of its deposits, especially at Mersin, the Levantine Neolithic culture must have lasted a very long time and must rival in antiquity anything known in the Nile Valley or Mesopotamia [41]. It may indeed prove to be descended from the Natufian or some other local Mesolithic culture, as it is believed that its province offers the botanical and zoological conditions for the Neolithic revolution.

And so to return to our starting point, the Caspian area and its claims also to have been an important centre for the origins of agriculture. Coon [45] believes that the best place to look for the beginnings of agriculture is not at the bottom of mounds, but in caves. The earliest agriculturists were cave-users when caves were available. Particularly before they had begun to raise cereals these people may have practised slash-and-burn agriculture. Coon postulates that after ringing the trees of a few acres of forest and allowing the wood to dry out, they would burn them and plant some unspecified crop in the soil around the stumps. After a few years the underbrush would have become so dense that it would be easier to move on to a new spot—thus we have a from of nomadic or shifting cultivation, with people not remaining long enough at one site to produce a mound.

In 1949 and 1951, an expedition of the University of Pennsylvania dug a site in northern Iran called Belt Cave, which contained a sequence of cultures; at the bottom dated at 9530 B.C. ±550 was a Mesolithic level with many seal bones and every evidence of a wet climate. Next came a dry climate Mesolithic culture, dated at 6620 B.C. ±380, in which the gazelle was the dominant animal. After this came the beginning of the Neolithic, with domestic goats and sheep but no pottery, date 5840 B.C. ±330. Somewhat later, 5330 B.C. ±260, the people had begun to make pottery and to reap grain (a finding doubted by some authorities) as well as to keep pigs and, a little later, cows. It is on the basis of this evidence that Coon considers the most likely place in which to look for the beginnings of tillage and animal husbandry is the narrow belt of land lying between the Elburz Mountains and the southern shore of the Caspian Sea. This prehistoric Côte d'Azur, playground of the Mesolithic idle rich, had fertile black soils, heavy rainfall, mild climate with only rarely frost or snow, abundant wild fruits, the sea full of fish and sturgeons spawning surplus caviar in the streams, brush alive with pheasants and grouse, swampy lagoons with ducks and geese, and on the mountainsides, red deer, boar, wild sheep and mountain goats, quite a contrast to the tough retreats from desiccation in Jericho, Jarmo and Hassuna.

At the other extreme in the aridity scale and much later in our time sequence we have the agriculture of the Nabataeans in the Central Negev, based primarily on the efficient conservation and use of run-off water. The elevated mountain ridges north and west of Makhtesh Ramon as well as the adjoining escarpments running north and west form an enclave of Irano-Turanian vegetation, with poor or fair Saharo-Sindian at lower levels. Under an average annual rainfall, probably of 100 to 150 mm., it may reasonably be assumed [225] that the ancient inhabitants of the Negev maintained a relatively stable form of agriculture by harnessing run-off water for the irrigation of their fields. The ebb and flow of history is difficult to follow in the absence of the usual *tells*. War tended to be total: 'And he took the city and slew the people that was therein, and beat down the city and sowed it with salt' (Judges IX. 45). The scouts of Moses probably found the central Negev as desolate as it is today [76, 103, 171, 185].

Cultivation was confined to valleys, which were covered by loess and were conveniently situated topographically for the use of run-off water as supplementary irrigation. This harnessing of water was achieved through the erection of elaborate systems of dams and terrace walls. It seems probable that winter cereals sown in these ancient fields grew well even in rather dry years; fruit trees seem also to have been cultivated, to judge from isolated specimens occurring today and the remnants of wine presses. The Central Negev is a clearly demarcated agricultural unit, distinct from the desertic southern Negev, and also from the northern Negev, which appears always to have been an area of unsettled extensive dryland agriculture.

It was originally believed that these agricultural achievements were characteristic of the Nabataean, Roman and Byzantine civilizations, but Evenari and others [64] have found remains of civilizations which preceded the Nabataean/Byzantine periods (*c.* 200 B.C. to A.D. 600). These earlier remains fall mainly into two periods: (a) Middle Bronze Age I (about 2000 B.C.); (b) Israelite period (III)—the period of the Judaean kings (about 850 to 600 B.C.). The agricultural features were dated according to the age of the following structures: buildings associated with the agricultural areas; forts and guard-posts which protected them, and routes along which the 'farm units' were built.

The Judaean kingdom built by David and Solomon had many colonies in the Negev (see reference to King Solomon's copper mines, p. 80). The cities of Solomon were destroyed by the Babylonian invaders in the sixth century B.C. and the Negev again became a wilderness occupied by Bedouins. About the second century B.C. the Nabataeans moved in from Arabia and built a thriving civilization made possible by thousands of water-storing cisterns, some still watertight, and cleared the hilltops of stones to make rain-catching areas. Still later, the Byzantines used the same successful methods until the Muslim conquest of the seventh century A.D. once more laid bare the country and returned it to the nomadic Bedouins. Throughout the history of our region, we find a continuous struggle between the desert and the sown, '. . . along some Strip of Herbage strown That just divides the desert from the sown' (Omar Khayyam) where took place the eternal struggle between nomad and peasant, between desert and civilizations even at such places where no literary documents have been found (Reifenberg, [163, 164]). Elsewhere we give the example of Palestine through the centuries and refer to the vulnerability of the Tigris-Euphrates basin as compared with the Nile valley.

Hans Bobek [15] also refers to increased pressure by nomads and semi-nomads on the settled communities of irrigated regions in Iran, although he does not consider that this is due to the deterioration of condition of the grazing lands. Bobek gives some examples of historical cultural regression in various parts of Iran : (a) the Fars, the heart of Achaemenid and Sassanid Persia, a typical example of a tract where decadence cannot be due to a deterioration of natural conditions, and which can still be regenerated; (b) various parts of the Zagros, inhabited from prehistoric times to the Sassanid or even the Muslim era, where degradation is again due to historical causes; (c) the vast area of the ruins of Susa, etc., where there is no insurmountable technical obstacle to reclamation; (d) the Mughan Steppe (Azerbaidjan) and Atrek (Gorgan), until recently inhabited by nomads, but which are covered with ruins from prehistoric, classical and Islamic times, and are also reclaimable; (e) Seistan, the old Iranian cultural nucleus, where the decrease in cultivated land seems to be connected mainly with the deterioration of irrigation systems, aggravated by considerable fluctuations in the volume of the Hilmand River, which Bobek believes may be due more to small climatic variations than to deforestation itself.

Soil degradation, very pronounced in certain localities, e.g., in Mazanderan, would seem to be at least balanced by the expansion of the cultivated area and does not appear to have led to a regression in population numbers. To the question : Can other causes for the abandonment of cultivated land be found? Bobek's reply is in the affirmative; they are sometimes domination by the nomads, and sometimes social and economic conditions. Domination by nomads was certainly the decisive factor in Baluchistan, Fars, the marginal areas of the Zagros, the steppes of Mughan and Atrek, as well as other parts of Khorassan and many parts of the Elburz. The sedentary population retreated before the nomad groupes—Seljuks, Turkmens, Afjars, Mongols, Uzbeks, Qajars, Baluchis and Arabs. The appearance of the nomad warriors, riding first horses and then camels, occurred during the last centuries of the second millennium B.C. During the first centuries of the first millennium, they are followed by Iranian horsemen, in the ninth century B.C. by Assyrians. The countless polychrome potsherds of the agricultural civilization found throughout the Iranian Plateau witness the retreat of the sedentary population during the second millennium B.C. A second human cause has also played a role, namely, the feudal social and economic structure, with its oppression of the peasant and thus a tendency towards the abandonment of settled life. Bobek [15] concludes :

> It cannot be denied that over thousands of years the cumulative effect of destructions of the original plant cover has led to a degradation in natural conditions. However, this applies mainly to the extensively used regions and has had hardly any influence on the major regressions in civilization and the great depopulation waves attested in history. The latter are indeed to be attributed mainly to the historical and social causes mentioned above, among which brutal domination by nomad groups and oppression by a corrupt administration are the major factors. On the other hand, these conditions have contributed to further depradations of natural resources and, through the abandonment of cultural practices (irrigation), to additional deterioration in the general conditions of the country.

Also under the heading of the origins of agriculture, it is appropriate to consider the origins of the different cropping systems which are still characteristic of the various parts of our region. To judge from the early references to the need to maintain the fertility of cultivated soils, to the value of fertility-maintaining rotations incorporating leguminous crops and related matters, it appears obvious that our early farmers did the best they could to adopt suitable cropping systems. The change from the original system of shifting cultivation, in which a patch of wooded land was cleared by burning and cultivated for as long as it retained its fertility, to the basic cereal-fallow system characteristic of low rainfall conditions, with a Mediterranean or similar type of climate, was probably made at a very early date.

With the early advent of irrigation in the valleys, now supplementing the renewal of fertility by the annual deposition of silt, it became possible to till the same ground for generations. It should be realized, however, that much of the soil structure, both under irrigated and dryland conditions, has long been lost. Be that as it may, the early farmers were able or were obliged to adopt improved methods of tilling the soil on the wider expanses of flat and fertile soil now available to them. Woolley [215] notes that the primitive method of sowing by dropping the seed into holes dibbled into the ground with a pointed stick gave place to hand furrowing, which continued for a long time; the settlements of the Al'Ubaid people, the first immigrants into the Euphrates valley, are marked by the vast numbers of heavy flint hoes which litter the site. The wooden or nail plough brought about the change from plant cultivation to field tillage. The date of its first appearance cannot be determined, but Woolley states that the ox-drawn plough was in use in Mesopotamia by 3000 B.C. and perhaps long before that. The plough actually occurs as a pictograph in the earliest known tablets from Mesopotamia, probably several hundred years earlier than 3000 B.C. It is not possible to credit any particular country with this invention.

The larger harvests which were now obtainable demanded an improvement in the method of reaping. In the upland clearings the thin crop had been gathered by hand, generally roots and all, still by no means an unusual practice in these regions. The earliest sickles, flint flakes mounted in a straight wooden bar, were found on Mount Carmel; denticulated and plain flint blades were fitted into curved wooden sickles with the aid of bitumen both at Hassuna and Jarmo; in Mesopotamia the same principle was employed, but the handle might be of baked clay. Woolley refers to a curious alternative found on sites of village settlements of the Al'Ubaid period—terra-cotta sickles with a sharp cutting edge, the clay fired so hard as to be not infrequently vitrified. The Uruk people introduced the copper (or bronze?) sickle. When metal was so rare and expensive, worn metal tools would not be thrown away, but would be melted down and recast. Consequently it is not surprising that the earliest metal sickle recorded from Mesopotamia dates only from the Early Dynastic times. To judge from documents of that period, metal remained too expensive to be used for tools by the ordinary peasant, and denticulated flint sickle blades remain common on all sites up to the middle of the third millennium B.C.

The history of cultivation practices has been reviewed by Russel, who concludes that tillage originated in Iraq. The oldest human record is in the traditions of the descendents of Abraham of Ur, as recorded in the Bible. The earliest tillage that can be confirmed on the basis of relicts was at Jarmo in the Chemchemal valley. The discovery there of hand sickles made of stone leads one to presume that they were used for harvesting grain, that the grain was probably cultivated, and that cultivation presumes tillage. It has been noted, however, that the presence of stone sickles on Mount Carmel is taken to indicate that wild grasses, not necessarily cultivated crops, were harvested.

Russel believes that the first digging would have been done with sharp pointed or sharp-edged stones, many of which were found at the site. Tillage in Iraq is divided into three types : Jarmo tillage; tillage in other upland plains to 4500 B.C.; and tillage of the lowland plains to 3800 B.C. The first Sumerian ploughs were made from the forks of trees, probably tamarisk because of its toughness and hardness. At one stage the Sumerian plough had a tube extending downwards behind on the handle through which seed could be dropped from a funnel on the top. The plough was not the only tillage tool of the Sumerians. One record contains an involved dialogue between a plough and a spade as to which of the two should be most respected. In the end the spade wins on the basis that it has more good uses: loosening soil, digging ditches, cleaning canals, mixing mud for bricks, etc. The design of the spade of Sumerian times was almost exactly the same in principle as that used by Iraqis at the present day, the only difference being that the modern one is made of iron, the ancient one of wood first and then bronze. The Sumerian hoe probably originated before either the spade or the plough. There are a few references to a drag implement which translators have called a harrow, perhaps incorrectly as it was apparently merely something which was dragged over the soil to smooth it and make it fine, as is the practice throughout India at the present day. One notable fact about Sumerian tillage is that it was considered a dignified pursuit. Russel discusses a period which he calls 'the dark ages of Iraqi tillage' from 1600 B.C. to A.D. 636.

In the course of the Bronze Age, the agricultural economy of the ancient world assumed, according to Woolley, the form which it was to retain with very little change until mediaeval if not until modern times. By 1200 B.C. the people had selected and developed the best-adapted types of cereals; the methods and the tools would be used for at least another millennium, the only change being that iron would soon take the place of bronze. All the domestic animals of the present day were already serving man, although the horse was limited to the war chariot. The fig, apple, pomegranate, peach and mulberry were cultivated and dates were the most important product of southern Mesopotamia. The market gardeners produced a considerable variety of vegetables. Although flax was a major crop in Egypt, wool was generally preferred for clothing in the colder winters of Mesopotamia, and flax was of secondary importance. Cotton growing did not spread from India to the west or the east until much later.

The earliest settlements, both on the Anatolian Plateau and in the Aegean province [126], must be correlated chronologically with the tail-end of the Mesopotamian Chalcolithic (Hassuna, Samarra, Tell Halaf, Al'Ubaid, Uruk and Jemdet Nasr), and can be considered as a kind of 'Indian summer', perhaps even post-dating its termination in lands further to the south. When one reads Lloyd's account of the sites preceding, contemporaneous with, and subsequent to the Hittite period, one obtains little idea of the environmental background of events and ways of life from 'early' and 'late' Neolithic (Mersin) and Chalcolithic onwards, that is, before the second millennium B.C. when the Hittites were at their peak. These people were mainly devoted to agriculture and cattle raising under a strict military and political administration [78]. The principal food crops were barley and emmer wheat, produced for flour, breadmaking and the brewing of beer. Cereals, wine and oil were staple products; the olive flourished in the Mediterranean environment in Melitene and on the Pontic coast, but naturally not in the continental climate of the plateau; almond oil may also have been used [154]. Peas and bean are mentioned occasionally and flax may have been grown locally as it is today.

There is also mention of ox, horse, mule, ass and pig.

We have lists of fields and elaborate title-deeds containing inventories of estates which were apparently of considerable size. Legal tablets found at Boghazköy refer to detailed legislation concerning land tenure, offences in connexion with vineyards and orchards, and relating to canals. There were penalties for setting brushwood on fire. There must have been a considerable drain on the natural vegetation to provide fuel for the iron-smelting in which these people were pre-eminent [157]. The smelting was probably done in winter when the peasants were not occupied in the fields.

Thus the over-all pattern of land use was laid down at a very early date, and the wars, invasions and rise and fall of dynasties and civilizations which followed merely caused relatively slight changes in that pattern, (although Jacobsen and Adams [100] suggest a cumulative change in the character of the irrigation régime between early and mediaeval times), generally in the direction of deterioration of the land resources in their widest sense, and in the increased impoverishment of the peasantry over whom the successive waves passed and from whom was demanded the taxes and the share of their crop. A profitable aspect for further study and review would be the complex systems of land tenure and ownership which, coupled with land taxation, governed the extent to which the cultivators could afford to practise good farming or were inclined to accept responsibility for the conservation of natural vegetation or the maintenance of fertility of cultivated land [44]. This introduces complex legal questions, from the Laws of Moses and the Code of Hammurabi to the Ottoman Land Code [68] and subsequent developments. Brunhes [32] has described the distinction and relations between the cultivator and the shepherd which are a predominant characteristic of the region and the background for the constant rivalry between the desert and the sown. Lambton [118] has reviewed very thoroughly the history of the relationship between landlord and peasant in Iran. FAO organized a Centre on Land Problems in the Near East in Iraq in October 1955 [69]. Klat [109] has reported on the origins of land ownership in the Syrian Province of the United Arab Republic, the outcome of a long process of evaluation based essentially on the Islamic conception of immovable property; the same author has discussed the social and legal bases of the *musha* (nearest equivalent 'communal') holdings and land fragmentation in Syria and has referred to the writings of Haidar [80], Mounayer [137] Latron [120], Weulresse [202] and Poliak [156].

## FIRE, FUEL AND TIMBER

The burning of natural vegetation, the cutting of trees, secondary growth and scrub for fuel [82], and the felling of timber for building houses, temples and ships have all played a very important role in the history of land use in the region (for a figure indicating the earliest evidence of the use of fire in the major provinces of the Palaeolithic world, see Oakley [141]). Anthropologists and geographers have long recognized the making of fire as a culture trait, ranking with the manufacture of stone implements as 'the cultural achievements recorded in ancient strata of the earth as indicators of the beginning of humanity' [182]. The following mixture of quotations from Stewart and Sauer [168] will indicate the status of knowledge on this aspect at the present time.

> The unrestricted burning of vegetation appears to be a universal culture trait among historic primitive peoples and therefore was probably employed by our remote ancestors. Archaeology indicates that extensive areas of the Old and New Worlds were being burned over ten thousand years ago. It is logical to assume that some of the reasons which motivated historic and Neolithic men would also have motivated our remote ancestors to set vegetation on fire. One may conclude that fire has been used by man to influence his geographic environment during his entire career as a human. Furthermore it is impossible to understand clearly the distribution and history of vegetation of the earth's land surfaces without careful consideration of fire as a universal factor influencing the plant geography of the world.
>
> Through all ages the use of fire has perhaps been the most important skill to which man has applied his mind. Fire gave to man, a diurnal creature, security by night from other predators. Hearth and home are still synonymous. About the fireside the last duties of the day are done, the events of the day reviewed and the morrow planned. The fireside was the beginning of social living, the place of communication and reflection.
>
> Feeding the fire, man learned wood-working, how to point a shaft, hollow out a vessel, and thus later to make a boat. Above all, fire provided ways of experimenting with food. . . . Cooking by dry or moist heat long preceded boiling. Hearths on top of the ground and cooking pits dug into the ground are both very ancient. . . . Fuel always is in major demand. Through the ages, man has moved more ton-miles of fuel than of any other commodity, whatever his cultural level. Where he lived on sea coasts and river banks his stock of driftwood might be replenished perennially. Elsewhere man found in time that his fuel consumption exceeded the natural rate of supply, which was mainly dead stuff fallen to the ground. Also he was, early, a user of bark and bast and thus came to know that a tree with its phloem destroyed died. He acquired therefore the basic knowledge necessary for keeping up his wood supplies and also for clearing ground by deadening trees rather than by felling them. As professional camper, he chose his camp first by water, next by the available fuel. . . . . Everywhere that man travelled, he made campfires and left them to ignite any and all the vegetation in the vicinity. Campfires of a sparse population might not do much igniting in many regions. In flat country which dried out at certain seasons, and where strong winds occurred with the drought, a few abandoned campfires might influence the vegetation of a large area.

In the absence of any over-all review of the actual and possible influences of fire in the land use pattern of the Near East, one can merely make deductions from other data from the region, or study the use of fire by modern native cultures as an indication of what might have been common practice in our own time range. In doing so, we must realize that although it would obviously be unlikely that the present sparse degraded types of vegetation would provide conditions for the rapid movement of natural fires, this was probably not always the case. 'Hunting and gathering folk hundreds of thousands of years ago may be presumed to have developed many of the techniques for exploiting the natural environments which people at the hunting level of culture still employ.' [182]. Thick forests and dense jungles of brush were of little use to the hunter and food collector and he would have burnt them to create a better and safer environment of widely spaced trees and grassland plains. He would also have used fire to rouse or drive game. When man became a grazier, he would have burnt grasslands and forests, particularly Mediterranean maquis, to produce new green growth and to keep the scrub from becoming dominant. Broadcast burning may have been adopted to increase the yield of seeds of wild grasses and herbs collected for food. 'I am aware that some scholars appear reluctant to grant that the hunters and collectors had any influence on the geographic environment. . . . Notwithstanding the increase of open lands in Europe, brought about by cultivation, fire as a tool without agriculture should not be minimized.' (Stewart [182].)

Whatever may have been the impression made upon the Near East as an outcome of the land use of these primitive pre-agricultural peoples, there would appear to be little doubt that the landscape was greatly affected by the activities of subsequent cultures. Where slash-and-burn was adopted as the basis for shifting cultivation and when graziers burnt vast areas of plains or whole mountainsides, the extent and frequency of destruction of the natural vegetative cover and its deterioration to lower ecological levels must have been major factors in the developing use of the land. The situation in the central and eastern Mediterranean region as described by Semple [170] was a common characteristic for periods much earlier than the Roman with which she was concerned.

We must also consider the long-term destructive effects of the scorched-earth method of defence used in war, for example, in the retreat of the Scythians before the army of Darius (Herodotus [92]) or the retreat of the Berber Queen across North Africa in the face of the Bedouin invaders from Arabia. Much more recently, sections of armed forces were surrounded and burnt out in the Turkish-Greek wars in the Anatolian Plateau.

But much more continuous and of much longer duration has been the constantly increasing demand for fuel for centres of population to which reference has already been made, a demand for ever greater production of a wider variety of products requiring progressively higher temperatures—domestic fuel, charcoal, poor and high-quality pottery, metals and bricks. It is only necessary to remember that Erech covered 1,100 acres, that a reliable archaeological assessment of the size of ancient Babylon puts it at 2,470 acres and that Woolley claims for Ur an area of 1,450 acres and a population of a quarter of a million people (calculated on the basis of 150 persons per acre in Aleppo and Damascus). Hans Bobek and Robert M. Adams do not accept Woolley's estimate, but nevertheless early centres of civilization of anything approaching this size must have demanded many donkey and camel loads daily of wood and brushwood from the neighbourhood to supplement straw as fuel and maintain the population and their industries.

The admirable pottery described by Childe [41] was fired in proper kilns, fragmentary remains of which have been found at Arpachiya and Carchemish, and in which a firing temperature as high as 650° C. was sometimes attained. The use of still higher temperatures for the smelting of copper was already a characteristic of the second millennium B.C. To smelt copper from the ore a relatively low temperature, 700°-800° C., is needed in the reducing atmosphere of a closed kiln such as that used for primitive pottery-making. The transition from a closed kiln to a smelting furnace involves no great mental labour, and it is therefore not surprising that evidence of the earliest copper smelting should be found among the makers of painted pottery. But the melting of copper when in metallic form so that it can be cast requires a much higher temperature, 1,085° C., which could be reached only in a more advanced type of kiln than would produce the heat necessary for smelting of the ore. For a considerable time, copper must have been worked by hammering and cutting only, whether from the natural metal or from metal smelted from ore, and the further development of furnace types seems to have taken place in Mesopotamia. Piggott [153] believes that, by the time the earliest agricultural communities were being founded in the Indus Valley, it is unlikely that the lack of copper tools in them means anything more than poverty, and that their 'stone age' was forced on them by sheer lack of purchasing power (see also [6, 29]).

In 1937, Nelson Glueck led an expedition of the American Schools of Oriental Research through the Negev to Wadi Araba, found copper ores in the soil, and at Tell-el-Kheleifeh, near Akaba, smelting kilns of a highly developed kind which used the prevailing winds down the Wadi Araba to produce the necessary draught. This centre, probably the largest in the Near East, dates from 1000 B.C. in the time of Solomon. What fuel could have been used in this region, now almost devoid of any cover? In his more recent book, *Rivers in the Desert*, Glueck [76] states that today Israeli miners are exploiting copper lodes that Solomon's men passed over as too lean for their primitive smelting methods—could it have been rather that they had exhausted their meagre local fuel supplies? Near Gaza, Flinders Petrie found what were first thought to be iron smelters with kilns of the same type, only smaller [104], but these are now taken to have been for the melting of pig iron and not for the smelting of iron ore; they are blacksmiths' furnaces [215]. Before the time of David, only the Philistines produced iron, having brought the secret with them from their successful invasion of the Hittite Empire, which until then had had a monopoly.

In addition to this continuous drain on the land for purposes of fuel collection, we have the felling of trees in the former extensive forests of the region for the construction of buildings, and ships of various types and sizes for warfare or commerce by sea and river. The Phoenicians must have used a great deal of their forest resources to build their navies and mercantile marine, and for export to Egypt. In exchange for the cedar and pine to build his temple, Solomon granted Hiram, King of Tyre, the right to use Elath in the Gulf of Akaba, thus providing him with an outlet to the Red Sea. As there were only palm trees in the area, Hiram had to send the timber from Tyre, enough to build ten ships, carried on the backs of 8,000 camels. There are also reports that the commercial products from the upper reaches of the Tigris and Euphrates were transported on rafts made of newly cut timber, which was used for building purposes at the port of arrival. The boats made on the lower reaches were constructed of willow and skins because of the scarcity of other timbers. The ruins of cities and temples do not generally provide enough evidence of the extent of the use of timber for roof-trees and other purposes. These timbers would either be burnt in the general destruction of an early site by invaders, or would be carried off by nomads to provide fuel.

So, for these reasons combined with the clearance of land for cultivation, the forest resources of our region were dissipated unwisely, and on a vast scale. The bald mountains and foothills of the Mediterranean littoral, the Anatolian Plateau and Iran stand as stark witnesses of millennia of uncontrolled utilization, and there is still little sign that the lessons of history have been read and understood or that the opposite trend in land use has yet arisen.

## DOMESTICATION OF CROPS

It may be said that the co-operation between archaeology and agricultural botany began in the second half of the nineteenth century, with Alphonse de Candolle [38] who, according to Hans Helbaek, based his reasoning on Oswald Heer's account of the discovery of pile dwellings in his *Pflanzen der Pfahlbauten* [84]. De Candolle considered that it should be possible to arrive at a theoretical definition of a wild type of a cultivated plant by deducting all the characters for which the crop plant is cultivated; it would then be possible to search for the actual wild progenitor which most closely corresponded to this abstract definition.

Another classic of the same period is Charles Darwin's *The Variation of Animals and Plants under Domestication* [48] in which he stated:

> From a remote period, in all parts of the world, man has subjected many animals and plants to domestication or culture. Man has no power of altering the absolute conditions of life; he cannot change the climate of any country; he adds no new element to the soil; but he can remove an animal or plant from one climate or soil to another, and give it food on which it did not subsist in its natural state. It is an error to speak of man 'tampering with nature' and causing variability. . . . If organic beings had not possessed an inherent tendency to vary, man could have done nothing. He unintentionally exposes his animals and plants to various conditions of life, and variability supervenes, which he cannot even prevent or check. Consider the simple case of a plant which has been cultivated during a long time in its native country, and which consequently has not been subjected to any change of climate. It has been protected to a certain extent from the competing roots of plants of other kinds; it has generally been grown in manured soil; but probably not richer than that of many an alluvial flat; and lastly, it has been exposed to changes in its conditions, being grown sometimes in one district and sometimes in another, in different soils. Under such circumstances, scarcely a plant can be named, though cultivated in the rudest manner, which has not given birth to several varieties. It can hardly be maintained that during the many changes which this earth has undergone, and during the natural migrations of plants from one land or island to another, tenanted by different species, that such plants will not often have been subjected to changes in their conditions analogous to those which almost inevitably cause cultivated plants to vary. No doubt man selects varying individuals, sows their seeds, and again selects their varying offspring. But the initial variation on which man works, and without which he can do nothing, is caused by slight changes in the conditions of life, which must often have occurred under nature. Man, therefore, may be said to have been trying an experiment which nature during the long lapse of time has incessantly tried. Hence it follows that the principles of domestication are important for us. The main result is that organic beings thus treated have varied largely, and the variations have been inherited. This has apparently been one chief cause of the belief long held by some few naturalists that species in a state of nature undergo change. . . . With extremely few exceptions, all animals and plants which have been long domesticated have varied greatly. It matters not under what climate, or for what purpose they are kept, whether as food for man or beast, for draught or hunting for clothing or mere pleasure—under all these circumstances races have been produced which differ more from one another than do the forms which in a state of nature are ranked as different

species. Why certain animals and plants have varied more under domestication than others we do not know, any more than why some are rendered more sterile than others under changed conditions of life.

Today many sciences contribute to our growing knowledge of the history of cultivated plants [87]. Linguists interpreting the earliest written documents were able to point out when and where certain plants were grown from the dawn of literacy, and also to find evidence of cultural relations on the basis of related plant names in different languages. Plant geographical maps show the range of distribution of the possible wild progenitors, thus delimiting the areas in which alone cultivation could have begun. Geology and climatology may modify this picture by disclosing ecological changes in the relevant areas in the course of time. Above all, genetics, by observing morphological changes caused by mutation and hybridization, can be used to outline the possibilities of evolution in the species, at the same time narrowing the field of possible ancestors. All these sciences, however, suffer from one common disadvantage. They cannot lay hands upon the actual plants of antiquity. This is where archaeology comes in. Archaeology can recover the plants themselves and put at least a relative date to them. The botanical archaeologist can define morphologically the features and depict them exactly as they looked millennia ago.

When did the domestication of crops take place? Sauer [167] states that, although conventional agricultural origins are placed at the beginning of Neolithic time, it is obvious that the earliest archaeological record of the Neolithic presents a picture of an accomplished domestication of plants and animals, of peasant and pastoral life resembling basic conditions that may

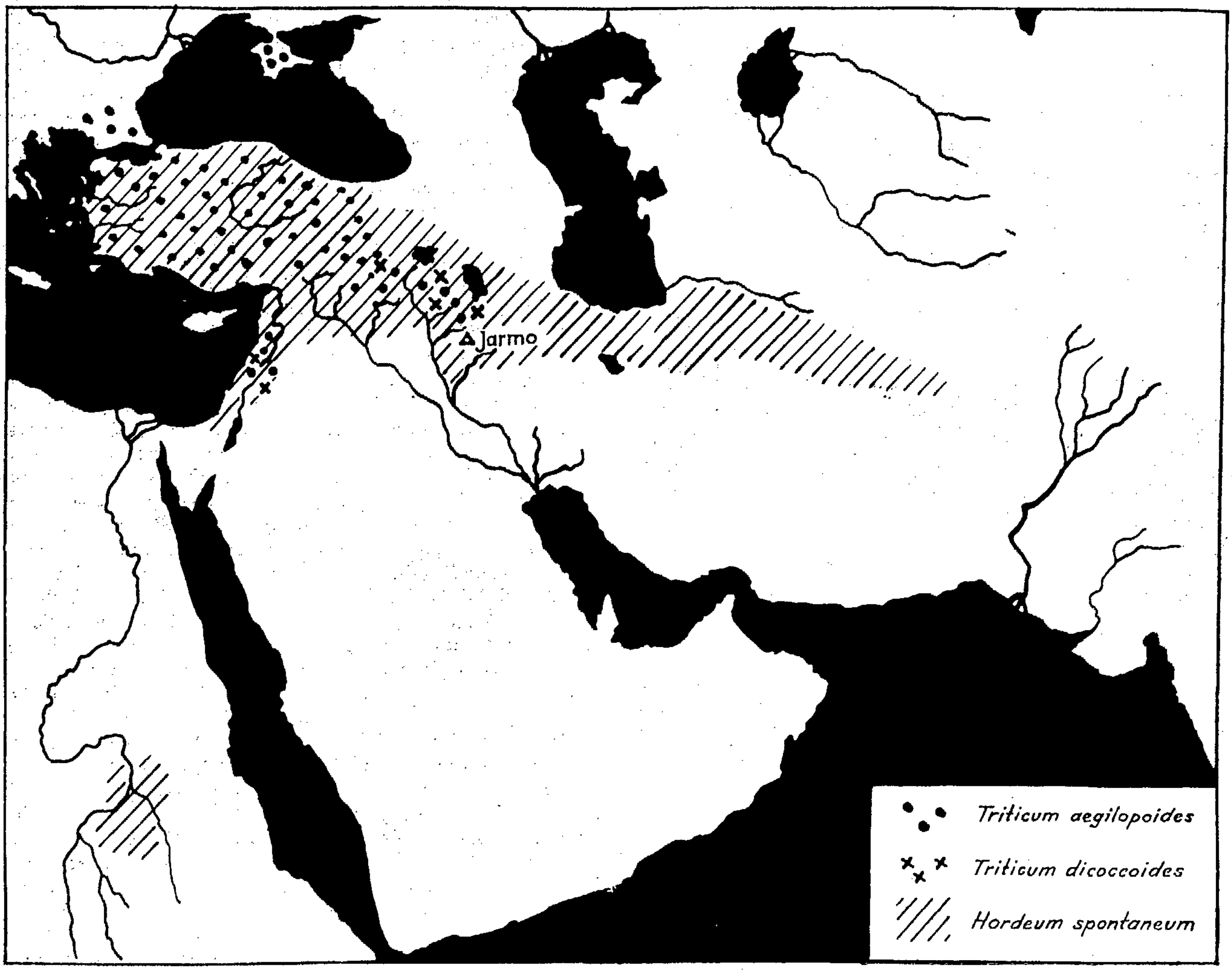



FIG. 4. Domestication of food plants in the Old World. (From Helbaek [89].)

still be found in some parts of the Near East. Helbaek [89] states the interrelations of archaeology, palaeobotany and ecology in concluding that the centre for the domestication of a wild plant must necessarily be its area of natural distribution, and thus that a human culture type dependent upon wild wheat or wild barley as its main food grain must have developed within the boundaries of natural distribution of that species at that time. Since all the primary agrarian cultures in this region which had the chief bread grains grew both wheat and barley together, it becomes possible to relate the centre of emergence of the wheat/barley cultures to the common area of distribution of the two species in natural ecological communities (see also Schiemann [173, 174]). Helbaek's map shows that the wild domesticable barley, *Hordeum spontaneum*, is distributed from Turkestan to Morocco, but that the large-grained wild wheat which he calls *Triticum dicoccoides* grows exclusively in a small area within the wide range of the barley distribution (Fig. 4).

On this basis, it is concluded that the cradle of plant husbandry in the Old World lies within the general area of the arc constituted by the western foothills of the Zagros Mountains (Iraq-Iran), the Taurus Mountains in south Turkey and the uplands of Galilee in northern Palestine. It would be interesting to make an ecological study of these three areas (which probably all exhibit similiraty in their Mediterranean type of climate, or an intermediate stage between Mediterranean and Irano-Turanian), try to form a picture of the original climax vegetation with its various communities and floristic composition, and so discover what other prototypes of food crops may have occurred there. In these studies, however, one must bear the desiccation arguments in mind, since these associations may perhaps have retreated from lower to their present higher elevations, because of the operation of this factor. It is a well-known fact that wild grasses are characterized by marked seed shattering, their almost exaggerated dropping as soon as they mature, which is an essential feature in their natural dispersal, as distinct from the retentive characters of cultivated varieties. In wild wheat and barley there is a recessive tendency to develop toughness of the spike axis. Early man would collect a steadily increasing proportion of tough-axis spikes, would perhaps half-intentionally select types with the tough-axis gene until no shattering types remained in his field.

In the domestication of many of our modern crop plants of temperate climates [117] it would appear that the first objective was the production of carbohydrate and protein, whereas fat was obtained from wild plants such as the fruits of the oaks and pistachio collected in the mountains around Jarmo and similar centres. Zeuner [220] believes that green vegetables are likely to have been cultivated early; although there is little archaeological evidence for these perishable commodities, records are mainly based on seeds which would not normally have reached dwelling places (see however Deimel [50]). Primitive horticulture would not quickly produce characters distinguishing cultivated fruit from the wild, so that the first phase of fruit cultivation remains uncertain. Helbaek [90] states that several wild species of *Linum* represented the starting point for cultivation for oil and remained so for millennia.

The early developments in crop husbandry involved tilling the soil, concentration of the desired crop by sowing seeds, exclusion or removal of unwanted plants from the tilled plot, and protection of the crop plants against attacks by animals and birds. Helbaek postulates that it must at an early stage have proved practical to move the wheat down from its exposed natural habitat on the mountain slopes at elevations of from 2,000 to 4,500 ft. to lower and more level ground. Proximity to open grasslands, domestic water supplies and the other needs for human habitation was necessary, provided these were combined with adequate winter and spring rainfall for the cereal crops. One result of this forced movement of these primitive cereals beyond their natural habitat by human transplantation may presumably have been the emergence of mutations and hybrids; the natural selection which then began favoured individuals that had little chance of survival in the original natural habitat. Thus the biological and morphological course was set which resulted in the domesticated type of the wild *Triticum dicoccoides*, named *Triticum dicoccum* (Emmer). From this species have been derived all other species of cultivated wheat except Einkorn *(T. monococcum)* which is the progeny of the small-grained wild wheat, *T. aegilopoides*. Both Emmer and Einkorn were no longer able to survive without the care of man, and on the other hand man had become dependent on his plants for a steady and ample supply of plant food derived from his fields.

Our region of study and its adjacent lands contain three of the more important centres of origin of cultivated plants (Vavilov [196]), namely : (a) the Central Asiatic centre, including north-west India and Pakistan (Punjab, North West Frontier Province, Kashmir), Afghanistan, the Soviet Republics of Tadjikistan and Uzbekistan, and western Tian-Shan; (b) the Near Eastern centre, comprising the interior of Asia Minor, the whole of Transcaucasia, Iran and the highlands of Turkmenistan, and (c) the Mediterranean centre, comprising, as far as we are concerned, the countries of the Eastern Mediterranean and including the coastal regions of Asia Minor.

Vavilov indicated whether he regarded these areas as representing the basic centre of origin, one of the centres, or a secondary centre of many important crops of the present day:

| Centre | Crop Groups | No. of genera and species |
|---|---|---|
| Central Asiatic | Cultivated grain crops | 21 |
| | Fibre plants | 1 |
| | Vegetables | 9 |
| | Spice plants | 1 |
| | Cultivated fruits | 10 |
| Near Eastern | Cultivated grain crops | 10 |
| | Forage plants | 8 |
| | Oil plants | 9 |
| | Essential oil, alkaloid and tannin plants | 7 |
| | Vegetables | 11 |
| | Cultivated fruits | 24 |
| Mediterranean | Cereals | 16 |
| | Forage plants | 11 |
| | Oil and fibre plants | 7 |
| | Cultivated fruits | 2 |
| | Vegetables | 30 |
| | Essential oil and spice plants | 15 |

The Central Asiatic centre is one of the most important, since it is the native home of common wheat, with a tremendous potential source of varieties: 'also of *Triticum compactum* and *T. sphaerococcum*, peas, beans *(Vicia)*, lentils, *Lathyrus sativus* and *Cicer arietinum*. Here many oil plants have had their origin and cotton was perhaps first cultivated on a large scale. In spite of the barrier presented by the Himalayas and the Hindu-Kush, it seems necessary to combine a large part of Middle Asia and the north-west corner of Pakistan and India into one centre.'

Vavilov's Near Eastern centre is notable for its wealth of varieties of cultivated wheats, nine species being endemic to the region. In Asia Minor and Soviet Transcaucasia is the centre of origin of rye, an amazing diversity of forms, very different from the single variety found in Europe. The world's potential sources of western orchard fruits are concentrated in the Near East, the native home of the grape, pear, cherry, pomegranate, walnut, quince, almond, apricot and fig. The first orchards were undoubtedly located in the Near East. In Soviet Georgia and Armenia one may still observe all phases of the evolution of fruit growing—from wild groves consisting almost wholly of wild fruit trees through transitional methods to those approaching modern fruit growing, including the grafting of the better wild varieties on the less valuable wild forms. Here also one may see that primitive man, while clearing away forests to make room for grain fields, has left standing the better specimens of wild apple, pear and cherry. It appears that viticultural methods and all the more important grape varieties have been acquired from the Near East, where one can still find wild forms quite suitable for culture in vineyards. In *Medicago*, *Pyrus* and *Amygdalus* and to a considerable degree in the wheats, species formation has been active and is still occurring. Natural polyploidy has been discovered among wheats and numerous species of wild plants, particularly in alpine and subalpine zones. From Turkey, Iran and Soviet Central Asia has come the world's wealth of melons, and the leading forage crops, lucerne, Persian clover, a number of species of *Onobrychis*, *Trigonella* and vetch.

In the cultivated plants of the Mediterranean centre, one can already trace the important role played by man in selecting the best cultivated forms; the Mediterranean forms of flax, barley, beans *(Vicia)* and chickpea are notable for their large seeds and fruits in contrast to the small-seeded forms of Central Asia, their basic place of origin, where most of the dominant genes of these plants are concentrated. The western dispersal of vine, olive, fig, stonefruits, bread wheat, rice, ornamental and shade trees was apparently partly or wholly due to the spread of Greek and Roman civilizations. To this the Arabs added the sugarcane, date palm, cotton, some types of citrus, lucerne and other plants [167]. The grapevine and lucerne also went eastwards into China and are clearly attributed to Chang Chi'ien about 140 B.C. [140].

There is much to be done by the geneticist, taxonomist and palaeoecologist to amplify and perhaps in some cases correct this picture of the situation as described by Vavilov. The geneticist, for example, no longer accepts the hypotheses completely, noting among other things that there may, particularly in cross-fertilizing plants, be just as great an explosion of variability in the country to which new genotypes have been introduced as in their so-called original centres of maximum variability, looking at the question from the point of view of an environmental archaeologist. Helbaek [90] states that Vavilov was not a cultural historian, and did not correlate his theories of emergence of cultivated plants with reliable assumptions from cultural history. Thus he proposed the emergence of wheat, barley and *Linum* in areas other than those in which the earliest archaeological evidence of crop husbandry has been found. His hypotheses presupposed that India, Afghanistan and Ethiopia were under cultivation before Mesopotamia and Egypt. He did not accept the primary qualification that a cultivated variety must have arisen within the area of distribution of its wild progenitor. Helbaek wonders if Vavilov confused a comparatively recent but isolated community with an old stagnated culture, and queries whether he allotted to the time factor the role which belongs rightly to the ecological circumstances. If a plant is taken beyond the limit of its original natural habitat and maintained by cultivation, the process of adjustment (what Braidwood has called permissive mutations and/or introgressive hybridizations which allowed expansion of peoples with their plants and animals outside the zone of the natural habitat) may result in new gene combinations and the formation of a multitude of morphological types deviating from the original.

In revising Vavilov's theory that the variability of a crop plant is greatest near its centre of origin, it must also be remembered that the distribution of variability is dependent upon the nature of the breeding system [96]. In outbreeding crops, even when only 15-20 per cent natural crossing occurs, new centres of variability are developed in the many regions in which the crops have been established. Even in pre-eminently self-fertilized crops such as wheat, there is enough crossing in northern India, one of Vavilov's centres for this plant, to give a degree of heterozygosity in excess of what would be expected in long inbred material (see also Frankel [72]). Hutchinson believes that 'self-fertilization is a recent and unfortunate accident' in a crop's history. Stebbins [180] also refers to self-fertilization as a derived condition from cross-fertilizing ancestors, an outcome of pioneering in new and difficult environments. One reason why some species have given up cross-fertilization 'with its attendant advantages of population variability and genetic heterozygosity' may be that self-fertilization is a means of fertility insurance in plants which are subject to periodic drought.

Since Helbaek [90] has been primarily concerned with the archaeological botany of the material collected by the Oriental Institute of the University of Chicago at Jarmo, the early prehistoric site in the uplands of Iraq-Kurdistan, he is particularly well qualified to comment on the data which have been obtained from this site. The outstanding fact is that wild cereals here made their earliest appearance in any known cultural context, and the present estimate of the actual date of Jarmo is the beginning of the seventh millennium B.C. The material recovered consists of imprints of grains and spikelets in baked clay and adobe as well as carbonized grains and seeds and spikelets. In the carbonized material evidence is available of two types of wild wheat kernels; the straight, flat-bottomed type similar to *T. dicoccoides* and a smaller type with a convexly curved ventral and dorsal side corresponding to *T. aegilopoides*. In the imprints have been found very good examples of spikelets closely resembling those of *T. dicoccoides*, larger and rather coarse; on the other hand the same advanced domesticated type similar to Emmer *(T. dicoccum)* is represented by many specimens, while many kernels of the typical shape of Emmer are encountered among the carbonized grain. Thus there have been found at Jarmo two wild species which normally still grow together in the Kurdish localities alongside the offspring of the larger-grained species already characteristically transformed into Emmer (see Oppenheimer [144] for discovery of wild Emmer by A. Aaronsohn 50 years ago, and also Kuckuck and Schiemann [116]). As in practically all Near Eastern grain deposits except those from Egypt, kernels and fragments of the sturdy glumes of *Aegilops* were present.

In the sixth millennium B.C. (Hassuna period), in the village site of Matarrah, still in the Kurdish uplands but at a lower elevation than Jarmo, is to be found only the cultivated Emmer; it has not been established whether Einkorn was already grown there. The Halafian communities of the upper Euphrates-Tigris region appeared to have grown mainly Emmer with a sprinkling of Einkorn. During this period, the fifth millennium B.C., colonization of the alluvial plain of lower Iraq was undertaken and Emmer adjusted itself excellently to the artificial ecology of the irrigated land while Einkorn did not. From the nuclear mountainous arc, agriculture spread to the Mediterranean littoral and presumably all over Asia Minor. Boat traffic along the coast must certainly have accounted for many migration routes to Egypt and Europe, so that by the end of the fifth millennium Einkorn and Emmer were cultivated in the large loess plains stretching intermittently almost from the delta of the Danube to the mouth of the Rhine. The two original cultivated wheat species adjusted themselves more or less successfully to the increasingly harder climates as farming cultures moved northwards. 'Einkorn reached its peak of flourish in Asia Minor, while in Britain it seems never to have got above the status of the poor relative.'

In the other direction, the movement that brought the alluvial plain of Mesopotamia under cultivation probably branched out and settled in the high plateaux of Iran; agricultural centres were shaped in the third millennium B.C. in the Indus Valley (by 2300 B.C. grain was being grown here on a very large scale, as is shown by the granaries at Harappa) and there is evidence of agriculture in the region south of the Aral Sea before the middle of the second millennium.

Whereas Einkorn and its progenitor are diploid ($2 \times 7$ chromosomes), Emmer and its progenitor are tetraploid ($4 \times 7$ chromosomes). Club wheat *(Triticum compactum* s.l.*)* belongs to the Bread wheat *(vulgare)* group which is hexaploid ($6 \times 7$ chromosomes). Geneticists have established experimentally that the crossing of Emmer and *Aegilops* may produce hexaploid wheat with several features in common with the *vulgare* group. This presupposes the emergence of the *vulgare* group of the Near East but it appears that Club wheat has not been found in early archaeological contexts while later it appears only in minor proportions compared with Emmer. The evidence with regard to Club wheat relates to Egypt but the earliest appearance in Iraq is reported by an imprint at Jemdet Nasr of about 3000 B.C. and a few imprints of the middle of the third millennium in the Nabur area in the north. The earliest actual cultivation of

Club wheat in Iraq is documented by a find from eastern Upper Iraq covering a few centuries around 2000 B.C. During the second millennium are found traces of a cultivation of Club wheat in Asia Minor, Syria and Palestine. Whenever Club wheat appears, Emmer is also present. Only at about 1000 B.C. and later does Club wheat cultivation supersede that of Emmer.

Club wheat may have emerged as a hybrid in the Near East, but ecological circumstances may not have favoured its development, and it might have disappeared and reappeared as a kind of freak during early phases of agriculture. When it reached more suitable regions it may have produced a rather hardy type which flourished in mountainous environments in the Einkorn-Emmer fields. This may have happened very much later somewhere in Asia Minor, a region which is a *terra incognita* as far as palaeo-ethnobotany is concerned (although Seton Lloyd and his colleagues working at Beycesultan have collected and passed to Helbaek much carbonized and other seed material which has not yet been identified).

Scanning the Near Eastern wheat field of today we note that Emmer is no more to be found; that Club wheat is absent and Bread wheat rare or of no importance. The field is populated by wheats structurally parallel to the *vulgare* group, but cytologically allied to Emmer, having $4 \times 7$ chromosomes. We can only guess at the phylogenetic origin of the very diversiform group of these tetraploid naked wheats which comprise Hard wheat (*T. durum*), Rivet wheat (*T. turgidum*), Polish wheat (*T. polonicum*) and several characteristic subspecies.

They may have arisen by mutation or hybridization between extreme varieties of Emmer or even by interspecific crossings. Hard wheat is the most important. As opposed to the free-threshing species of the *vulgare* group, it flourished under a modest rainfall or irrigation and a completely dry ripening season. It is the wheat of the summer dry steppe regions throughout the world. This wheat first appeared among the non-carbonized wheat deposits of the Ptolemaean period in Egypt after 300 B.C., and seems to have spread rapidly over the Near East, occupying plains and mountain tracts at the expense of Emmer. The last stronghold of the latter is Ethiopia, where it was probably introduced with agriculture in late Egyptian dynastic times before it went out of use in Egypt itself, and where it is still being grown under the name of Adjaz.

Kuckuck [115] has reported on his studies in Iran on the distribution and variation of cereals, and Kuckuck and Schiemann [116] have described the occurrence of *T. spelta* and intermediates between *T. spelta* and *T. aestivum* on a plateau 2,000-3,000 m. above sea level in the Baktiari region near Isfahan, where the crop has probably been cultivated since antiquity. The Iranian spelt shows little morphological variability and conforms in its general characters to the European spelt. A remarkable character is the frequency of three-grain ears.

All the known ancient agrarian peoples of our region also grew barley. Barley makes up the bulk of the plant remains from Jarmo. The kernels are hulled, straight and unwrinkled and some specimens consist of the median fertile floret with one of the lateral male florets attached. The lateral florets are not sessile as in modern, 2-row barley, but have a short pedicel. This Jarmo barley conforms fairly closely with the wild 2-row *Hordeum spontaneum* which is naturally distributed throughout its arc-shaped region of origin and far beyond. The spike was not brittle as in the wild form, an incontrovertible indication of domestication. In its native habitat the wild barley grows practically everywhere. During man's first attempts at tilling the soil, barley must have been domesticated along with the first wheat by sharing in the automatic selection for tough-axis species. Barley might therefore be termed a secondary cultivated plant. It would eventually have lost most of its prickly and very coarse character. For a long time this species was grown only in Kurdistan. It abounds in the Matarrah material and as late as Hellenistic times is the principal barley of this hilly region.

When agriculture extended to the river basins of Mesopotamia and Egypt in the fifth millennium B.C. 2-row barley disappeared and was replaced by the 6-row species. Not until the ninth century A.D. does the 2-row form make its reappearance in archaeological material from the Mesopotamian plain. Helbaek [91a] has now obtained evidence to explain the origin of the 6-row barley, and confirmed his basic assumption that *Hordeum spontaneum* must be able to mutate into the 6-row condition. It is also assumed that the first mutant in Jarmo did not mutate in row number (or rather did not stabilize a 6-row mutant, the environment being the same) but in rachis condition. Seeds collected in Kurdistan were treated with X-ray, and one of these grains gave a lax 6-row spike with all lemmas awned, all lateral spikelets pedicellate as in *H. spontaneum*, and most lateral florets fertile. The second generation retains this fundamental pattern, but three plants have lost the pedicels on the lateral florets (see also [233]).

The domestication of the weed grasses of these early cereal crops took place later and far from their own centres of natural distribution. Thus rye and oats were introduced into Europe as weeds in the wheat field—rye probably from western Central Asia and oats from the Near East or eastern Europe. Kranz [113] has published an account of studies of population genetics of primitive Iranian ryes with reference to the systematics, evolution and breeding of the crop. Oats attained the status of a crop plant during the first millennium B.C. and rye was brought into secondary domestication in Central Europe shortly before the birth of Christ. Broomcorn millet appears for the first time about 3000 B.C. in Jemdet Nasr in lower Iraq; while not important in the Near East, it was widely cultivated in the Far East and in Europe about 2000 B.C. The progenitor of broomcorn millet is not known, whereas Italian millet is considered to be a straight-line descendant of the wild green millet, *Setaria viridis.* Millet is called Juar-i-Hindi in Persia, suggesting that it came from India. Strabo reports rice cultivation in Babylonia, Bactria, Syria and the valleys of the Euphrates and Tigris about A.D. 1. It is mentioned in the Talmud, but not in the Old Testament.

In Jarmo, Helbaek found evidence of the use of field peas, lentils and blue vetchling as food, although it is not possible to claim their actual cultivation at that time. The horsebean appears around the Mediterranean during the third and second millennium B.C. and later spread to Europe, arriving in Britain in the late first millennium B.C. Chickpea, which is now grown extensively in India and may have had its centre of origin in the Deccan or the Indus plain, occurs in Palestinian finds of the fourth millennium or possibly earlier. Vegetable oil has long been valued highly as human food; at Jarmo it appears that this commodity was obtained by crushing the nuts of wild trees such as acorns and pistachios, and in other regions hazlenuts, acorns and olives.

The wild species of flax was domesticated very early although it is not yet certain which species was the progenitor or were the progenitors of cultivated flax. Helbaek [90] has reviewed the evolution and history of *Linum* without necessarily making the distinction between the oil and fibre varieties. The main problem to be faced concerns the large-seeded *Linum* of Dynastic Egypt, which was a summer-annual type, and the small-seeded, winter-annual 'piled-dwelling' *Linum* of Neolithic Switzerland. If it were possible to find a mean between these two extremes, a form intermediate in respect of seed size and life duration, and at the same time to evolve a reasonable histo-geographical explanation of the phylogenetic relation of this form to some wild member of the genus *Linum*, a solution would be possible. The recently discovered material from Arpachiyah and Brak may constitute this mean, and the two hitherto incompatible *Linum* types in question may be regarded as two ecologically adjusted products of radiation from a common nucleus, climatically placed in the middle, and, as it happens, in the distributional area of the most probable progenitor, *Linum bienne* Mill. This is the only wild species of the genus which can be crossed successfully with *L. usitatissumum* to give fully fertile hybrids. There is no reason to expect that the early Near Eastern imprints will remain the earliest evidence, as L. *bienne* was certainly domesticated long before the emergence of the Halafian culture.

The wine grape, naturally distributed in mountainous forests (Amanus and Lebanon) in certain parts of the Near East, was cultivated in the fourth millennium or earlier. Traces of this plant are dispersed and rare and the story is not yet complete. Olives and dates are also found in Palestinian and Egyptian finds of the fourth millennium B.C. but both species were probably exploited at an earlier date.

The deposits of carbonized plants recovered from Lachish, Tell-el-Duweir, in Palestine [88] have by their nature thrown unexpectedly comprehensive light on plant husbandry and food-gathering of the peasants of the early Bronze Age and Iron Age. In the many-sided agriculture of those days, two products are especially important; cereals and olives. The universality and abundance of occurrence of the remains of olives as compared with the other foodstuffs suggests production for more than home consumption. At both times wheat was an important food; while early Bronze Age specimens were supplemented by smaller amounts of barley, wheat was the only cereal in the Iron Age, although barley is an important Iron Age crop in other parts of the Near East and elsewhere. In the course of the second millennium the species of wheat changed, in that Emmer, the main bread corn of the Bronze Age, was replaced almost completely by Club or Bread wheat. Since grape pips are present in all the mixed samples of both periods, it appears that the vine was commonly grown and that grapes were consumed with the daily meal. Several species of the pea family are represented. There seems to be no reason to suggest that the hawthorn and the pistachio were cultivated in the Bronze Age. The occurrence of their dried stones among seeds of cultivated plants must mean that they were gathered on the hillside. It was the fruit flesh of the hawthorn that was consumed whereas it was the fat and palatable seed of the pistachio nut which attracted the ancient peasants. It would appear that Palestine is also the original home of the important clover of the present day in Egypt and the Near East, *Trifolium alexandrinum.* Of the group of species most closely related to *T. alexandrinum*, *T. berytheum* must be regarded as the main genetical source (possibly with contributions from the wild races of *T. alexandrinum* which appear to exist in the upper Jordan Valley) from which man developed the present-day berseem by selection [144*a*].

This information on the plant remains of well-dated prehistoric and early historic sites, whether in the form of mummified or carbonized material or as impressions in baked clay, is of the greatest interest to both the cultural and natural historian. Helbaek [90] states :

The cultural historian seeks to know the economic background for the achievements and migrations he is able to visualize through his investigations and in its ultimate definition economy means food. The botanist is anxious to know whence the cultivated plants came, how long it took them to develop their present form and the physiological qualities by which they differ from the wild species. He seeks to know how this happened, and, not least, from which wild plants or combinations of plants his domesticated forms descended. By keeping a record of stratification, modern archaeology has means by which to tell the date of plant material and by specialization botanists will in the long run learn to identify the battered remains of plants. Thus, by joining hands, the two sciences establish a third, palaeo-ethnobotany, which endeavours to help delineate man's victories and defeats in his battle against nature for survival and multiplication, and to unravel the complicated history of the plants upon which even modern civilization is ultimately dependent.

## THE NATURAL FAUNA AND DOMESTICATION OF ANIMALS

If we were to follow the ecological approach adopted in the botanical section of this review, we should attempt to discover the nature and geographical distribution of the original fauna of our region, and its relation to the major plant geographical zones and lesser vegetation communities, the two together comprising a kind of equilibrium that American ecologists would call the semi-arid biome. Little evidence of this nature has been found, and it is very doubtful whether it can be expected to become so readily available as botanical evidence. The piles of bones in caves or in other sites, the existence of game traps [161] and the general archaeological history of the early peoples indicate the wide extent of hunting of a fauna which is now largely extinct. Again, we have to decide whether to believe that these wild types of animals were eradicated as long ago as the hunting era, or whether the advance of desiccation and/or the deterioration of their plant habitat and the resultant loss of food and cover were the chief causes.

Apparently a rich desert fauna existed in eastern Jordan, especially of gazelles, at the time of the building of Qasr-el-Hamra and Qasr-el-Kharana. The rich fauna of Palmyra in Palaeolithic and Neolithic times has been noted by several writers including C. S. Coon. The stag was an important and sacred animal of the Hittites, a fact which may indicate greater extent of forests at that time [78]. The desert fauna of Palestine in Babylonian and Persian times is described by Albright [3]. The fauna of ancient Mesopotamia as represented in art has been described by Hilzheimer, [94] and van Buren [195].

There is an extensive literature on the domestication of animals, of which we may mention Hahn [79], Hehn [85], Hilzheimer [94], Duerst [58] and Hančar [81] on the horse in prehistoric and early historical times. The theories of domestication of animals have been reviewed by Zeuner [219], who has deduced an order in which he considers that they are likely to have appeared. The scavengers were domesticated first, and this would have been possible even at a Palaeolithic level. The second group, the nomadic animals (presumably animals adapted to man's nomadic way of life and not themselves nomadic in habit in their original undomesticated state), would not have been suited to a Neolithic economy with agriculture, and may have been domesticated earlier than the true Neolithic, and at the latest in the late Mesolithic. As these animals enabled man to obtain food by slaughtering in addition to hunting, human habitations could become more permanent; thus the domestication of goat and sheep would have preceded agriculture (contrary to other views expressed later in this chapter), occurring as early as 6000 B.C., according to radiocarbon dating, or perhaps even earlier for the goat. A greater number of immature as compared with mature specimens is regarded as important evidence of domestication. Zeuner's third group includes those animals for the maintenance of which settled life is essential, at least in the early stages; the chief members of this group are cattle. A fourth category comprises animals which were domesticated primarily as a means of transport, as beasts of burden, for riding or for traction. The origin of this group is obscure, but it appears to be more recent than the third group. Its members are not normally slaughtered for food, perhaps because of religious inhibitions. The use of animals for transport was probably developed mainly with cattle. Zeuner's tentative grouping of some of the early domesticated animals is therefore : (a) dog; (b) reindeer, goat, sheep; (c) pig (?), cattle; (d) horse, ass onager.

The early history of domestication is also described by Heichelheim [86], who states that the taming of animals is in the main a masculine achievement, derived from hunting. The earliest tamed dogs are dated 8160 B.C. ±1,400, using the radiocarbon method, in north and central Europe and in Asia at the end of the Palaeolithic. Heichelheim believes, basing his theory on early remains of sledges, that the dog was the first draught animal. The Tarpan horse (the ancestor of ponies and small horses) was first tamed in Eurasia between Scandinavia and Turkestan. The ancestor of the so-called Arab horse of Mongolian descent appeared in Turkestan and Iran during the sixth to fifth millennium B.C. During the fifth millennium B.C. the donkey was domesticated in Nubia and Egypt, giving rise to the breeding of mules. The elephant was first tamed in the Indus Valley civilization, and at a slightly later date in Africa. The earliest finds of domesticated cattle come from Mesolithic northern Europe and from Egypt, and later from the Mediterranean, the Near East and northern India. Sheep, descended from a Trans-Caspian wild race, were domesticated at an early date in Europe, and interbred with the Mediterranean wild mufflon and an African species after 5000 B.C., though independent domestication in the Mediterranean or Caucasus region and in Egypt or the Sahara is not discounted. The breed was improved and differentiated in the Bronze Age of the Near East and Europe and also in India and China. The Markhur goat, the first to be domesticated, appears to have spread from the Altai, and, like the domestication of sheep, took place, according to radiocarbon dating, in 6135 B.C. ±1,400. Both were common in Neolithic Europe.

The pig was domesticated in Europe at the beginning of the Neolithic, independently in Sweden and Italy from two different species of wild pig. Heichelheim states that cats, ducks and geese were domesticated relatively late in Egypt. Remains of domesticated fowl are first encountered in the Indus, possibly contemporary with peacock in Indochina, Malaya or Indonesia, between the third and second millennium B.C., and were known everywhere during the Iron Age. The town civilizations of the Bronze Age were mainly responsible for the breeding of carp and other fish, hawks, falcons and pheasants. Heichelheim believes the conscious care of bees may be even older than the domestication of the dog. Silkworm culture began in China around the third millennium B.C.

Hahn [79] considers domestication of animals to have arisen as a result of religious rites. Animals had to be sacrificed on certain dates; since hunting was fraught with risks and hunters frequently returned empty-handed, animals intended for sacrifice might be caught previously and grazed near the camp till they were required. The earliest sacrificial animal was the bear, remains of which date to Palaeolithic times. Processions in which oxen and cattle drew images of the gods on carts later gave rise, so he believes, to the everyday use of the cart with other draught animals. The whole social life of man was revolutionized during the beginning of the Mesolithic and Neolithic by conscious planting of edible grasses and berries, and animal breeding, increasing food sources such as meat, milk, eggs and honey, the range of clothing (wool, silk, fur, leather) and of tools which, in addition to flint, could be made of horn, bone or feathers. These commodities, like number of heads of cattle, created new economic capital.

Menghin [132] produced a classification of Neolithic cultures on the basis of types of livestock and the grazing lands or fodder crops on which they depended for their sustenance, namely, the cultures of the pig breeders, of the breeders of horned animals, and of the breeders of horses, mules and camels (equids and camelids). Menghin believes that these major types of animal husbandry are related to the types of implements used by the three groups of breeders.

The pig breeders' culture is believed by some to have had its origin in India, east Turkestan and China, and to have spread through the Mediterranean region to Europe, following the *Walzenbeilkultur*. Robert Adams states, however, that the domesticated pig was present in the Mesopotamian uplands more than two millennia before the earliest known agricultural settlements in India. The statement that the home of pig-breeding lay in India would therefore appear to require some qualification. It is assumed to have been closely associated with row cropping, since no bones of draught animals were found in the sites concerned. In Egypt, large quantities of pig bones are found in early Pre-Dynastic levels, but few later; this may have been due to the social superiority claimed by the later ruling culture. Sauer [167] follows a similar line in relating household animals—dog, pig, fowl, duck and goose—with vegetable farming. He does not accept the idea, originating from Roman literature, that hunters became pastoralists and finally farmers, that hunters were the animal domesticators and that food collectors learned how to grow plants. 'The dependence of the nomadic pastoralist on agricultural communities is well known and general, and his way of life is derived from the sedentary farmer. . . Abel was a keeper of sheep, but Cain was a tiller of the ground, and both were of one family. . . . The original and absolute pastoralists can scarcely be said to exist or ever to have existed; they derive from a farming culture in which livestock was an original element.'

Sauer [167, chapter V] summarizes present knowledge and theory with regard to the domestication of livestock, its ceremonial basis, the origin of milking as part of a fertility cult, and related matters. His eleven domesticates—the common cattle, zebu, water buffalo, yak, goat, sheep, reindeer, dromedary, Bactrian camel, horse and ass—are all now or were once milch animals. Apart from the reindeer, all are first known from ancient seed agricultural centres, and their wild ranges are in or marginal to such areas.

Turning briefly to some of the evidence from our main sites in the region, Duerst [56] states that when the lowest layers of the Northern Kurgan at Anau were being formed, man lived entirely without domestic animals. The wild ox, *Bos nomadicus*, and the small wild horse roamed on the steppes and oases of the Kara-Kum Desert and sought shelter in the forests which probably then occupied the valleys and slopes of the Kopet Dagh. There lived also large-horned sheep and the gazelle. Duerst concludes, from the absence of stone weapons, that man lived on a friendly footing with these animals and that he could gain possession of them only by depriving the wolves of their prey or by the use of fire-hardened wooden weapons. It would be guess-work to assume that these animals voluntarily (or compelled by the necessity of food from outside the oases) approached human dwellings in order to graze on the weeds and other plants and so were gradually brought into companionship with man, who then assumed the care of their nourishment. Be that as it may, after the accumulation of the lowest ten feet of the strata in the North Kurgan, the same wild ox occurs in an almost equally large but certainly a domesticated form, becoming more and more frequent in the higher strata when the horse and sheep also pass over into the domesticated condition.

A review of the explorations made in Turkestan by the Pumpelly expedition by C.H.H. in the *Geographical Journal* states, however, with reference to Duerst's examination of the bones of sub-fossil and later animals that:

> ... we have a careful and skilled investigation of the remains of horse, ox, sheep, dog, camel, etc. The contributions to our knowledge of the horse are especially valuable and one of the species appears to approximate closely to Przewalski's horse. He claims to have found a domesticated breed of sheep in the First Culture stratum and the shepherd dog in the Second. It seems a daring thing, in our present state of ignorance, to form an absolute chronology on the base of the differentiation of animal forms and their migrations, as deduced from their appearance in different places, but Dr. Duerst, in agreement with Professor Pumpelly, does not hesitate to tell us that the shepherd dog appeared at Anau *c.* 5850 B.C. and that the turbary sheep attained its full development 6250 B.C. ... according to Professor Pumpelly's stratigraphic chronology, which is without doubt the most exact chronological table that we possess, the 20 feet of culture stratum at the base of the North Kurgan dates from the latter half of the ninth millennium (8250 B.C.).

It is now realized that these so-called precise dates are wholly arbitrary, being based on an assumption of the longevity of each stratum. The 'most exact chronological table that we possess' is not literally acceptable today, nor has the Anau chronology been taken seriously for several decades.

Toynbee [191] uses the data from Anau to show that the agriculturist had far greater potentialities for domesticating wild animals than the hunter. The agriculturist did not prey upon the wild animals and so did not inspire them with fear; he would possess food supplies attractive to the ruminants like the ox and the sheep, which would not be attracted by meat or the other products of a hunting or fishing life, as dogs are. 'The recurring challenge of desiccation' in Eurasia is regarded by Toynbee as the main factor in the origins of nomadism. He assumes that one group of the cultivators and stockbreeders of the Transcaspian oases trekked across the withering steppes with their seed corn and their cattle to less arid areas. They may, however, have had brethren who responded to the same challenge in a more audacious fashion. This group would have abandoned their staple occupation of agriculture and staked their existence on the recently acquired art of stockbreeding, but by following a nomadic existence on the steppe. To practise this art successfully under exceedingly exacting conditions, the wandering peoples had to develop a special skill and, to exercise this, to develop special moral and intellectual powers. This, combined with the belief that the domestication of animals is a higher art than the domestication of plants, provides the basis for the conclusion that nomadism is superior to agriculture in several ways. In addition to the domesticated animals which he keeps alive in order to live off their products, the nomad keeps other animals, the dog, the camel, the horse, to assist him in his pastoral task. The training, as distinct from the mere domestication, of these auxiliary animals Toynbee regards as the nomad's crowning achievement.

Probably the most prominent domestic livestock of the present day over much of our region are the sheep and goat. The fat-tailed sheep of south-western Asia includes the Awassi breed of Israel and adjacent Arab countries. Records of this type of sheep are found in old Assyrian monuments as reproduced by Kronacher [114] representing the booty captured at a Jewish town at the time of Tiglat Pilesser (745 B.C.) and in the detailed descriptions by Herodotus (500 B.C.). A discussion on the domestication of different types of goats is to be found in *Antiquity* for 1956 and 1957 [159]. There is no doubt that the intensive study of animal remains at Jarmo will make an important contribution to the history of the domestication of animals. Similar work by Zeuner at Jericho has yielded remains of two breeds of goats, those with straight, upright or 'scimitar' horns in the oldest pre-pottery strata, and a type with spiral or screw-horns in the Early Bronze Age level. On the Jericho evidence, it appears that the straight-horned goat was second only to the dog among the animals to be domesticated. Zeuner has stated that the screw-horn goat appears, and possibly replaces the straight-horned in the economy of the Early Metal Age all over the Fertile Crescent and the eastern Mediterranean. They probably became the parent stock of most modern breeds.

Since these paragraphs were written, Reed [160*a*] has reviewed the evidence concerning the animal aspect of the 'food-producing revolution' (Fig. 5). It appears that domestication of goats and sheep occurred in a central core area in south-western Asia in prehistoric times, probably about the seventh millennium B.C., cattle being domesticated somewhat later, and pigs even later. Domestication of the food-producing animals probably occurred in village-farming communities in the hilly flanks area of south-western Asia; thus cereal agriculture and the settled village are considered to antedate the domestication of all animals except the dog. Relatively intensive and successful agricultural and stock-breeding societies developed in the Zagros hills and their grassy forelands and in the lower Jordan valley before the appearance of the earliest societies of this type elsewhere. Similar Iranian and Egyptian cultures

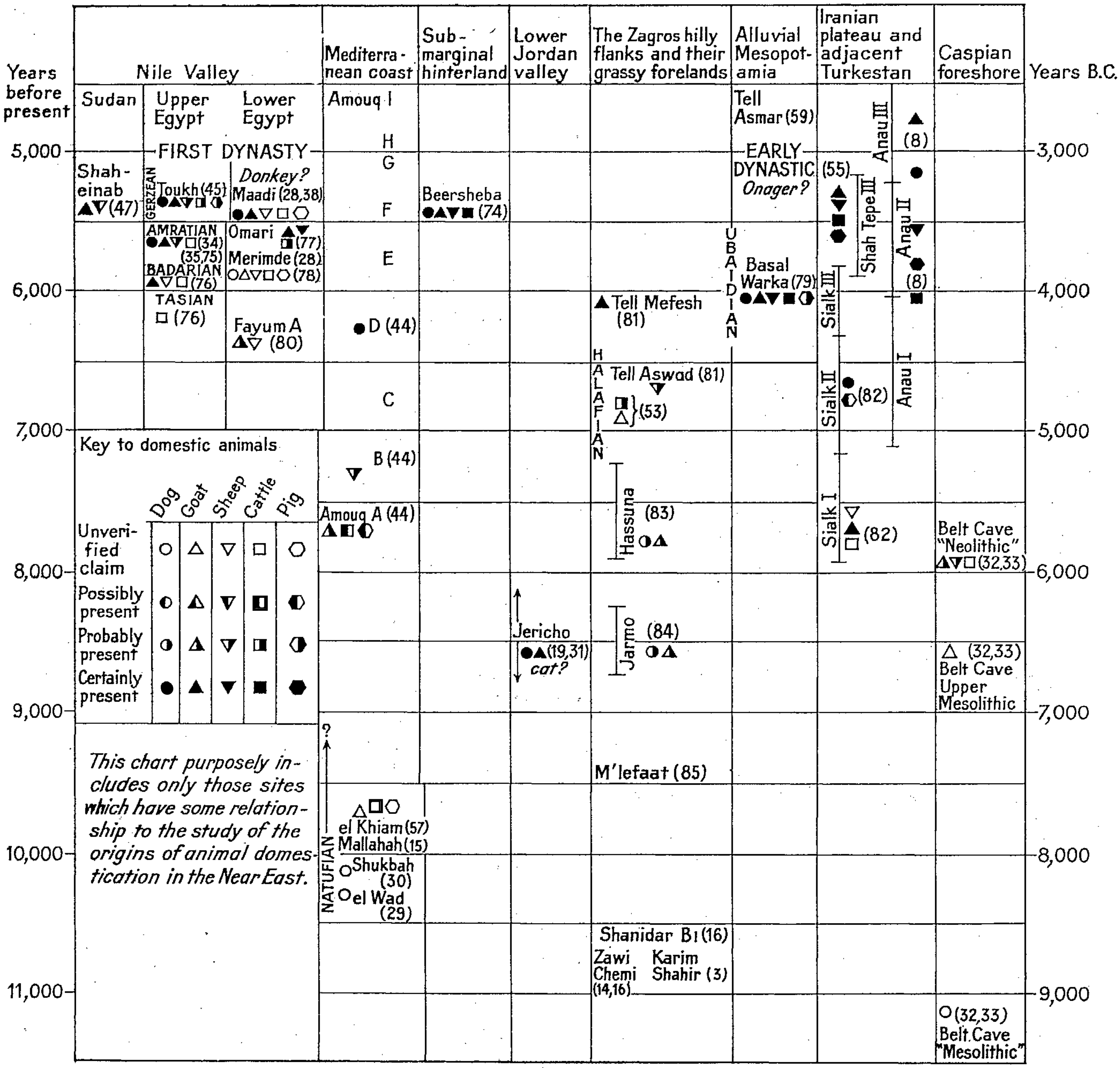



FIG. 5. A chronological chart, subdivided into geographical areas, of the known history of animal domestication in the prehistoric Near East. The estimated time is not to be regarded as absolute; the top of each column is fairly well fixed, temporarily; but any part of any column may be elongated or shortened as a result of future discoveries (after Reed [160*a*]).

are believed by Reed to have developed later and peripherally. No dramatic environmental change has been detected by the Chicago workers at the end of the Pleistocene in south-western Asia. It is therefore concluded that the all-important food producing revolution was apparently not stimulated by the challenge of a post-Pleistocene climatic change.

## IRRIGATION AND SALINITY

Some rudimentary form of agriculture without irrigation may have been practised in the Near East even before Neolithic times, particularly in the regions with copious spring rainfall in Palestine, Syria and the Caucasus where today barley and

Emmer wheat grow wild [55, 226]. The food-gatherers must soon have appreciated the advantages of growing the wild grasses near streams, by springs and in the dry beds of water-courses. People still in the food-gathering stage have been seen to create rough stone dams, or to scratch conducting runnels. Deliberate watering of the ground and preservation of seed from season to season must, according to Drower, have gone hand in hand.

The earliest peoples who settled in the lower part of the Tigris-Euphrates valley, familiar with the legend of 'that greatest of floods, which destroyed all but one of mankind, the Sumerian story from which the story of Noah derives', must have built embankments along the rivers near their homes and dykes around their homesteads to keep out the threatening waters. The ultimate origins of irrigation in the area are still apparently obscure. From their beginnings, the Sumerians probably practised a simple form of perennial irrigation which entailed keeping the soil covered with a few inches of water from sowing in November to harvest in April or May. It would be an obvious sequel to ensure the success of such an operation by providing a carefully regulated network of water-channels, with land divided into field and smaller plots. Although little is known of the elaborate system of canals of Babylonia before Sassanian times (before the third century A.D.), countless ruined canals, marked by great parallel lines of mounds, indicate a widespread ancient irrigation system. There are many references to canal building from the third millennium B.C. onwards in the records of the rulers of Sumer and Akkad, and later of the united country called Babylonia. The conquest by Hammurabi (about 1760 B.C.) of the entire Tigris valley and part of the Euphrates led to strong centralized control of irrigation and resultant prosperity. Several of the laws in his Code deal with irrigation [55] (see also [1, 73, 149, 150, 210, 211, 215]).

The natural conditions of Mesopotamia as a background for the development of irrigation and the civilizations based thereon afford in many ways a marked contrast to those of Egypt. Between hills of marl containing salt and gypsum lies a wide plain, flat in cross-section and with a seaward slope only half that of the Nile Valley. The Tigris is of relatively little use for irrigation because it has a deeply cut bed and the normal level of its waters is too low for efficient use by any simple system of canalization. The Euphrates is the basis for agricultural production in a land with scanty rainfall and greater extremes of heat and cold than occur in Egypt. The Euphrates has a current flowing at 5 miles an hour at Carchemish, for example, and carries five times as great a silt load as the Nile. When it enters the flat alluvium of the delta, much of the sediment is dropped. The bed of the river is raised until in time it flows above the level of the plain. It is relatively easy to cut the banks and irrigate the land with the silt-laden waters.

The date of the annual floods depends upon the weather in the mountains of Anatolia, and cannot be forecast precisely. In any case they come late in spring, at a bad time for the farmers. The flood had to be kept in check if it were not to damage the ripening winter crops or the newly sown summer crops, but at the same time controlled use of the floodwaters was necessary if full benefit was to be derived from the precious load of silt they contained. The careful utilization and control of these always dangerous floodwaters demanded not only a vast amount of manual labour but also an elaborate organization, a co-operative effort and centralization of control quite beyond the scope of a village community.

The planning and upkeep of an interdependent system of canalization required the direction of a regional authority enjoying absolute powers. 'By the mere logic of circumstances the Euphrates delta was from the outset parcelled out into a number of agricultural units, each having its own centre of administration, and the development of the city state was due not to the peculiar mentality of the Sumerian people but to the physical character of Sumer.' (Woolley [215].) As the conditions of agricultural life in the valley demanded co-operation and centralization within each irrigation unit the non-labouring intellectual class naturally assumed the direction of the communized body and something in the nature of an official hierarchy took shape.

Although Ur, like the other Sumerian cities, started as the administrative centre of an irrigated district, Woolley [215] states that no purely agricultural economy could have led to the growth or maintained the existence of anything like the estimated population of about a quarter of a million on an area of 1,450 acres. The farming of the rich delta plain was, of course, of great importance in feeding this large population; the ultimate dependence of the city upon its locally-grown food was proved when, at a much later date, the Euphrates changed its course, the whole elaborate system of irrigation was hopelessly dislocated and Ur was abandoned by its citizens.

A review of the extent to which progressive changes in soil salinity and sedimentation contributed to the disintegration of past civilizations, based primarily on the early results of the Diyala Project in Iraq (see below), has been presented by Jacobsen and Adams [100]. A survey of ancient water courses and settlements in Central Iraq has been made by Adams [2]. It appears from the work of Lees and Falcon [121] that some of the older archaeological theories on the geographical history of the Mesopotamian plains are based on an unjustifiably simple assumption.

The Tigris, Euphrates and Karun rivers are not building forward a normal delta; they are discharging their load of sediment into a tectonic basin which is the successor to a geosyncline in which many thousands of feet of sediment have been accumulated in the past, over a period to be measured in hundreds of millions of years. The balance between subsidence and sedimentation in the recent past seems to have been finely poised; subsidence was episodic and in the intervals the depressions tended to fill up with sediment. But in general subsidence has been dominant, with the exception of some minor local uplifts representing a late movement of anticlinal structures.

'The soils of the oldest cultivated area in the world' have been described briefly by Buringh [34] and the same author has described living conditions in the lower Mesopotamian plain in ancient times [35]. Cereals were milled and prepared for human consumption [49], beer was brewed [83], plants were used for making drugs [111], animal husbandry and breeding were important [54], and there was a fishing industry [53].

The FAO Irrigation Team in Iran [70] has described the early history of the Khuzistan area (Iran) as a background for the present development project, and refers to the hypothesis that the plain had been gradually extended by the silting up of the Persian Gulf (see Fig. 6) which was supported by archaeological evidence and generally accepted until the interpretation of Lees and Falcon, referred to above, introduced subsidence along with siltation.

Ancient irrigation in the Khuzistan plain probably consisted of a system by which the diversions from the various rivers were interrelated. Impressive remains of ancient dams are still available, including the multi-purpose scheme built in the third century and still in operation at Shushtar. The water in these ancient systems was artificially lifted from the canals to the fields, which would have automatically reduced the danger of over-irrigation and salinization. Barley was an important crop in the Khuzistan plain in ancient times. Sugarcane, cotton, fruits and silk became important throughout the area. The area concerned was in ancient times an important centre of civilization and its prosperity continued, although in a lesser degree, through the Middle Ages. The modern plan for the development of the land and water resources of Khuzistan is in fact aimed at the re-establishment of the agricultural prosperity which for a very long time flourished in these areas. A careful historical study may obviate mistakes in future projects.

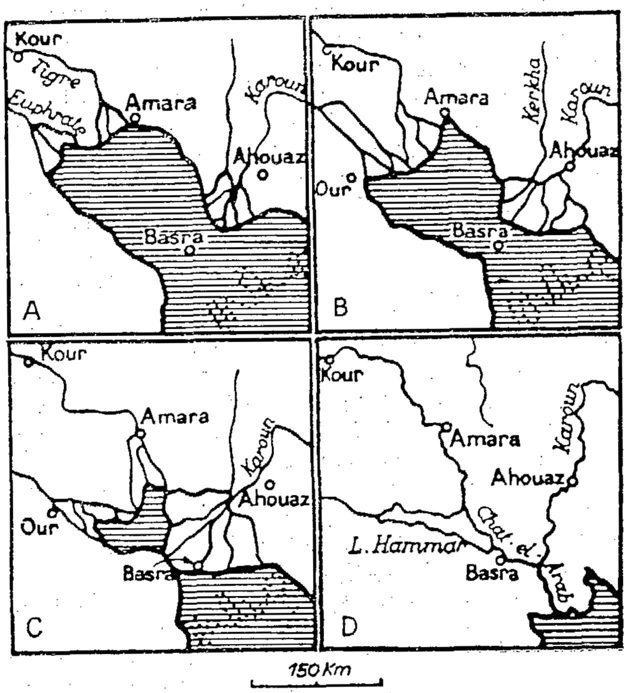



FIG. 6. The silting up of the Persian Gulf (after de Morgan). Key : A, 3000 B.C.; B, 2000 B.C.; C, Roman epoch; D, present day.

The most ancient remains in Iran were found at a site north-east of Shushtar and date back perhaps to 10000 B.C., a cave dwelling of prehistoric man who was still a hunter and food-gatherer. Excavations at Giyan and Susa have shown the remains of settled communities of the fourth millennium B.C. The extremely important stage in the development from early communities was the concentration of urban life at centres in the Mesopotamian plain following the advent of irrigation on a large scale. In the Khuzistan plain, in particular, this led to the creation of the first civilized city in what is now Iran, namely Elam. During the third millennium B.C. the Elamites had already formed a dynasty which ruled over a wide area of plains and mountains. In the subsequent millennia, the region was the location of a long sequence of struggles of the Mesopotamian kingdoms and alternations of independence and domination by other peoples.

Apart from siltation, the great problem of the Tigris-Euphrates valley is, of course, salinization. The recent study of the history of salinity quoted below is an example of team work by specialists in different subject-matter fields, a method of approach which is increasingly being accepted as the best way of obtaining a complete picture of historical events and sequences.

The Diyala Basin Archaeological Project was established in 1957 by the Iraq Development Board to undertake an investigation in the basin with the purpose of identifying ancient irrigation and agricultural practices, with special attention to draining facilities and the salinization of soils. This is a joint undertaking of the Director-General of Antiquities of Iraq and the Oriental Institute of the University of Chicago. Thorkild Jacobsen is the director, and the field staff includes Fuad Safar, Robert M. Adams, Mohammed Ali Mustapha, Hans Helbaek, Professor

J. C. Russel, Adnan Hardan and others. The project began on 1 June 1957, with an investigation of ancient written sources from 2600 B.C. to A.D. 1400. In September 1957, the field work began, with studies of the history of settlement, irrigation systems, ancient crops and salinization, by excavation, ceramic surface survey and palaeobotanical inquiries. A report covering the period June 1957 to June 1958 has been prepared by Professor Jacobsen [99].

The present soils in the irrigated plain are alluvial, largely man-made as a result of irrigation. At Tell Asmar, the soil on which the first settlement stood in 4000 B.C. is now 10-11 m. below the surface, in the Diwaniya area the same layer (from the Ubaid period) is now 6 m. below the surface and at Ur 2 m. The groundwater which moves through these old settlement layers is extremely saline, and this is the immediate source of the salts. When land is irrigated, the magnesium precipitates as carbonate, the sodium stays in soil solution. If the water table is high, the sodium concentration in the topsoil increases, causing deflocculation of colloids, and in turn causing the clay structure to disappear and the soil to become impermeable. The water table may rise through floods, rain, irrigation and capillary action; this action is slight in dry clay, considerable in wet clay. Sodium chloride and sulphate are the most common salts, but others present in lesser amounts include calcium and magnesium chlorides, magnesium sulphate and magnesium and calcium nitrates.

From references to salinity and saline conditions, a rough outline of the distributional picture can be obtained, showing two major concentrations distinct in time, area and kind of salt involved. The first begins with the earliest mention of salt as an agency destructive of cultivation in documents from Girsu as early as 2400 B.C. and continues to 2100 B.C. when the evidence suggests sporadic salinity to have been present over most of southern Babylonia; the salt appears to have been white, non-deliquescent sodium chloride (in Arabic *Shura*). Then the sources are silent for some 800 years, until references to salt begin again about 1200 B.C., but now from northern Babylonia and relating to the deliquescent 'wet salt' (calcium or magnesium chloride, in Arabic *Sabkh*). This continues to the Neo-Babylonian period (*c.* 600 B.C.); again the sources become silent and continue so to the end of the Abbasid period. Since the occurrence of salt and the gradual salinization of lands previously salt-free are certain to affect cropping patterns and to cause shifts from less to more salt-tolerant crops, it was important to discover from carbonized remains, imprints in pottery and bricks, and references in ancient documents, what types of crops were grown and whether they had any relation to increasing salinity of the soils. Two-row barley *(Hordeum distichum)* and types of Einkorn and Emmer wheats very close to the wild species were cultivated in northern Iraq in the Jarmo period (*c.* 6000 B.C.) and continued through the Hassuna (5000 B.C.) and Halaf (4500 B.C.) periods, while southern Iraq, deficient in rain, still lay uninhabited, visited only by nomads for game and spring grazing. When southern Iraq was finally settled in the Ubaid period around 4200 B.C. the settlers brought Emmer and barley, not the two-row variety of the north but a six-row variety, *Hordeum hexastichum*, of still unknown origin. The only other field crop of this period was flax. Cultivation of Emmer and barley with the new techniques of irrigation agriculture continued through the Warka (*c.* 3800 B.C.) and Protoliterate (*c.* 3500 B.C.) periods, imprints of grains show that these farmers produced crops of high quality. New crops begin to appear about 3300 B.C.—naked wheat, millet (*Panicum* sp.) and garlic. The field crops of the Early Dynastic (3200 B.C.) and Protoimperial (*c.* 2400 B.C.) periods increase steadily in variety; the Sumerians recognized several different varieties of Emmer and barleys. Onions and pulses including peas appear, and in the following Agade period (*c.* 2300 B.C.) we find sesame, chickpeas and beans; cress, known earlier, is common in Kassite times (*c.* 1300 B.C.); rice, perhaps introduced from India in late Achaemenid times, appears in the Diyala studies in the Seleucid period (*c.* 300 B.C.).

Evidence shows that a fall in the acreage of the less salt-tolerant wheat in favour of the more salt-tolerant barley coincides with the early references to salinity in Girsu and southern Iraq generally. Wheat as a percentage of total crop acreage in southern Babylonia was 16 per cent in 2400 B.C., 1.8 per cent in 2100 B.C. and zero in 2000 to 1700 B.C. In the rain-fed area of Chemchemal-Kirkuk, wheat represented 32.9 per cent of the cultivated land in 2300 B.C. Yields also, originally about the same as nowadays, dropped due to salinity in southern Babylonia. In about 500 B.C. the tenant had to pay two-thirds of his yield to the owner when the latter supplied seed and ploughing oxen, or ten times the seed if only the seed were provided by the owner. The yield was about 15-fold, although Herodotus claims it was 200- to 300-fold. The production of barley in south and central Iraq in the early Abassid period was about 840,000 tons; in 1956, 550,000 tons. The comparable figures for wheat are 600,000 and 207,000 tons.

The Diyala group used the statement of the complete ancient cycle of agricultural works contained in the Sumerian Georgica, earliest of agricultural handbooks, to discover whether these practices had any bearing on the history of salinization in Iraq. This was done because the occurrence and degree of salinity in cultivated areas may be considerably influenced by the prevailing agricultural practices, by the intensive or extensive use of the land, the amounts of irrigation water used, factors which tend to be more critical the more vulnerable an area is or may become through a rise in the water table. The Sumerian Georgica contains the instructions of the god of farming, Ninurta, to his son; according to Jacobsen, it would seem to have been composed in the south of Sumer at some time during the Third Dynasty of Ur (*c.* 2100 B.C.) and to have been copied repeatedly (see also [112, 119]). Jacobsen presents a paraphrase of the text with frequent quotations, relating to the following practices :

| Practice | Months |
|---|---|
| Preparatory irrigation | June/July |
| Weeding | July/August |
| Preparing the ploughing teams | August |
| Ploughing and harrowing | September |
| Clod-breaking with mattocks and hoes | September/October |
| Sowing | September/October |
| Gathering of clods | October |
| Irrigating (four for barley at specified times) | November to February |
| Reaping | March/April |
| Preparing the threshing floor and bringing in harvest | May |
| Threshing | May/June |
| Winnowing | June |

The Diyala team comments in more detail on irrigation, seeding rates, drainage, fallow and the question of summer crops. The seeding rates in central and southern Iraq were remarkably low, due to the wide spacing of the furrows. There is no evidence that drainage of irrigated land was practised. Some of the effects of drainage may have been achieved by the use of the weedy fallow, particularly when the deep-rooted weeds *Prosopis stepheniana* and *Alhagi maurorum* were present to dry the soil deep down and to create a protective dry zone between the water table and the root zone (Professor J. C. Russel).

The Diyala study shows that a particularly close relation existed between the flourishing of irrigation agriculture and the presence of a stable and vigorous central government. When these government centres weakened, and internal conditions became disturbed, the great disastrous abandonments of land took place, accompanied by incursions of nomadic tribes and damage to the irrigation systems. Irrigation agriculture itself is particularly vulnerable; since it must rely on water supplies from beyond regional borders, it is likely to be disastrously affected by floods arising in these supply areas, and is also seriously affected by siltation. It is felt that the relative height of the water table may in fact have been the crucial factor in the history of southern and northern Babylonia. The evidence shows that, after some 1,000 to 1,500 years of the successful irrigation agriculture which produced the brilliant Sumerian civilization, a very serious salinity problem developed. From about 2400 to 2000 B.C., severe salinity had detrimental effects on crop preferences and yields. When the country thus became progressively weakened economically, the long political and cultural supremacy of the south could not be maintained and the last Sumerian Empire, the Third Dynasty of Ur, fell. By 1700 B.C., when wheat had completely disappeared in the south, and barley yielded only 879 litres per hectare, the centre shifted to the north, where Babylon under Hammurabi began to emerge. From this disastrous first salting up of its lands the south never really recovered, although human skill and tenacity made it possible to maintain a certain amount of production. It was never finally abandoned, but could not regain its earlier economic and political leadership. There is no evidence of a similar spread of salinity in the middle and north of Babylonia, Akkad.

Toynbee [191] uses the Tigris-Euphrates basin as an example to support his belief that loss of command over the environment is the determining factor in the breakdown of civilizations. According to Le Strange [122], the historian Baladhuri dates the origin of the Great Swamp as far back as the reign of the Sassanian king, Kubadh I, near the end of the fifth century A.D. The dykes along the Tigris channel as it then ran had been neglected for many years; the waters suddenly rose and poured from a number of breaks in the dykes, flooding the low-lying lands to the south and south-west. During the reign of Anushirwan the Just, son and successor of Kubadh, the dykes were partially repaired and the lands brought back under cultivation; but under Khusraw Parwiz, the contemporary of the prophet Muhammad, and in about the year 7 or 8 after the Flight (A.D. 629) the Euphrates and the Tigris again rose, and in such a flood as had never before been seen [122]. 'The waters could in no wise be got back, and the swamps thus formed became permanent.' Subsequent invasions, diverting care from the land, consolidated the position, and thereafter in the thirteenth century the whole irrigation system of Iraq was allowed to go to ruin [210, 211]. Why, asks Toynbee, did the inhabitants of Iraq abandon the conservation of a system which their predecessors had successfully maintained for some thousands of years without a break—a system on which the agricultural productivity and the maintenance of the dense population of the country depended? This lapse in a matter of technique was, according to Toynbee, not the cause but the consequence of a decline in population and prosperity which was in itself due to social causes. Both in the seventh century of the Christian Era and afterwards in the thirteenth, the Syriac Civilization was at so low an ebb in Iraq, and the consequent general state of insecurity was so extreme, that nobody had either the means of investing capital or the motive for employing energy in river conservancy and irrigation work. In the seventh century the true causes of the technical failure were the great Romano-Persian war of A.D. 603-628 and the subsequent over-running of Iraq by the primitive Muslim Arabs; and, in the thirteenth century, the Mongol invasion of 1258 which dealt the Syriac society its *coup de grâce*. Jacobsen and Adams [100] however show that the Mongol invasion was not the cause of failure of the irrigation networks, but that internal political and economic deterioration was responsible both for the breakdown and for the weakness which invited Mongol inroads.

In south-west Asia and North Africa an important supply of water is obtained from underground infiltration tunnels or 'horizontal wells', variously known as *kanats*, *karez* or *foggaras* [7, 47]. When the Aryans first settled on the Iranian Plateau they supplemented the natural rainfall with irrigation from rivers and springs. According to Feylessoufi [69], they also turned their attention to the best method of utilizing the underground water. They started to dig canals at the foot and on slopes of the hills. As they approached the higher hills and mountains, the depth of the canals began to increase until the excavations took the form of tunnels or underground galleries. It was not easy to excavate these with their continually increasing depth; furthermore, in order to ventilate these galleries and to provide facilities for their excavation, it became necessary to dig vertical shafts from the surface down to the gallery level. Thus it became possible to collect the water provided by rain and snow following its infiltration through the soil and to use it for drinking water or irrigation. The exact date of digging of the first *kanat* in Iran is not known, but ancient literature seems to indicate that the practice dates from before the Islamic era. Cressey, however, takes it further back, stating that it originated more than 2,000 years ago, and that the palace city of Persepolis is thought to have been supplied by *kanats* about 500 B.C.

There were, of course, other but lesser developments of irrigation agriculture in historical times which it would be interesting to follow. Petra and Palmyra in their most prosperous days in the later part of the Roman era stood in the midst of irrigated gardens such as still surround Damascus. The irrigation system around that city was built by the Ummayid Jesid I (A.D. 600-683). In 1230 Kassar ibn Abi-al-Kasim built irrigation works with large water wheels on the Orontes in Syria.

## SOME HISTORICAL SEQUENCES

So far we have made the point that the general pattern of land use in our region of study was laid down in very early times, and that the events of subsequent periods did not greatly change this basic pattern. It would, however, be of great value if students were in future to trace the complete agrarian history of the different natural subdivisions or political units within the region from the earliest days to as recent a period as possible. As already indicated, such a study would involve a review of literature sources quite different from those used for the preceding sections. Instead of the literature which is primarily of an archaeological nature, it would be necessary to study, for example, the Greek, Roman and Byzantine periods, the history of the campaigns of Alexander the Great, the story of the Arab outpourings of peoples and livestock from the Arabian peninsula, and the history of the Turkish domination. All these events had a marked effect on the basic land resources in relation to the degree of use and misuse which they practised, and the land, in its stages of continuous progressive deterioration, had a marked effect on the parallel stages of human development, governing what was or was not possible in the provision or production of food, grazing, fuel, timber and other economic needs. Several examples of this alternative approach will now be given.

### PALESTINE AND SYRIA (6000 B.C.-A.D. 1917)

It so happens that two writers, probably using the same source material, have described a complete history for that part of our region which was recently Palestine and now comprises Israel and part of the Hashemite Kingdom of Jordan [163, 164, 187], and to some extent also of Syria. A brief summary of this history is presented primarily as an example of a desirable objective of research (see also Albright [3]).

#### *Prehistoric period: the beginnings of agriculture (c. 6000-3000 B.C.)*

The beginnings of agriculture and possibly of the domestication of animals are found in the Natufian period of the Mesolithic (seventh to sixth millennium) [41]. The discovery in a cave on Mount Carmel, by Dorothy Garrod, of flint sickles set in curved bone handles is taken to indicate that cereals were cultivated, and Aaronsohn has found wild wheat and barley on the slopes of Mount Hermon and in the Jordan Valley. In the Neolithic (sixth to fifth millennium) and the Chalcolithic (*c.* 4000-3000 B.C.) periods, first copper and then bronze implements appeared, with stone objects still predominating. Cities developed wherever springs permitted human settlement, and Albright [3] has called the Chalcolithic the 'irrigation culture' because it was then that the digging of canals and the building of dams began, not only in Palestine but also in Predynastic Egypt. Crops in the fourth millennium were wheat, barley, durra millet, olives, figs, grapes, sesame and flax.

*Bronze Age* (3000-1200 B.C.)

Egypt and Mesopotamia had a great influence on the irrigation culture of Palestine, and with the arrival of the descendants of Abraham in the eighteenth century B.C. agriculture must have attained a high standard. The presence of numerous flocks is mentioned in the Sinuhe story and the irrigation culture of the Jordan Valley is described in the Bible. Timber was being exported from the Lebanon to Egypt, and cedars from both Lebanon and Syria.

*Early and Middle Iron Age* (1200-586 B.C.)

Canaanite settlements were mostly situated on foothills near fertile plains where springs or wells provided the necessary water. With few exceptions, the mountainous regions were not occupied by a sedentary population before the arrival of the Israelites. The invention of a mortar impervious to water made possible the construction of cisterns for the storing of rainwater and explains the rapid expansion of Israelite settlement in the mountainous regions. The woodland in the Judaean and Samaritan mountains was cut down and turned into arable land. The plough was still of the primitive type. Wheat was used for bread, barley for fodder. Hillsides were carefully terraced. Ancient wine and olive presses were widespread. There was a tendency against the formation of large estates, but there were already crown domains with special jurisdiction in Davidic times. Although primarily needed for the copper mines or for felling timber in the Lebanon, it appears that forced labour was also used on these royal estates. A strong administration safeguarded the flourishing agricultural community and protected it against nomadic raids, but the small farmers, who paid heavy taxes in kind, were faced with the encroachment of the State and big landowners.

*Neo-Babylonian, Persian and Hellenistic period* (586-63 B.C.)

The Babylonian conquest almost entirely devastated the flourishing villages and towns in the Judaean Mountains; only half the population of 300,000 survived at the end of the eighth centhry B.C. and the cream of the population was carried into captivity. The southern hill country was gradually occupied by Adomites and the country was open to attack by Ammonites, Edomites and Arabs. The land began to recover after the fall of Babylon in 539 B.C. and the return of the Jews, but the rich, who had in the meantime accumulated large estates, were obliged to return them again to the peasants. After the overthrow of the Persian Empire by Alexander the Great, Greek influence became dominant, great urban centres were formed or small settlements became cities in the Hellenistic sense of the word. In the beginning of this period, agriculture was the chief occupation throughout the Fertile Crescent, but with the establishment of large estates by the State came high officials of big landowners, a tendency which became more marked in the Roman period.

*Roman period* (64 B.C.-A.D. 330)

In no period of the history of the Levant was so much land brought under cultivation, supported by the construction of magnificent aqueducts, irrigation works and other devices for the conservation and supply of precious water to marginal areas. Although it was still the practice to leave half the land fallow, rotation of crops came to be known, organic fertilizers were applied, and terraces were well in evidence. The flourishing conditions in the Fertile Crescent under Roman rule were due to the strong and efficient administration, and to the protection afforded against nomadic invasion from the desert. Taxes were low at first, but later increased considerably. The distinction between urban and rural life became more marked, the formation of large estates continued until the third century A.D., when a devastating inflation took place, levies to support the armies weighed heavily on the agricultural population, and a profound change took place in the general state of agriculture.

*Byzantine period* (330-640)

Continued inflation, the increase of taxation from what had been one-fifth of a tenant's produce in Ptolemaic times to one-half, and a chronic state of indebtedness caused the peasant farmers to leave their land, thus leading to a great shortage of agricultural labour. A law was introduced to tie the peasants to the land, a servile or quasi-servile system of land tenure which reduced personal initiative on the part of the *coloni* and produced a deplorable inefficiency. The formerly flourishing towns also suffered through the inflation and the oppressive taxes for which they were held responsible. The land soon became the private property of big feudal landowners, but yet these general conditions, although hard on the individual, had in many respects a beneficial effect. The establishment of the water-distributing installations in the Negev was done by forced labour, and the population of that area is estimated to have been about 80,000-100,000. Churches and monasteries were erected throughout Syria and Palestine, and these in turn gave rise to flourishing communities. The strong hand of the State guaranteed safety from nomadic raids and brigandage.

*Early Arab and Crusader period* (640-1250)

When the Arabs invaded the countries of the Fertile Crescent, including Syria and Palestine, and defeated the Byzantine forces on the Yarmuk River in 636, they found a smoothly working Byzantine administration to support the machinery of State. After the Arab conquest, the type of land use began to change fundamentally, since the new masters were stock husbandmen driven out of their desert homes by a combination of religious fanaticism and economic necessity. So the natural vegetation was destroyed, terraces were neglected and land deterioration was general. In the first centuries of Abbasid rule, however, agriculture revived, deserted farms and ruined villages were gradually rehabilitated. Then in the tenth century, internal rivalries led to a sharp decline in the prosperity of the Abbasid rule, and early in the eleventh century the situation was ripe for the successful incursions of the Crusaders. Although the native peasantry now paid their rent and taxes to the new masters instead of to Byzantine or Arab overlords, and the feudal oppression was very hard, it appears that Syria and Palestine were flourishing lands. The Jericho area had abundant trees, palms, fruits and sugar plantations, the neighbourhood of Jerusalem and Hebron was rich in wheat, vines, carobs and fruit trees. In 1189 the Latin Kingdom of Jerusalem came to an end in much of the country, and in the first half of the thirteenth century, Syria and Palestine were the scene of feuds between various Arab princes and the Crusaders.

*Mameluke period* (1250-1517)

Towards the end of the thirteenth century, the Levant suffered from Mongol invasions [101] until they were halted by the Egyptian Mameluke Sultan Beybars, who also broke the last Frankish resistance in 1291. The flourishing towns of Ascalon, Arsuf and Caesarea were laid in ruins and most of the cultivable land was given as fiefs to Mameluke knights and emirs. Although the former system of taxation was at first retained, in 1313 a uniform system was adopted, and the peasants became serfs of their lords. The temporary character of the feudal land tenure prevented the formation of landed estates, except in the rapidly growing sugarcane plantations, where forced labour was employed. In the Muslim world, uncultivated lands were always considered as commons, the right of pasturage on them and on stubble land being accorded to all herd-owners. This, combined with the absence of any restraint on forest exploitation, had a disastrous effect on the natural vegetation. 'The exorbitant taxes, famine and the plague resulted in a sharp decline of the population towards the end of the fourteenth century. If we add to this the invasion of the Tartar hordes in 1401, it is small wonder that at the end of the fifteenth century the pilgrim Felix Fabri was able to state that the land of Palestine was a desert because there were no people to cultivate.' (Reifenberg [163].)

*Turkish period* (1516-1917)

The Ottoman Dynasty ruled the Near East for four centuries after Selim I defeated an Egyptian army near Aleppo and the Mameluke rule came to an end. Many districts were now turned into crown domains and granted to native nobles of Turkish officials for a period of one year only. The Imperial Government was too weak to control the powerful tribal chieftains or local governors. The demands of these overlords for levies amounting to one-half or two-thirds of the crops increased the indebtedness of the peasantry, who abandoned the countryside, and sought refuge in the cities. Palestine was the most deserted district, being so overrun by Bedouins that it became impossible to travel in safety from Gaza to Acre. The Turkish Mesha system of tenure, under which land is held in common by village communities and is divided into shares instead of areas, also had a devastating effect on agriculture. No one was interested in investing money and labour in land which continually changed hands by lot. Terraces were not maintained or constructed, no trees planted, and no manure applied to the land. The practice of ploughing up and down the slopes was introduced, since each man was given strips covering both the flat and the steep land.

## IRAN (10000 B.C.-A.D. 1925)

*Prehistory*

At a time when the greater part of Europe was covered by glaciers, Iran was passing through a pluvial period, during which time the great salt desert of the plateau was an immense lake, fed by rivers from the high mountains. Man at this period was a hunter, while women gathered edible roots or berries and made the first experiments in agriculture on the alluvial terraces which were formed at the mouths of rivers [75]. Progressive drying up of the valleys, caused by a period of drought which occurred between 15000 and 10000 B.C., and the shrinking of the central lake left fertile land which became covered with rich pasture and savannah. The hunter followed the animals down the mountainsides, extended his agriculture and became a stockbreeder, as indicated by the bones of domesticated sheep and oxen found at Siyalk (Period I). The remains of stone spindle whorls, used in a primitive textile industry, are evidence that flax was grown in the area.

Bones of the greyhound and Przewalski horse, found in Period II at Siyalk, show that these were domesticated around 4000 B.C. The Przewalski horse, thought to be intermediate between the onager and the modern horse, would have greatly facilitated field work. The plough was in use, and communal labour brought about land clearing and irrigation.

Wheat, barley, fruit and cattle were the chief agricultural products, and were used as primitive currency. In this way plants and trees were spread from Iran to Egypt and Europe; millet from India was found in Italy and European oats and poppy appeared in Asia and China.

The urban life which, during this period, grew up in the fertile plains of Mesopotamia was impossible under the harsh conditions prevalent in the plateau, except in Elam, situated in the Plain of Susiana, a geographical extension of the Mesopotamian Plain.

### *Third millennium* B.C.

During this period a slow infiltration of peoples, believed to have originated in Russian Turkestan or farther afield, took place in the north-east, penetrating to the very heart of the plateau. The newcomers brought with them a nomadic way of life, and though there was conflict with the urban civilization of Mesopotamia, economic intercourse took place, since Iran was rich in raw materials.

### *Second millennium* B.C.

The second millennium marked the appearance of the Indo-Europeans in the Near East. These warrior horsemen introduced the horse and horse-breeding into Iran (the Babylonians called the horse 'the ass of the East'), and two of their many tribes were the Medes and Persians, future empire-builders. Their fusion with the Kassites led to vigorous progress; rural centres grew larger, though the expansion of agriculture was still retarded owing to lack of water. Nomadism or semi-nomadism was the accepted way of life.

### *First millennium* B.C.*: the Iron Age*

A second invasion of Indo-Europeans, probably in search of new pastures for their larger flocks, coincided with the increased use of iron. Production expanded and hitherto uncultivated fields came under the plough. Agriculture and stockbreeding centred round the city-states, each of which was surrounded by gardens and fields. Around 900 B.C. the kingdom of Urartu was founded in the north, in a fertile, well-watered region with a favourable climate, characterized by extensive forests. Gigantic irrigation works were undertaken, transforming vast areas into agricultural land; sheep and horses were bred.

### *Ninth to fourth centuries* B.C.

Media was conquered by the Assyrians, though freedom was regained in 626 B.C. Scythians and Cimmerians poured into the Near East, laying waste to Urartu and spreading westwards. Battles took place between the Medes and Persians, leading finally to the victory of the Persian Cyrus. The Achaemenids were humanitarian conquerors, granting land to the vanquished, and preserving individual city cultures. The army dug vast irrigation canals and new areas of land were cultivated. Taxes were paid in horses, cattle and food as well as in precious metals. Cyrus exempted the inhabitants of Persis from any fiscal liabilities, though they brought him presents of fine fruits on all festivals, and peasants greeted him with similar gifts whenever he passed; he frequently joined them in their meals of a mess of figs, the fruit of the pistachio tree, and sour milk.

Darius fostered an interest in arboriculture and the propagation of new species. Under his orders, fruit trees were transplanted to Asia Minor and Syria, and due to his efforts rice was introduced into Mesopotamia, sesame to Egypt, and a degree of forest exploitation was practised. Darius was also responsible for the establishment of a great water basin in the Herat district, designed to facilitate steppe cultivation.

Wheat, barley, vines and olives were the chief crops; cattle, sheep and goats were bred extensively, as well as draught animals such as mules, donkeys and, of course, horses. Bees were kept, since honey was used for sugar.

### *Fourth to first century* B.C.*: Alexander and the Seleucids*

For the first time wealth gained in conquest was used for development purposes. Colonists from Greece and Macedonia received land, seed, cattle and a house, and many new settlements grew up, especially in the fertile area between Kermanesh, Hamadan and Burujnd. Irrigation canals, damaged during the wars, were repaired and new canals and drainage works undertaken. A flourishing economy arose based on the export of wood, clothing, drugs, seed corn, carpets, lead and metals, and also of pedigree dogs! Papyrus was planted in an effort to break the Egyptian monopoly, and parchment was produced. An increase in plant cultivation spread to southern Europe, especially Italy, where the introduction of cotton, lemon, melon, sesame, the oriental nut, dates, olives and figs, as well as the Asiatic ox and the duck, brought about an agrarian revolution. Agricultural techniques were developed to a degree unknown under later Islamic times. Triple crop rotation was practised; a new plough, together with new methods of vine cultivation, of forestry, orchard and garden management and of irrigation were introduced. The division of the former large estates brought about the liberation of the peasants.

### *First century* B.C. *to second century* A.D.*: the Parthians*

Gradual enfeeblement of the empire and increasing loss of territory in wars had already led in 248 B.C.

to the founding of the Parthian Empire under Arsaces. The rise to power of the Arsacids, despite continuous conflict with the Romans and Scythians, represented a victory of the nomadic north over the sedentary south. From the middle of the second century B.C., revolutions and revolts following the collapse of the Seleucid Empire led to an impaired economy, a fall in production and eventually widespread wars and pillage.

Hellenistic principles and institutions gradually disappeared; the nomads became 'Iranianized'. The coming to the throne of Augustus coincided with a general desire for peace which was responsible for the preservation of the Parthians, whose position was far from secure. Iran's position as middleman in growing west-east trade led to the improvement of roads, the sinking of wells and provision of caravanserais. The technical advances made by Rome in leatherwork and the manufacture of textiles, pottery, arms and glass were repeated in Iran. Roman enterprise brought about the creation of latifundia at the expense of the former small estates. This, in turn, led to the growth of feudalism, which, although again imposing restrictions on the peasants, also permitted technical advances which would have been beyond the scope of the small landowner. Agricultural science remained static, though advances were made in animal breeding. The peach, apricot, and sugarcane were introduced from China in exchange for lucerne, the vine, saffron, onion, cucumber and jasmine.

### *Second to seventh centuries: the Sassanids*

Achaemenid traditions were continued under the Sassanids, who were more vigorous rulers than the Parthians. Corn, cattle and manufactured goods were the chief products of a flourishing economy. The mulberry and silkworm were introduced during the fourth century. During the seven years of the Emperor Valerian's captivity by the Sassanids, he was employed in building the Great Weir across the Dujayl (Karun). The land which thus came under irrigation produced a sugar of particularly fine quality; its dates were also famous. This period was characterized by great feudal estates where the peasants were tied to the land. Corn, oil, wine, fruit and meat were produced at each estate for its own needs, and canals and water supplies were provided by peasant labour.

### *Seventh to eleventh centuries: the Islamic conquest*

Iran passed into Arab hands under the Caliph Othman in A.D. 652, with the maritime provinces of Iraq, Khuzistan, Fars, Kirman and Makran. From this period until modern times European sources contain few references to agriculture, being chiefly concerned with internecine, tribal, dynastic and foreign wars which devastated the country and ruined its economy. The Omayyads ruled Damascus until the Abbasid conquest in 749, when Baghdad was founded. The Arab generals established towns during their conquests to strengthen operations, and trade flourished as a result of the Mecca-bound pilgrims. The Arab geographers commonly divide Iran into two regions, separated by an east/west line, referring to them as the Hot Lands and the Cold Lands [122]. In mediaeval times the Karun River of Khuzistan had a separate estuary into the gulf at the town of Ahwaz, and its waters were controlled for irrigation by the Shahdurwan dam. According to Muqaddasi, the tenth-century writer, three canals left the river above the dam with regulating sluices to protect the town from inundation [212]. The district watered by the canals was accounted among the richest in Persia, and was particularly famous for its sugarcane, fully justifying the name of the province which means 'The land of the sugarcane'. However the water was a breeding-ground for mosquitoes and malaria was rife in the area until the disappearance of the dam. Rice-flour bread was the staple food. The same writer describes Shushtar, 60 miles north, as surrounded by orange, date and grape gardens. Flax grew throughout Fars and dates were exported. A dam over the River Kur, according to Muqaddasi, was 'one of the wonders of Fars'; its waters, with the help of ten water wheels, irrigated 300 villages, while corn was ground at each mill. Ibn Hawkal states that the area north and east of Tustar, known as the Lur country, was fertile, though exceedingly mountainous. An eleventh-century writer referred to the lack of wells at Mahruban, stating that the inhabitants relied on rainwater stored in cisterns and reservoirs. Provisions came from neighbouring towns, and fish was the only produce. This site has now disappeared, apparently engulfed in the Hindiyan delta. Istakhri describes Siraf, the principal port of Fars at this period, which was situated near the present-day Tahiri, as obtaining all its drinking and irrigation water for the cultivation of the narrow coastal strip from the mountains above the town. Shapur in the tenth century produced sugarcane, olives, grapes, fruit, flowers, (fig, jasmine, carob), though it was ruined during the twelfth century. The great salt lake of Bakhtigan, into which the Kur flows, though now surrounded by desert land, was in the Middle Ages bordered by many villages and towns situated in richly cultivated territories [122]. The plain of Marvdasht was famous for its irrigated corn lands. The oak forests of Kamfiruz were roamed by lions. The celebrated attar of roses, famous throughout the world, was made from red roses growing in the plain around Jur; many other perfumes, precious oils and unguents came from this town. The arable plains of Dasht Run gave four crops a year under irrigation.

*Eleventh to thirteenth centuries*

The eleventh century saw the growth of Turkish influence in Persia and the Seljuk Dynasty was founded, lasting until the Mongol invasion. Under the Seljuks the desert area of Kirman was flourishing, cultivated land, but gradually went out of cultivation until the invasions of Timur made the ruin permanent. The groups of villages which abounded in the fertile area of Fars were entirely absent in Kirman. Qais succeeded Siraf as the principal port of Fars. An early thirteenth-century writer mentions a species of acacia grown in the island, the fruit of which was used for tanning. The island was covered with cultivated irrigated fields, and with flocks and herds. Palms grew extensively.

*Mongol invasion*

The Arab and Turkish rule, while bringing little change or improvement in methods of agriculture as practised under the Achaemenians and the Seleucids and during the period of Roman influence, had preserved the ancient institutions reasonably well, in spite of tribal warfare, impaired economy and poor administration. Now the appalling devastation, abominable massacres, the burning of towns and villages and the destruction of crops transformed flourishing, cultivated lands into deserts in the wake of the Mongol hordes who poured across Asia in the mid-thirteenth century. Only southern Persia escaped the onslaught, and, in the words of Sykes [184], '. . . it was probably owing to this happy circumstance that the recovery of Iran was ultimately more rapid than could have been anticipated'. The Mongols were later converted to Islam, and a period of expansion under the steppe tradition was followed by an attempt to subordinate the tribe to settled government. Their failure, however, to solve monetary and tribal problems had a disastrous effect on agriculture. Flocks grazed on conquered land, migrating from summer to winter quarters, and the depradations of the nomads were a source of constant anxiety to the settled population [118]. Cattle and land taxes were universal, the peasants paying twice and the nomads once a year. The military were paid by draught, but frequently descended on villages and forced levies of animals and fodder; villagers, hearing of their approach, hid in underground water channels. The peasants were frequently on the verge of famine so that much-needed distributions of seed were used as food. Certain reforms were carried out under Ghazan whereby land laid waste after battle was reclaimed and taxes on wheat and barley were controlled. Advances were made to peasants and some dam building and irrigation took place. Manuring and composting were practised, orchards and vineyards were cultivated and flocks and domestic fowl including hens, duck and geese were tended. These measures were not, however, widespread and a general decline in productivity took place, leading to the break-up of the empire into separate geographical and economic units, an easy prey for the campaigns of Timur the Lame, or Tamerlaine. Timur was renowned for his justice and clemency and, though he sprang from nomad stock, appreciated the value of settled agriculture and encouraged arable farming and land settlement. Waste land was exempted from liability to tax during the first two years of reclamation. New irrigation works were built. Mustawfi, writing during the fourteenth century, described the forests of Fars which abounded with lions. According to him the plain of Dasht Arzin was famed for its pastures, and, near the town of Kavar, was made fertile by a dam thrown across the Sakkan for irrigation purposes; sour cherry, almonds and pomegranate grew there. Awjan, on the Sarav River near Lake Urmia, was surrounded by cotton, corn and fruit. Mustawfi attributes the Sha'b Bavvan's fertility, one of the Muslim earthly paradises, to the fact that the surrounding hills stored the winter snow, ensuring water during summer. Marand was famous in his time for rearing the Kirmiz-worm (cochineal).

*Safavid Dynasty*

This dynasty was separatist, which roused the hatred of the Traditional Ottoman ruler who defeated Ismail in 1514, laying waste to the land. However, when Turkish fanaticism lessened the Sultan treated with the Persians as with a defeated power, and in 1555 it was agreed to respect frontiers as they then stood. Anarchy followed the death of Tahmasp, and in 1587 Shah Abbas I, a wise and able ruler, came to the throne. After defeating the Uzbegs, he safeguarded the frontier by placing there the flocks and families of several thousand nomadic Kurds. Realizing, however, that his forces were insufficient to defeat the Sultan, he made a peace which brought Turkey to the Karun and the Caspian. In the meantime he created a regular army, trained with the assistance of the English Sherley brothers, in high favour at his court, and lost territory was regained after a series of campaigns against the Turks. Trade was encouraged, bridges and roads and caravanserais built and brigandage repressed. His religious devotion deeply impressed his subjects and he is generally accredited with welding the Turks, Arabs and Persians under his rule into a nation and creating a national spirit [118]. The capital was built at Isfahan.

During this period conditions were similar to those under the Seljuks whereby a mixture of settled and nomadic existence prevailed. Under the ancient crop-sharing system the landowner provided all the necessary water and all or half the manure required. The peasant worked the land, sowed and harvested and bore all cultivation expenses, gaining one-quarter to one-half of the produce. The landowner took one-half to two-thirds of the produce of fruit trees, and of ordinary trees two-thirds. Of rice, millet, cotton, beans, fenugreek, melon and pumpkin crops the peasant received two-fifths, and of opium eleven twenty-eighths.

After Shah Abbas II, who ruled from 1642-1667, the Safavids declined, followed by a period of Afghan domination in the eighteenth century, remarkable for the ruin and disorder which it brought.

Control of trade had been wrested from the Arabs in the fifteenth century with the arrival of the empire-building Portuguese, who gained control of the Gulf with the island of Hormuz as their trading depot. Lord Curzon describes them as fanatical and oppressive, and their constant raids on Persian ports had long roused the ire of its rulers. With the arrival of the British in 1601, the Shah saw hope of delivery. Their broadcloth was traded in Persia, since the Indian climate was unsuitable for its use in that region, and in exchange silk was traded, thus breaking the Turkish customs monopoly. English assistance was sought in dislodging the Portuguese. The island of Kishur, which provided Hormuz with water and supplies (Hormuz was entirely barren, since it was covered with a salt efflorescence), was captured and Hormuz finally defeated, thus ending Portuguese domination in the Gulf.

### *Ghilzai Dynasty*

During the Afghan rule the Russians gained territory under Peter the Great, and, under a treaty with the Turks, gained the three Caspian provinces (which were restored at his death) while the Turks gained the western provinces held before Shah Abbas. A Persian revival took place and the combined forces of the dethroned Tahmasp and Nadir (who later assassinated Tahmasp) defeated the Afghans and regained much territory lost to the Turks, as well as marching through Kabul and Peshawar to Delhi, where the Indian army surrendered. Nadir was the last great Asiatic conqueror, but the tremendous riches gained in his battles were not used wisely and his great abilities declined into avarice and cruelty. Afghanistan was founded at his death in 1747. From 1750 to 1794 the Zand dynasty ruled in Persia until their defeat by the Qajars.

### *Qajar Dynasty (eighteenth to twentieth centuries)*

Aga Mohammad Khan was crowned in 1796 after reducing various factions in the country to obedience. The early period of this dynasty's rule was characterized by insecurity, which naturally led to apathy in the peasants' attitude towards their land.

Napoleon attempted to gain influence in Persia since he wished to use it as a base for his fantastic plans in India. In 1814 a treaty concluded with the British ensured an agreement that Persia would conclude no treaties with enemies of Britain in return for an annual payment of £150,000 should Persia enter into any war. There were, however, wars with Russia in an unsuccessful attempt to regain Georgia, and with Afghanistan for Herat. As a result the country was on the verge of revolution and bankruptcy at the death of Mohammad Shah in 1848.

During this period the bodyguards of the princes are described as having a daily payment of barley, wheat and straw except in spring when horses could graze [118]. Each had an allotment of land for the maintenance of their families which they tilled, sowed and reaped. The standing army's depradations were a source of terror to the peasants. Fraser [74] states that the country between Teheran and Qazium was made a desert by military movements just before and after the death of Fath Ali Shah; he mentions the cutting of fruit trees near Burujiro by troops. Throughout this period the power lay with the landowners who kept armed retainers. As large regions were tribal areas there was constant strife which, in addition to the skirmishes with the Ottoman Empire, Russia and Afghanistan, can have done little for settled agriculture. The semi-nomads grazed their flocks of sheep and goats and also possessed cows, horses, asses and bees. In 1829 Malcolm found that the tax on land was one-fifth in kind, whether wheat, barley, tobacco, silk or indigo, and on vegetables and fruit one-fifth in cash, though this was by no means universal; a complicated and variable fiscal system prevailed.

Though little interest in agriculture appears to have been shown by Mohammad Shah, apart from a distribution of seed to the peasants during a famine, his successor, Nasir-u-Din, had a most able adviser who endeavoured to abolish corruption, thereby arousing such hatred that he was assassinated. Unfortunately Nasir then reverted to the old method of governing and the country again headed for bankruptcy. There are records, however, that cultivators were encouraged to work unirrigated government land, chiefly with rice and grain [118]. Taxes on land varied according to the source of water—whether it came from a spring, river, underground channel, well or reservoir; there were frequent imposts for such vital purposes as the financing of a royal wedding or the entertainment of a visiting potentate. Decay, maladministration, oppression and insecurity were generally characteristic of the entire Qajar period.

Growing discontent and a desire for reform in the second half of the nineteenth century led to the granting of a Constitution in 1906 by Muzaffer-u-Din. His successor, the last of the oriental despots, Mohammed Ali, tried to overthrow the Constitution, but was himself overthrown in 1909. Trade and foreign influence penetrated the country with the 1907 treaties with Russia and Britain. Financial difficulties under Sultan Ahmad Shah led to the calling in of the American Morgan Shuster in 1911 and the Swedes to advise on the organization of the police force, though the efforts of neither were attended with any conspicuous success.

Sykes states that in pre-war days Russo-Persian trade flourished, especially as Russia discriminated her tariff in favour of cotton and other raw materials such as wool, and also of carpets, dried fruits, wheat and barley. Wool, opium, pistachio nuts, carpets and some wheat were exported to Britain. In 1923 and 1926 treaties of 'perpetual peace' were signed between Afghanistan, Persia and Turkey and the three Islamic states agreed to 'westernize' their subjects [184].

The end of the Qajar dynasty and the coming to the throne of the revered Shah Riza was marked by his determination to secure the complete independence of his country and the establishment of law and order.

## IRAQ

To give a complete sequence of the history of land use in Iraq would involve too much repetition, since so many examples from the Tigris-Euphrates valley or its associated desertic region, oases or 'hilly flanks' have already been used. Only a brief recapitulation will be given, supported by a chronological table (Fig. 7) quoted from Piggott [153] to indicate the early sequence and its relation to Iran, the Caucasus and adjacent regions (with the qualification that the date sequence may have changed, particularly in the case of Anau, since the use of the carbon-14 method).

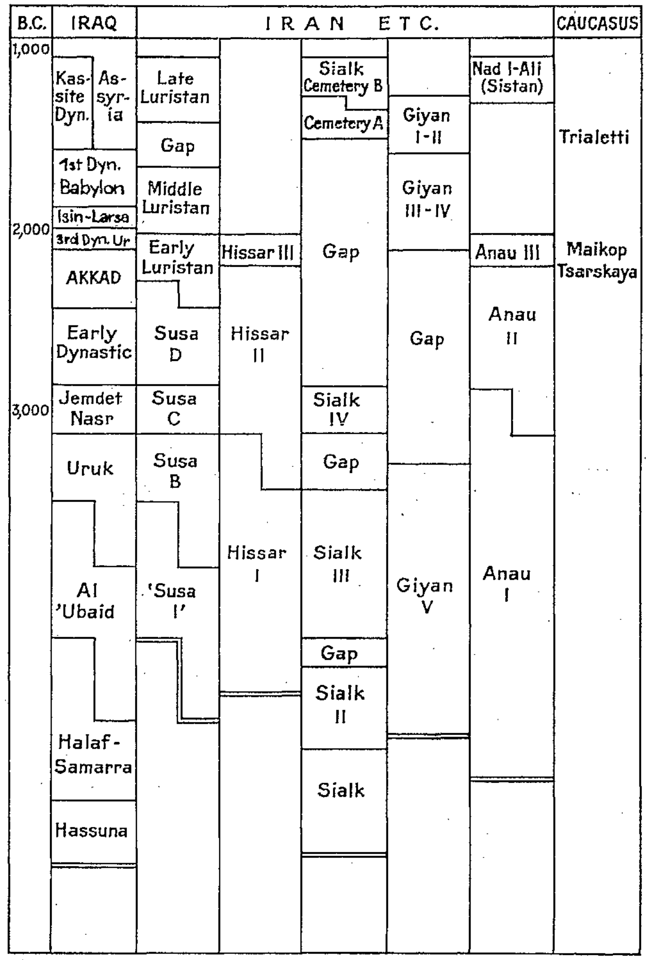



FIG. 7. Chronological table of communities in Western Asia. (After Piggott [153]).

### *6000 B.C. to Halaf-Samarra period*

The oldest traces of human occupation are from the Palaeolithic and Neolithic periods, namely in the foothill area of the Zagros mountain range in the north-eastern part of the country [21, 177, 217], although there is little reason to doubt that similar sites will not be found in the Iranian part of the Zagros adjacent to Khuzistan, the region in which Robert Braidwood and his associates are now working.

It is also probable that there were human habitations in Palaeolithic times around natural depressions and areas of internal drainage in what is now the arid country of western Iraq. There is evidence that some of these depressions were lakes in those times, caused by at least one humid interval (fluvial period) which occurred during the Palaeolithic [197]. Flints found in the Western Desert near Rutba indicate human occupation during the Stone Age.

The oldest, non-sedentary people lived in caves, but may have occupied open sites as well, and they subsisted by food-collecting and hunting. Rock paintings of these early people have been found in the Zerzi and Hazar-merd caves near Sulaimaniya, and near Agra. The oldest evidence of sedentary agriculture of the pre-pottery era (Early Neolithic *c.* 6000 B.C.) found near Jarmo, north-east of Kirkuk, has already been discussed in sufficient detail [21, 214]. Sites of this type were apparently followed by more settled communities in the sub-montane plain in north-eastern Iraq (Hassuna period, approximately 5000 B.C.).

### *City-States, Sumeria, Akkad and Ur*

However, Mesopotamia was not considered suitable for human occupation in the Neolithic or Pre-Halafian period, or during the Halaf-Samarra period, and was apparently used only for grazing in spring and early summer and for hunting game. Southern

Iraq or Lower Mesopotamia was settled in the Al Ubaid period (about 4200 B.C.) by the Sumerians who brought with them *Triticum dicoccoides*, *Hordeum hexasthicum* and flax. Flaked chert hoes were used for tilling and sickles from hardened baked clay or of flint set in bitumen were used for reaping. Game and fish were important items in the diet [198]. Crops were grown under irrigation and date orchards were found along the rivers.

Meanwhile, the organization into city-States had gradually taken place (Early Dynastic period, 2700-2400 B.C.). Co-operation and centralized control were necessary for the proper functioning of the irrigation systems essential to agriculture in southern Iraq. One or sometimes two of the city-States would have hegemony over the others and the dynasty of kings of that State would have nominal authority over a whole federation of States. However, irrigation disputes frequently led to inter-State wars, and there were the periodical floods to destroy man's work. These floods and the irrigation, which has been practised for about 6,000 years, have had marked effects upon the physiographic characteristics of the alluvial plains of Iraq. The rivers have changed their courses many times, so that the pattern of levee soils and basin soils is now found not only in the horizontal but also in the vertical direction, causing in many places a stratification of alluvial deposit several metres thick. The silt-laden irrigation water necessitates constant cleaning of the system, leading to the raising of the banks and finally to abandonment of old and the digging of new canals, often parallel to the original ones.

The first central government in Lower Mesopotamia was established during the Akkad period (2360-2300 B.C., Sargon I) when Sargon first subdued the northern tribes and those from the Zagros Mountains and then conquered Lagash and the other Sumerian cities. His son, Naram-sin, consolidated these conquests, but shortly after his reign a catastrophic economic collapse took place, accompanied by an invasion of nomadic tribes from the mountains to the east, the Gutians. This is a recurring pattern in the history of Iraq, a period of flourishing economy and civilization being interrupted by a period of internal strife, followed by economic crisis, and ultimately by foreign invasion. Jacobsen [99] writes :

> The internal strife concentrates the attention of the warring local powers on immediately compelling military tasks. As the government forces are withdrawn from their peacetime function of policing and maintaining law and order, and as resources and manpower are drained away from essential works to maintain the canal system and from work in the fields, rapidly growing lawlessness interferes more and more with communications, with commerce, and with the normal agricultural pursuits; pasturing and work in the fields become difficult and perilous; silting and breaches put canals out of function, agricultural production declines sharply. If such conditions continue, the results are economic disaster, breakdown of orderly life, and infiltration from plundering nomads across the unprotected borders into fields and open areas between the towns, even invasion in force by conquering hordes.

These chaotic conditions continued until a strong government was again established under the Third Dynasty of Ur. But now a new enemy, salinity, was arising to threaten the prosperity and power of the State.

### *Babylonia, Assyria and the Achaemenian Persians*

After the disintegration of the Sumerian Empire, earlier settlements were resumed in other parts of the Mesopotamian plain under independent rulers; in the central area, settlement extended into swamps which were drying up. Meanwhile a western Semitic dynasty under Hammurabi, the seventh and most important king of this Amorite dynasty (beginning about 1750 B.C.) became established at Babylon. Hammurabi subjugated Ashur, the birthplace of the future Assyria. A detailed description of agriculture during this prosperous old Babylonian period is given by Meissner [131]. Agriculture was an esteemed vocation since it was from godly origin. Ninurta and Ningirsu were gods of agriculture. A farmer was called 'a man of Ningursu'. Nebuchadnezzar later called himself 'the irrigator of the fields, the farmer of Babylon'. It was a saying that tilling of the land was as necessary as the fulfillment of marital duties : 'A field which is not cultivated is as a woman without a husband.'

The best and most extensive areas were the property of the royal family. The priests, as representatives of the gods, also owned land and there thus arose rivalries with the king. The temples, priests, priestesses and most powerful landlords leased their land; the cultivators, however, were in constant debt to the moneylenders and bankers. Landowners and bankers constructed canals; the cultivators had to pay for the use of water (in the case of dates this amounted to a quarter of the harvest), and also had to maintain the canals.

Wheat and barley used to be grazed before being left for grain. Horticulture was concentrated around the towns and horticulturists were usually better off than the farmers, especially when the orchards were in the fruit-bearing stage. But even they seem to have been bound by debts to the money-lenders and bankers. Meissner [131] gives some examples of lease contracts between landlords and cultivators. The land-tenure system, as well as other aspects of agricultural dealings, were included in the Laws of Hammurabi. Land was usually leased for one year and even if for some reason the land was not used after it had been rented, payment still had to be made. The lease for virgin soil was for three years. There were penalties for trespassing or for negligence of the irrigation system and fines were imposed for pasturing sheep on cropland without the owner's consent.

Land preparation, planting and maintenance of the crop were usually carried out by local manpower, often by slaves, though paid labourers from neighbouring tribes or countries came for the harvest. Dates formed an important part of the diet and many parts of the date palm were used for domestic purposes. The piths were used either as fuel for the furnaces of the blacksmiths or as cattle feed. Conquering armies did not usually destroy date palms and fruit-bearing trees. Figs, pomegranates and other varieties of fruit trees were planted between the date palms. Wheat, barley and millet were the staple crops and sesame the main source of oil. Pulses, flax and various vegetables were also grown. Goat's milk was widely consumed, while in the marsh areas fish and the wild boar formed important sources of protein. Mesopotamia is, however, repeatedly reported to have been deficient in trees for fuel and other purposes.

In Assyria, meanwhile, conditions were different. This country, covering the foothills and submontane plain of the north, depended on rainfall for its agriculture. Some irrigation was effected through the subterranean aqueducts *(kanats)* and a few canals, such as in the triangle between Nimrod, Tigris and the greater Zab, and some dams were constructed. When the Greeks arrived under Alexander, the irrigation system had become so ruined owing to the decline of the Persian Empire that the Greeks thought that the dams had been made to prevent the enemy from approaching the towns by ship.

The main crops in Assyria were wheat, barley, some millet and sesame, and the vine, to the cultivation of which numerous references are made. The olive was introduced. Sennacherib established experimental gardens near Nineveh where he planted species of plants he had obtained abroad during his expeditions.

The Kassites coming from the mountains in the east had conquered Babylon in about 1400 B.C., and Babylonia was subsequently invaded, frequently by tribes who came down the Euphrates. Babylonia then became a province of Assyria till, after the sack of Nineveh (606 B.C.) by the Medes, a Chaldean dynasty temporarily revived the glory of Babylonia. The Neo-Babylonian Empire ended when Cyrus, the Achaemenian Persian, conquered Babylon (539 B.C.). Persian kings ruled until 331 B.C. when they were in turn defeated by Alexander the Great. The Achaemenian Persians did, however, establish an orderly State, with a well-organized administration. A good road system connected the main administrative and commercial centres. The country became prosperous, as is illustrated by the fact that, when the Jewish exiles were allowed to return to Judaea, only some of them left Mesopotamia.

### *Seleucid Empire*

After Alexander the Great, Mesopotamia and the other areas now comprising Iraq became part of the Seleucid Empire (300-100 B.C.). Alexander and his successors undertook to urbanize the country [75]. Greek and Macedonian colonists were brought in and the Hellenistic influence was felt, especially in the higher classes of society. The colonists were given land, a farm, a house, seeds and cattle. Land was also allotted to the cities, and was cultivated by the peasants attached to them. They often formed communities enjoying a certain degree of autonomy. The status of farmers working on the land holdings belonging to the cities was, however, better than that of the farmers cultivating land belonging to temples, members of the royal family, or officials [75]. When the stream of Greek colonists slackened the prosperity of the cities and consequently of the country as a whole declined. Rice first appeared in Iraq about 300 B.C., probably as a result of the contacts made with the east through Alexander's expeditions to India.

The Seleucid Empire fell apart into petty States, ruled by satraps and feudal lords; finally, the eastern part was taken over by the Parthians, while the northern area was conquered by the Romans.

### *Roman period*

During this period vassal States on the borders, such as Palmyra, were first left more or less autonomous, and only in the first century B.C. was a more centralized administration imposed. The boundaries of the Roman Empire approximately skirted the northern part of Iraq. A frontier fortress which played an important role at this time was Singara, just south of Jebel Sinjar. Hatra, a kingdom formed in northern Iraq by an Arabian tribe, withstood Roman attacks and was only conquered later by the Sassanids. Many military expeditions were sent further south and east. Mesopotamia was the scene of numerous battles between Parthians and the Romans, and later between the Sassanians and the Romans. During this period there was no marked distinction between farmers and nomads in lower Mesopotamia. Tribes from Arabia came to graze in the area.

### *Sassanid period*

The country became prosperous again under the Sassanid king Chosroes (A.D. 531-578). Ctesiphon was his winter capital. His reign was characterized by actions to restore and develop agriculture and irrigation, rebuild villages, repair roads, etc. Chosroes is particularly noted for an irrigation work of great magnificence, constructed under his reign. The Diyala River had since ancient times irrigated an area east of Baghdad, which had followed roughly the same pattern of abandonment and re-settlement as other parts of Central Mesopotamia. In late Parthian times the Diyala was used to full capacity. In order to make more water available for the necessary expansion of agriculture, Chosroes ordered the construction of a new canal, branching off from the Tigris north of Samarra. This canal (Katul) was to feed the irrigation system in the lower Diyala region and, through the Nahrwan canal, to extend the irrigated area east of the Tigris almost as far as Kut. The Katul and Nahrwan together form one of the longest canals built in history, serving an area of over 200 miles in length. Several other canals had been dug in the early part of the Christian era, all branching off from the Euphrates, running in a south-easterly direction and joining the Tigris respectively between a location north of Baghdad and a point a few miles south of Kut. Some had been dug by the Romans during their campaigns against the Sassanids to transfer their fleets from the Euphrates to the Tigris.

### *Arab period*

After the death of Chosroes II feudal lords came to power and the Sassanian Empire crumbled into a collection of petty States. Disruption of the government administration again led to reduced prosperity. Moreover the almost perpetual struggles between Persia and Byzantium had exhausted the resources of the country. Under these conditions the Arab advance could hardly be opposed. Reorganization of the administration and resettlement of the rural areas took place during the Omayyad and early Abbasid periods (A.D. 650-950) Khalid ibn Abdulla al Qasri was the energetic governor for Hisham (724-743) who rebuilt dams and reconstructed irrigation systems. Part of the marshy area north of Basra was drained in the early Islamic period. At this time the Diyala region was one of the most prosperous regions of Mesopotamia.

During the Abbasid and subsequent periods there were five main types of land ownership : (a) Khalif's estates; (b) land granted by the khalif; (c) private lands; (d) *Wakuf* lands (donated and held in trust for the public or private benefits); and (e) public domains (for pasturing, with rights of use open to the public).

The history of land tenure, chiefly from the rise of Islam, has been described by Hassan Mohammed Ali [4].

### *Seljuk period*

With the advance of the Turks in A.D. 937 the Nahrwan canal was breached to inundate the area east of Baghdad for defensive purposes. This breach was later closed and some resettlement took place, but a later flood caused the final disruption of this canal system [99]. Meanwhile salinity again began to affect agriculture, this time in the central part of the alluvial plain, owing presumably to the gradual rise in the water table, and reduced the prosperity of the region, as it had done in the south in Sumerian times.

During this period the irrigation systems were again allowed to fall into a state of general neglect, the sultans being more interested in fighting each other than in constructive administration. Some degree of prosperity was, however, regained under certain Seljuk rulers, e.g., Malik Shah.

### *Mongol invasion*

Devastation reached a peak during the Mongol invasion and occupation in the mid-thirteenth century. During the three centuries that followed their advent, chaos prevailed. There was no security and thus no incentive to farming. The irrigation network was neglected, farmers were allowed to break dykes and banks of ditches and canals as they pleased, and canals were not maintained and kept at the required depth. Moreover 'tribe after tribe of nomads from the steppes of Nejd and the Jezirah crossed the Euphrates to the pastures of Iraq. Grazing grounds were allotted to the unending processes of tribal war and policy. From the Lurish hills to the Sinjar, Iraq became a country of few and small towns, while around and between lay tracts grazed and dominated by the tribes alone' (Seton Lloyd [125]).

### *Ottoman period to present day*

During the Ottoman era (from the sixteenth century onwards) several tribes remained fairly independent. A state of confusion prevailed, especially with regard to the land tenure system. Little reconstruction took place of what had been destroyed and neglected during the Mongol period. Taxes were high and tax-collectors enriched themselves at the cost of the farmers. Some governors were able to regain control over the outlying provinces *(vilayets)* and to establish a well-organized administration over the whole country. Among these were Ahmed Pasha and Sulaiman Pasha, under whom the country was ruled through the Mamelukes, administrators of Circassian slave origin.

In 1857, a land tenure law was drafted with the object of abolishing the system of land grants to the sheikhs. The law, however, was inadequately enforced and clashes were frequent. Madhat Pasha, Governor of Iraq in 1869, tried to solve the confused land tenure system which was hindering agricultural development, but later fertile lands were again given to high civil and military officials. In 1883, Sultan Abdul Hamid appointed a special committee to study land tenure problems and 30 per cent of the cultivable land was bought by the government at nominal prices. The administration also tried to introduce other improvements into the rural areas (schools, mosques). During the latter part of Turkish rule, the central government obtained more power and the tribal system started to disintegrate, but in the Mandate period the tribal system was again upheld as a basis for easier control of the country [4]. Also towards the end of Turkish rule, efforts were made to improve and extend the irrigation system, e.g., the barrage at Hindyia.

During the periods of the Mandate and of independence, further improvements were made in the irrigation system, including the new Hindyia barrage and the Kut barrage. Several new crops were introduced and found their place in the farming economy (cotton). The period following the second world war has been characterized by numerous projects financed by oil royalties, especially after the fifty-fifty share of profits between the government and the oil companies was arranged. Major undertakings include the flood control projects (Habbaniya Lake, Tharthar Depression), and the storage reservoirs in the tributaries of the Tigris to regulate the flow in these rivers (Dokkan and Derbendikhan dams). A major problem, however, remained unsolved : the land tenure system. It was not until the revolution of 1958 that drastic measures were taken to solve this. The problem which is second in magnitude, salinity, has received the attention of the various post-war governments to an increasing extent.

## THE INDUS VALLEY

### *Prehistoric Baluchistan and the Harappā culture* (*c.* 3000-2000 B.C.)

Agriculture was apparently introduced into the region from the west, probably well before 3000 B.C. The climate of Baluchistan and Sind must have been more humid then, since there are abundant traces of ancient occupation in the Baluchi hills, and *tells* of a hundred feet or more are a witness of long-enduring continuous occupation; a large number of stone-built dams and terraces for irrigation indicate not only greater rainfall, but also a large population to provide the necessary labour for their construction [153]. Remains of forests have also been found [95].

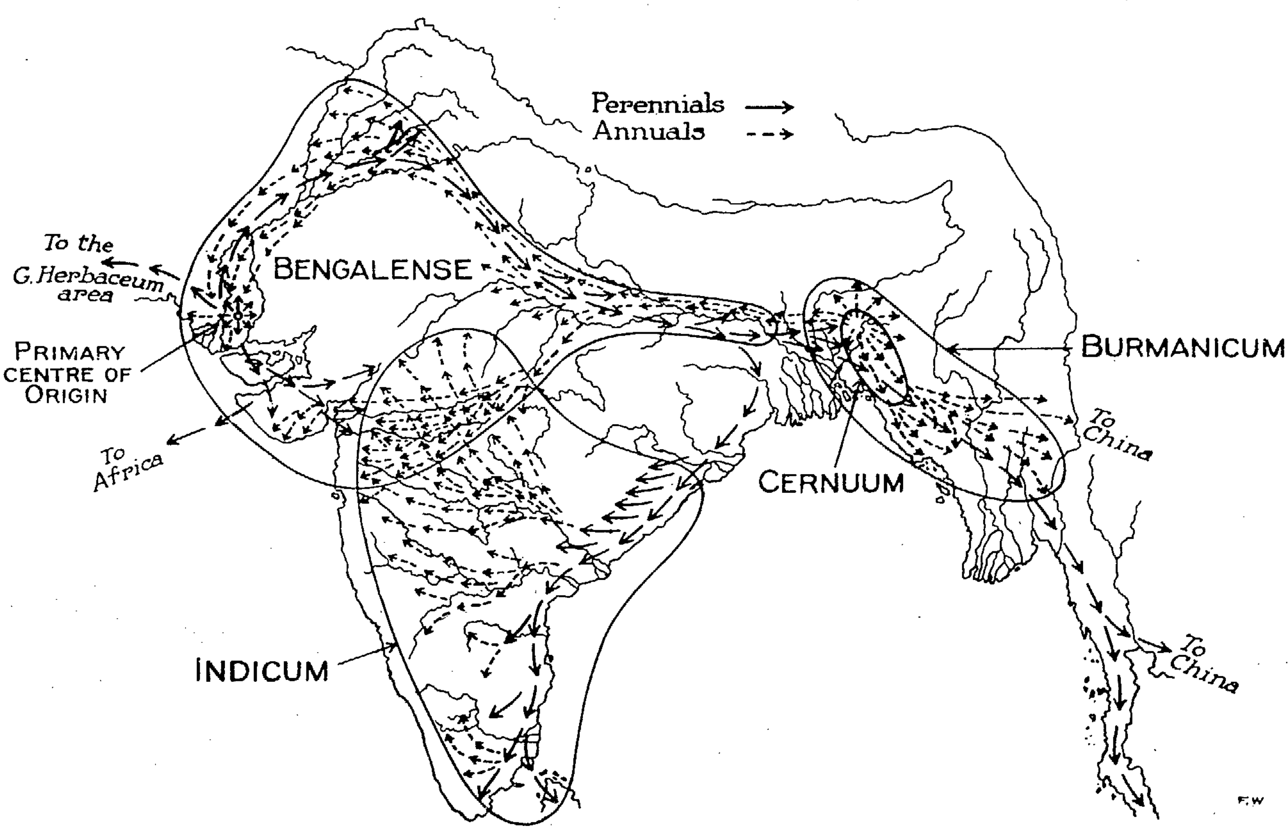



FIG. 8. Distribution of *Gossypium arboreum* (after Hutchinson *et al.* [97]).

The village settlements of Baluchistan and Sind are generally of earlier date than the cities of the Indus Valley, although some are contemporaneous. Pottery was widely used, and there is evidence of metal-working. Houses were built of mud brick. The domesticated animals included the humped ox, sheep, ass and horse; the evidence for goats is not quite conclusive. Trade between Baluchistan (Kulli) and both Mesopotamia and Harappā is attested to.

The Harappā culture, with its twin capitals, Harappā and Mohenjo-daro, covered an area extending from the Makran coast to Kāthiāwār and the Gulf of Cambay, north to the Himalayan foothills and eastward to the Jumna basin. The origin of this culture, which first appears in full maturity, is completely unknown. It was a highly organized civilization, with standardized artifacts, weights and measures. Agricultural production was under municipal control, and great granaries and grain-grinding floors existed in the cities [204]. To maintain the uncommonly high living standard of the urban population, a well-organized agrarian system must have existed, but there is no direct evidence of its nature or of the irrigation devices which might be expected to have existed. However the Harappans were builders of dams, tanks and excellent drainage systems for urban purposes. Bread wheat *(Triticum compactum* and *T. sphaerococcum)*, barley *(Hordeum vulgare* and *H. hexastichum)*, sesame, field peas and species of *Brassica* were grown. Dates were eaten. Cotton seems to have been an important crop, and probably constituted at least part of the trade with Mesopotamia [153]. According to Hutchinson *et al.* [97], however, Herodotus does not mention cotton being worn in Babylonia. The centre of origin of *Gossypium arboreum* lies in the Indus Valley (Figs. 8 and 9), and the factors governing primary differentiation must be sought in the geographical and ecological conditions of that region [209]. The domestic animals included the zebu, as well as a smaller, humpless short-horn buffalo, goat, sheep, pig, dog, cat, camel, horse, ass and elephant. Copper and bronze were forged and cast from the very beginning.

The Indus Empire appears to have been ruled by a priest-king. Certain elements of present Hindu belief, especially the worship of Sakti, the Divine Mother, and of Siva, seem to go back to these pre-Aryan times. Piggott [153] writes : '. . . the humped bull, whose privileged position today, as he noses his way unmolested through the bazaars, helping himself to whatever takes his holy fancy, must date back to the third millennium B.C. on the banks of the Indus and the Ravi'.

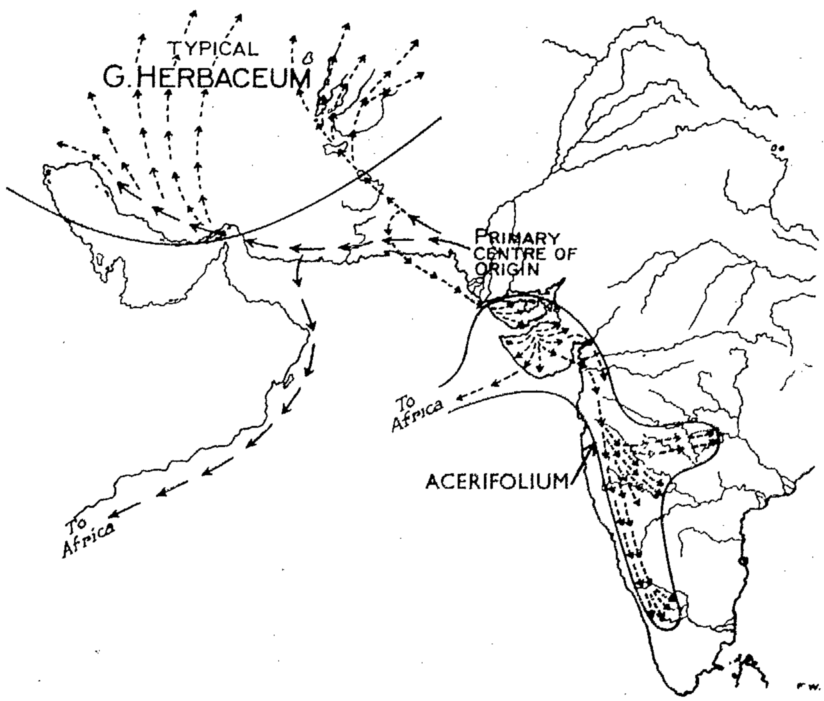



FIG. 9. Distribution of *Gossypium herbaceum* (after Hutchinson *et al.* [97]).

Piggott infers from the faunal representations on artifacts, the wood needed to burn so many million bricks and the implication of a flourishing agricultural background, that the climate must have been different from the present rainfall of less than six inches per year. The very use of burnt brick might imply the need for a durable building material under heavier rains. Piggott suggests that the climatic deterioration might have been caused by an eastward shift of the edge of the south-western monsoon, and that thus the Indus might formerly have been within the monsoon area. This, however, would make the absence of any devices for the control of floodwater even more incomprehensible [55]. However Wheeler [206] refers to embankments at Mohenjo-daro and Lothal.

### *Aryan invasion and Vedic times* (*c.* 2000-600 B.C.)

The Aryans who arrived in India from the west were an agricultural people, users of bronze but not of iron. Although they grew grain crops, probably mainly barley, livestock husbandry was of primary importance. Wealth was reckoned in cattle, of which red, black, dappled and light-coloured types (Sindhi, Gir and Hariana?) are mentioned in the Rig-Veda. Goats and sheep were also reared. The most characteristic animal was the horse, although the Aryans were not the first to domesticate it in India or the western borderlands. Milk and meat products were evidently an important item of diet, and beef was freely eaten. The ritual prohibition of flesh is connected with later ideas of transmigration which are foreign to early Aryan beliefs [153]. Fields were tilled with apparently fairly heavy ploughs, since teams of six to twenty-four bullocks were used. The practice of manuring has been suggested, although generally speaking the fields were productive [129]. Some artificial water supply is implied by a reference in the Rig-Veda to 'waters produced by digging', suggesting wells rather than irrigation schemes, although Majumdar *et al.* [128] mention the frequent use of irrigation canals.

The Aryans of Rig-Vedic times lived mostly in villages. There are different opinions on the nature of landownership; some scholars hold that the land belonged to the community, others that there was individual ownership by cultivators [129]. It is at any rate likely that grasslands were held in common. Houses were probably built of wood or reeds. Cotton, wool and deerskin were used for clothing.

In early times, Aryan society was divided into three classes, warriors, priests and cultivators. The basis of social organization was the patriarchal family. Small kingdoms existed in the whole country from Kabul to the upper Ganges, but in time some of the weaker tribes were absorbed by their neighbours and cities began to appear in later Vedic times. During this same period, the caste system began to take shape, the Brahmans acquired paramount importance, meat-eating was beginning to be looked upon with disfavour, and Hindu religion evolved towards its present form. In some of the villages, landlords obtained possession of the entire land and replaced the peasant owners. There were important developments in taxation and revenue administration. The system by which the Indian peasant still makes direct or indirect payment to the State is one of the oldest institutions of the country and is prescribed by the sacred law of Hinduism [136]. The payments were made in kind, and probably amounted to one-sixth of the produce, or sometimes perhaps even to one-third. Agriculture continued to be the principal occupation; farm implements were improved, and new kinds of grain and fruit trees grown. Rice, which may have been cultivated in early Vedic times, was certainly grown then [128]. Houses continued to be built of wood [59].

### *Persian Conquest and Alexander's Campaign* (*c.* 600-325 B.C.)

Western India was the most populous satrapy of the Persian Empire and paid a tribute proportionately larger than all the rest, equivalent to more than a million sterling.

A number of interesting points were reported by the chroniclers of Alexander's Campaign, as quoted by Theophrastus and Strabo. There is reference to pistachio, vine, olive and silphium (identified as *Ferula tingitana* in Theophrastus [189] in the mountainous region. Large quantities of fir, pine, cedar and other suitable timber were cut in the region between Jhelum and Chenab for the building of Alexander's fleet. 'The typical "monsoon" crops of cotton, cane sugar and rice were grown in the Indus valley, where the Greeks first made acquaintance with them.' (Cary, [39].) Millet, sesame, barley, pulses and bosmorum (a kind of corn smaller than wheat) are also listed by Strabo, *Sorghum halepense* and black gram by Theophrastus, who states that 'chick-pea, lentil and other such plants found in our country do not occur.' The ancient records suggest that the region of Musicanos (Sind) was still fertile, producing 'everything in abundance'. Wheat, grapevine, banyans, jack-fruit, banana, mango, jujube and possibly carob are mentioned. Aristobulus, however, remarks that he experienced no rainfall on his ten-month voyage down from the Jhelum, ending at the mouth of the Indus in late summer. 'It is admitted that the plains which are not overflowed do not produce anything for want of water.' (Strabo [183].) Gedrosia (Baluchistan) is described as a very barren country, with watering places often a heavy day's march apart, producing quantities of nard and myrrh, but little food beyond the date, which saved the life of many a Greek soldier.

### *Hindu India* (*c.* 325 B.C.-A.D. 700)

Megasthenes, ambassador of Seleucus Nicator at the court of Chandragupta Maurya, reported that the bulk of the revenue came from the taxation of the agricultural class, since all land belonged to the king and the farmers cultivated it on the terms of receiving as wages a fourth part of the produce [183]. The policy of the Maurya Government was to provide for the even distribution of the agrarian population by systematic plantation of villages in thinly occupied tracts. For the general improvement of agriculture, officials were appointed to superintend the rivers, measure the land and ensure an equitable distribution of irrigation water. The government water rate was, however, a heavy burden, varying from one-third to one-fifth of the produce [59]. The farmers were exempted from fighting and other public service.

When flood, fire or locusts destroyed the harvest, food was issued from the government storehouses. Herdsmen and hunters, who led a nomadic life and who alone were permitted to breed cattle, sell them or let them for hire, were also responsible for clearing the country of wild beasts and birds which ate the seeds. Implements for farmers were made by artisans who received maintenance from the royal exchequer. Vegetarianism had not yet been established, and even Brahmans ate meat, except apparently that of horned cattle (Strabo, quoting Megasthenes). However, Chandragupta's grandson, Asoka, who converted to Buddhism, abolished or restricted the slaughter and sacrifice of animals, put a stop to 'the massacre of living creatures to make curries in the imperial kitchen', and discontinued the royal hunt [128]. Brick again came into use during the Maurya period.

The death of Asoka was followed by various invasions of western India by Bactrian Greek and Seleucid armies. 'The slight information that we possess seems to show that no changes fundamentally affecting Indian life were made by the new Greek rulers' (Rostovtzeff, [165]). Later came the invasions of the Scythians (Sacas), Yue-chi (Kushanas) and the White Huns, with their attendant disturbances and destructions. When the Buddhist pilgrim Yuan-Chwang came to India in the seventh century, vast stretches of territory, notably in the Swat valley, once prosperous, wore an appearance of desolation [200]. In Kashmir, the founder of the house of Uptala (ninth century) was famous for his irrigation works.

### *Pre-Moghul Mohammedan period* (*c.* 700-1520)

Under the Arab conquerors of Baluchistan, Sind and the lower Punjab the local administration was largely left in the hands of the people of the country and the taxation of the Hindu population was eminently fair. With few exceptions, the Muslim conquests made little alteration in the land taxation system, which accorded with the existing institutions of Islam. But, according to Dunbar [59], the situation changed under the Afghan kings :

'The Muhammadans kept their hold by means of widespread garrisons, while great fiefs were scattered over the country to provide local governors or hold the Rajput and north-west marches. As regards the bulk of the people, the attitude of the Indian peasant towards the government. . . and the religion of his rulers has always been one of complete indifference, provided he is allowed to cultivate his land in peace and without oppression. The Slave Kings were . . . cruel and intolerant only towards rebellion and banditry. All the minor posts dealing with such matters as land assessment and revenue were in Hindu hands, and the normal custom of the central government was to confirm the Indian rulers and landholders, as vassals, in the possession of their inheritances.'

Under Ala-ud-din (1296-1316) Hindu taxation was raised from the customary one-sixth of all land produce to one-half, and duties were levied upon all cattle, goats and sheep. However, with the exception of the jizya (poll tax), these are the only instances of special laws against the Hindus in Mohammedan legislation [37]. These taxes were abolished by his son.

Tughlak (1320-1325) encouraged agriculture by limiting the taxation of the gross produce to a tenth, and by making irrigation one of the public works. Famines occurred under Muhhammad Shah Tughlak (1325-1351). He tried to provide famine relief and to advance large sums to the peasants for seed grain, stock and improvements. Had his measures been practical, they would have led to a great development of agriculture. As it was, the seventy million tangas made available as an inducement to establish a theoretical crop rotation led to no concrete result. His successor, Firoz Shah, returned to the system of paying government officials by grants of land and their revenue *(jagirs)*. He reduced taxation to a level which left an encouraging margin for the cultivator, and abolished the annual benevolences levied by the provincial governors. Firoz gave a further impetus to agriculture by extensive irrigation works and the sinking of wells, for which a 10 per cent water-rate was imposed. Five great canals were dug to distribute the waters of the Jhelum and the Sutlej. One of these, which still exists, ran for more than 150 miles to irrigate the desert country up to Hisar-i-Firoza. The cultivated area increased enormously. According to Piggott [153], climatic conditions in Sind were better up to Moghul times than they are at the present day.

Desolation, famine and pestilence followed in the wake of Timur's invasion in 1398.

### *Moghul Empire* (*c.* 1520-1750)

Sher Shah (1540-1545) introduced a number of admirable reforms. The principles of land survey and revenue then laid down were elaborated during the reign of Akbar. From Bengal to the Indus, a succession of wells were dug and lines of fruit trees planted by the roadside. After Humayun's reconquest of his empire in 1555, the country was ravaged by famines.

In 1562, Akbar started introducing his reforms. His 'system of land revenue administration' still forms, though remotely, the basis of modern scientific methods. The assessment of Todar Mal, Akbar's finance minister, is the connecting link between the land revenue system of ancient India and that of the British administration. Akbar's system varied in different parts of the country. In Sind the original Indian practice was followed, a proportion of the produce was taken, and the risk of a bad year was equally shared by the government and the cultivator. In the more productive part of the country, the regulation system of assessment was introduced. The *jagirs* were maintained.

The agricultural community in Moghul times had an even harder life than it does today. The menace of famines through the failure of rains hung over the country. The provincial governors were ordered to pay special attention to irrigation works, but these efforts were not systematic and were probably intended for the benefit of towns rather than for that of cultivators. According to Moreland [186], the peasant ran a real danger of having his holding taken from him by officials; the country was therefore badly cultivated. Also territorial forces were raised by the *zamindars* (landowners) when required. The chief agricultural products of the Moghul Empire were wheat, barley, rice, millets, pulses, oil-seeds, sugarcane, cotton, hemp, indigo, drugs, pepper and spices. Silk weaving was quite a minor industry. Comparatively little trade crossed the land frontiers, on two regular routes: from Lahore to Kabul, and from Multan to Kandahar [59].

Tavernier [187] a French merchant who visited India between 1641 and 1667, says of the peasants: 'They are reduced to great poverty because if the governors become aware that they possess any property they seize it by right or by force. You may see in India whole provinces like deserts from whence the peasants have fled on account of the oppression of the governors.' Aurangzeb proclaimed the abolition of 80 imposts, from transit dues down to the taxation of goats, but because of the cupidity of the officials these concessions remained a dead letter.

Throughout the Moghul rule frequent rebellions and invasions took place in the Punjab and on the north-west frontier. Dunbar [59] states: 'When Nadir Shah entered India, the Punjab, then under efficient local administration was peaceful and prosperous. When he left it, orderly rule had been exchanged for utter desolation'.

### *Sikh rule in the Punjab* (1760-1849)

The Sikh administration has been described by Sir Lepel Griffin (1892) as the process of squeezing out of the unhappy peasant, Hindu or Moslem, every rupee that he could be made to disgorge. The revenue officer had to maintain cultivation at the highest possible level and at the same time keep the cultivator at the lowest possible point of depression.

### *British rule* (1843-1946)

Before British rule, which began in Sind in 1843 and in the Punjab in 1849,

> . . . made peace and security a normal condition, *zamindars*, their intermediaries and the cultivators were bound together by the necessity of defending life and property. With the establishment of British government this common interest disappeared and the only bond . . . was one of hard cash. . . . The population rapidly increased, and the competition for land became a serious problem involving increasing poverty. The problem created by a rapidly increasing agricultural population has intensified with the years. Nor has the land-hunger been lessened by industrialization. . . . It was clearly necessary to protect the agriculturist from the excessive rise of rents caused by the exactions of landlords who were in the position of monopolists . . . and by the land-hunger of the peasants. In 1887 a Punjab Tenancy Act was passed. The Punjab is mostly a land of small landowners and peasant proprietors, and the Act regulated the relations between these owners and their tenants as regards rent and compensation for improvement. . . . The Punjab Land Alienation Act of 1900 aimed at preventing money-lenders and shopkeepers from buying land from hereditary cultivators, or from holding such land on mortgage for more than twenty years without government consent. But it was difficult to make these provisions effective, and the problems of rural indebtedness and the 'fragmentation' of holdings . . . especially prevalent in the Punjab, had to be tackled in other ways. . . . The only practical large-scale relief for land hunger was to be found in government irrigation schemes, the Lloyd barrage being the largest work of its kind in the world, which had added by 1935 nearly 32 million to the acres cropped in British India, an increase of about 15 per cent. (Dunbar [59].)

The co-operative movement, started by an Act passed in 1904, developed greatly in the Punjab, where the co-operative societies opened savings banks, encouraged livestock breeding, consolidated fragmented holdings, sank numerous wells and reclaimed waste land. Nevertheless, rural indebtedness continued to increase. After the serious famines of 1861, 1896 and 1900-1901, due partly to failure of rains and partly to unsettled conditions, famine relief measures, including the suspension of land revenue collection and the provision of loans for restocking the farms, were perfected. The cotton slump following on the boom caused by the American War of Secession had disastrous financial consequences.

### *Independence and Partition* (from 1946)

In Pakistan Punjab, and in the North-West Frontier Province, the average holding is less than five acres.

Land tenure in Baluchistan is characterized by a tribal structure, in Sind by the existence of vast *zamindari* or *jagirdari* areas. In the Punjab the government has abolished *jagirs*, and has passed laws which ensure fixity of tenure to the tenants and also secure for them an equitable share of the produce. The Punjab Tenancy (Amendment) Act of 1952 fixes the tenant's share at 60 per cent of the total produce. The Sind Tenancy Act of 1950 determines this share as one-half to two-thirds according to the tenant's participation in irrigation costs [69]. Eleven million acres of land are to be brought under cultivation by irrigation [108]. Priority is being given to vast afforestation projects and at least 10 per cent of the recovered lands in the Indus irrigation scheme have been secured by the Forest Department for plantation [201].

ACKNOWLEDGEMENTS

The writer expresses his sincere thanks to those who commented on the first draft of the manuscript and provided supplementary information (Professor R. M. Adams, Professor Hans Bobek, Dr. Hans Helbaek, Henri Pabot, G. Perrin de Brichambaut, Professor L. Dudley Stamp and Sir Leonard Woolley), and to Pauline Bush, Peter van der Veen and Gerda Whyte for preparing the sections on Iran, Iraq and the Indus Valley respectively.

# BIBLIOGRAPHY

1. Adams, R. M. Developmental stages in Ancient Mesopotamia. *Irrigation civilizations.* Pan-American Union, 1955. p. 6-18.
2. ——. Survey of ancient water courses and settlements in central Iraq. *Sumer*, 14, 1958. p. 101-103.
3. Albright, W. F. *The archaeology of Palestine.* London, Pelican, 1956.
4. Ali, Hassan Mohammed. *Land reclamation and settlement in Iraq.* 1955.
5. Amschler, W. Goats from Ur and Kish. *Antiquity*, XI, 1937. p. 226-228.
6. Annales de l'est. *Iron, international colloquium : Le fer à travers les âges. Hommes et techniques.* Nancy, 1956.
7. Awad, Hassan. L'eau et la géographie humaine dans la zone aride. *Bull. Soc. Géogr. Égypte*, 31, 1958. p. 195-208.
8. Barker, H. Radiocarbon dating : its scope and limitations. *Antiquity*, XXXII, 1958. p. 253-263.
9. Birand, H. Vue d'ensemble sur la végétation de la Turquie. *Vegetatio*, V-VI, 1954. p. 41-44.
10. ——. La végétation anatolienne et la nécessité de sa protection. *Report for Sixth Congr. Internat. Union Conserv. Nature.* Athens, 1958.
11. Birot, R.; Dresch, J. *La Méditerranée et le Moyen Orient.* Vol. 2. Paris, Presses universitaires de France, 1956.
12. Bobek, H. *Die natürlichen Wälder und Gehölzfluren Irans.* 1951. (*Bonner Geogr. Abhand.* 8.)
13. ——. Beiträge zur Klima-ökologischen Gliederung Irans. *Erdkunde*, 6, 1952. p. 65-84.
14. ——. Klima und Landschaft Irans in vor- und Frühgeschichtlicher Zeit. *Geogr. Jber. Öst*, 25, 1953-54. p. 1-42.
15. ——. *Vegetationsverwüstung und Bodenerschöpfung in Persien und ihr Susammenhang mit dem Niedergang älterer Zivilisationen.* Geogr. Inst., Univ. Wien, 1958. (*Union Internat. Conserv. Nature, RT 7/Coll./4.*)
16. Boyko, H. On the role of plants as quantitative climate indicators and the geo-ecological law of distribution. *J. Ecol.*, 35, 1947. p. 138-157.
17. ——. On regeneration problems of the vegetation in arid zones. *Internat. Union Biol. Sci.*, Ser. B. (Coll.), 9, 1951. p. 62-80.
18. Braidwood, R. A preliminary note on prehistoric excavations in Iraqi Kurdistan. *Sumer*, VII, 1951. p. 99.
19. ——. Early food producers : excavations in Iraqi Kurdistan. *Archaeology*, 1952. p. 157-164.
20. ——. From cave to village : birth of agriculture and animal husbandry. *Sci. Amer.*, 187, 1952. p. 62-66.
21. ——. The Iraq-Jarmo project. *Sumer*, vol. no. X, 2, 1954. p. 120-138.
22. ——. Origins of agriculture and of the historical process of cultural evolution. *Year Book. Amer. Philosoph. Soc.*, 1955. p. 311-313.
23. ——. The Old World : post-paleolithic. In : *Nat. Acad. Sci. USA. Nat. Res. Counc. Publication* 565, 1957. p. 26-27.
24. ——. Jericho and its setting in Near Eastern history. *Antiquity*, XXXI, 1957. p. 73-81.
25. ——. Near Eastern Prehistory, *Science*, 127, 1958. p. 1419-1430.
26. ——. *Prelude to civilization.* (Background paper for a symposium on the Expansion of Society in the Ancient Near East and its Cultural Implications, The Oriental Institute, the University of Chicago, 4-7 December, 1958.)
27. ——; Braidwood, L. The earliest village communities of south-western Asia. *J. World History*, 1, 1953. p. 278-310.
28. ——; Reed, C. A. The achievement and early consequences of food-production : a consideration of the archaeological and natural historical evidence. *Cold Spring Harbor Symposia on Quantitative Biology*, 22, 1957. p. 19-31.
29. British Association for the Advancement of Science. Section H. Technology of ancient glass and metal. *Nature*, 178, 1956. p. 1430-1434.

30. BROCKELMANN, C. *History of the Islamic peoples.* (Translated by J. Carmichael and M. Perlmann). London, Routledge & Kegan Paul, 1949.
31. BROOKS, C. E. P. *The evolution of climate.* London, Ernest Benn, 1925.
32. BRUNHES, J. *Géographie humaine.* (Abridged edition.) Paris, Presses universitaires de France, 1956.
33. BURINGH, P. Pluvial phases in the Pleistocene and their influence on present soil conditions in Iraq. *Rapp. 6e Congr. Sci. Sol.*, E., 1956. p. 87-88.
34. ——. Soils of the oldest cultivated area of the world. *Rapp. 6e Congr. Sci. Sol.*, E., 1956. p. 89-91.
35. ——. Living conditions in the lower Mesopotamian plain in ancient times. *Sumer*, 13, 1957. p. 1-18.
36. BUTZER, K. W. Der Umweltfaktor in der grossen arabischen Expansion. *Saeculum*, 8, 1958. p. 359-371.
37. *Cambridge history of India.* 1922.
38. CANDOLLE, A. DE. *Origine des plantes cultivées.* 1883.
39. CARY, M. *The geographic background of Greek and Roman history.* Oxford, Clarendon Press, 1949.
40. CHICAGO UNIVERSITY ORIENTAL INSTITUTE. The Iraq-Jarmo Project 1954-5. *Antiquity*, XXX, 1956. p. 113-115.
41. CHILDE, V. G. *New light on the most Ancient East.* London, Routledge & Kegan Paul, 1954.
42. CHILDE, V. G. Civilizations, cities and towns. *Antiquity*, XXXI, 1957. p. 36-38.
43. COLE, S. M. Differentiation of non-metallic tools. In: Singer, *et al.*, *A history of technology.* Vol. 1, 1954. p. 495-519.
44. COOK, Stanley A. *The Laws of Moses and the Code of Hammurabi.* London, Adam & Charles Black, 1903.
45. COON, Carleton, S. *The history of Man.* London, Cape, 1955.
46. CRAWFORD, O. G. S. Early goats. *Antiquity*, XXX, 1956. p. 108-109.
47. CRESSEY, G. B. Qanats, karez and foggaras. *Geogr. Rev.*, 48, 1958. p. 27-44.
48. DARWIN, C. *The variation of animals and plants under domestication.* London, John Murray, 1875. 2 vols.
49. DEIMEL, A. Die Verarbeitung des Getreides (bei den alten Sumerern). *Orientalia*, 14, 1924. p. 26-38.
50. DEIMEL, A. Der Gemüsebau bei den alten Sumerern. *Orientalia*, 17, 1925. p. 1-33.
51. ——. Die Viehzucht der Sumerer zur Zeit Urukaginas. *Orientalia*, 20, 1926. p. 1-61.
52. ——. Produkte der Viehzucht und ihre Weiterverarbeitung. *Orientalia*, 21, 1926. p. 1-39.
53. ——. Fisch-Texte der Zeit Urukaginas. *Orientalia*, 21, 1926. p. 40-83.
54. ——. Haus-, Feld- und Waldtiere, Körperteile als Opfergabe, Vögel und Fische, Klassifikation der Landtiere zur Zeit Urukaginas. *Orientalia*, 22, 1926. p. 1-60.
55. DROWER, M. S. Water-supply, irrigation and agriculture. In: Singer, *et al. A history of technology.* Vol. 1, Oxford, 1954. p. 520-557.
56. DUERST, J. U. In: R. Pumpelly. *Explorations in Turkestan: Expedition of 1904. Prehistoric civilization of Anau.* Washington, 1908. (*Carnegie Institute Publication*, no. 73.)
57. ——. *Grundlagen der Rinderzucht.* Berlin, Julius Springer, 1931.
58. ——. *Festschrift zum 60. Geburtstag von Neue Forschungen in Tierzucht und Abstammungslehre.* Bern, Verbandsdruckerei A. G., 1936.
59. DUNBAR, G. *A history of India.* London, Nicholson and Watson, 1949. 2 vols.
60. EIG, A. Les éléments et les groupes phytogéographiques auxiliaires dans la flore palestinienne I, II. *Fedde. Repert. spec. nov. regni. veg. Beih.*, 63, 1931-2. p. 1-201.
61. ——. On the phytogeographical subdivision of Palestine. *Palest. J. Bot. Jerusalem*, 1, 1938. p. 4-12.
62. ENGLER, A. Ubersicht über die Florenreiche und Florengebiete der Erde. In: A. Engler and E. Gilg. *Syllabus der Pflanzenfamilien.* (8th edition). p. 352-364.
63. ERDTMAN, G. Personal communication, 6 March 1959.
64. EVENARI, M.; AHARONI, Y.; SHANAN, L.; TADMOR, N. H. The ancient desert agriculture of the Negev. III, Early beginnings. *Israel Explor. J.*, 8, 1958. p. 231-268.
65. EVENARI, M.; KOLLER, D. Ancient masters of the desert. *Sci. Amer.*, 194, 1956. p. 39-45.
66. FAROUGHY, A. Introducing Yemen. *Orientalia*, 1947. p. 126.
67. FEYLESSOUFI, E. *Underground water: kanats and deep wells in Iran.* 1958. (*Independent Irrig. Admin., Publ.*)
68. FISHER, S. *Ottoman land laws.* Oxford, University Press. 1919.
69. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. *Centre on Land Problems in the Near East, Salahuddin, Iraq.* 1955.
70. ——. Irrigation Team in Iran. *Report to the Government of Iran on the development of land and water resources in Khuzistan.* 1956. (Report 553.)
71. FORDE, C. D. Foraging, hunting and fishing. In: Singer, *et al. A history of technology.* Vol. 1, Oxford, 1954. p. 154-186.
72. FRANKEL, O. Invasion and evolution of plants in Australia and New Zealand. *Caryologia*, 6-suppl., 1954. p. 600-619.
73. FRANKFORT, H. *The birth of civilization in the Near East.* London, Williams & Norgate, 1951.
74. FRASER, J. B. *Travels in Koordistan, Mesopotamia.* London, 1840. 2 vols.
75. GHIRSHMAN, R. *Iran.* London, Pelican, 1954.
76. GLUECK, Nelson. *Rivers in the desert.* New York, Farrar, Straus & Cudahy, 1959.
77. GRIFFIN, L. *Ranjit Singh.* 1892. (*Rulers of India* series.)
78. GUERNEY, O. R. *The Hittites.* London, Pelican, 1952.
79. HAHN, E. *Die Haustiere und ihre Beziehungen zum Menschen.* Leipzig, 1896.
80. HAIDAR, S. *Land problems in Iraq.* London School of Economics, 1942. (Ph.D. thesis.)
81. HANCAR, F. *Das Pferd in prähistorischer und früher historischer Zeit.* 1956. (*Wr. Beiträge zur Kulturgeschichte und Linguistik*, XI.)
82. HARRISON, H. S. Fire-making, fuel and lighting. In: Singer, *et al. A history of technology.* Vol. 1, 1954. p. 216-237.
83. HARTMAN, L. F.; OPPENHEIM, L. On beer and brewing techniques in ancient Mesopotamia. *J. Amer. orient. Soc.*, vol. 70, no. 4, 1950. (Suppl., no. 10).
84. HEER, O. *Die Pflanzen der Pfahlbauten.* Zurich, Neujahrsblatt der naturforschenden Gesellschaft in Zürich, 1865.

85. Hehn, V. *Kulturpflanzen und Haustiere in ihrem Uebergang aus Asien nach Griechenland und Italien sowie in das übrige Europa.* (7th edition.) Berlin, 1902.
86. Heichelheim, F. M. *An ancient economic history.* 1958. (*Wirtschaftsgeschichte des Altertums*, translated by Joyce Stevens).
87. Helbaek, H. Archaeology and agricultural botany. *Annu. Rep. Inst. Archaeol. Lond.*, 1953. p. 44-59.
88. ——. Plant economy in ancient Lachish. *Lachish IV: the Bronze Age.* Wellcome-Marston Archaeological Expedition., 1958. p. 309-317.
89. ——. Domestication of food plants in the Old World. *Science*, 130, 1959. p. 365.
90. ——. Notes on the evolution and history of *Linum. Kuml*, Aarhus, October 1959. p. 103-129.
91. ——. Personal communication, May 1959.
91*a*. ——. Personal communication, March 1960.
92. Herodotus, *The histories.* (Translated by G. Rawlinson.) London, Everyman, nos. 405/6, 1910. p. 366 and p. 353.
93. Hilzheimer, M. *Natuerliche Rassengeschichte der Haussäugetiere.* Berlin and Leipzig, 1926.
94. ——. Zoologische Bemerkungen zu den Tierdarstellungen. In: E. Heinrich. *Kleinfunde aus den archaisischen Tempelschichten in Uruk.* Berlin, 1936. p. 48-54.
95. Holdich, T. *The gates of India.* London, Macmillan, 1910.
96. Hutchinson, J. *Genetics and the improvement of tropical crops.* Cambridge, University Press, 1958.
97. Hutchinson, J. B.; Silow, R. A.; Stephens, S. G. *The evolution of Gossypium (and the differentiation of the cultivated cottons).* Oxford, Oxford University Press, 1947.
98. Huzayyin, S. Changement historique du climat et du paysage de l'Arabie du Sud. *Bull. Fac. Arts, Cairo Univ.*, III, part 2, 1935. p. 19-23.
99. Jacobsen, T. Salinity and irrigation agriculture in Antiquity, Diyala Basin Archaeological Project. *Report on essential results.* 1958. (Mimeographed.)
100. ——; Adams, R. M. Salt and silt in ancient Mesopotamian agriculture. *Science*, 128, 1958. p. 1251-1258.
101. Juvaini, Ata-Malik. *The history of the World Conqueror.* (Translated by J. A. Beyle.) Manchester, University Press, 1958. 2 vols.
102. Karatekin, N. Hydrological research in the Middle East. *Reviews of research on arid zone hydrology.* Paris, Unesco, 1952. p. 78-95. (*Arid zone research*, I.)
103. Kedar, Yehuda. Water and soil from the desert. Some ancient agricultural achievements in the Central Negev. *Geogr. J.*, 123, 1954. p. 179-187.
104. Keller, W. *Und die Bibel hat doch recht.* Düsseldorf, Econ. Verlag, 1955.
105. Kenyon, K. M. Jericho and its setting in Near Eastern history. *Antiquity* XXX, 120, 1956. p. 184-195.
106. ——. Reply to Professor Braidwood. *Antiquity*, XXXI, 1957. p. 82-84.
107. ——. Earliest Jericho. *Antiquity*, XXXIII, 1959. p. 5-9.
108. Khoja, M. A. H. *Consolidation of fragmented holdings in Pakistan*, 1955. (*FAO Centre on Land Problems in the Near East, Paper CP-10.*)
109. Klat, P. J. Musha holdings and land fragmentation in Syria. *Middle East Economic Papers*, 1957. p. 12-23.
110. ——. The origins of land ownership in Syria. *Middle East Economic Papers.* 1958. p. 51-66.
111. Kocher, F. *Keilschrifttexte zur Assyrisch-Babylonischen Drogen- und Pflanzenkunde.* Berlin, Akademie-Verlag, 1955.
112. Kramer, S. N. *History begins at Sumer.* London, Thames & Hudson, 1958.
113. Kranz, A. R. Populationsgenetische Unterrsuchungen am iranischen Primitivroggen. Ein Beitrag zu Systematik, Evolution und Züchtung des Roggens. *Zeitschrift für Pflanzenzüchtung*, 38, 1957. p. 101-146.
114. Kronacher, C. *Allgemeine Tierzucht.* Vol. 1, Part 1, Berlin, Parey Verlag, 1917.
115. Kuckuck, H. *Report to the Government of Iran on the distribution and variation of cereals in Iran.* (FAO Report no. 517.)
116. Kuckuck, H.; Schiemann, E. Über das Vorkommen von Spelz und Emmer (*Triticum spelta* L. und *Tr. dicoccum* Schübl.) *Zeitschrift für Pflanzenzüchtung, Iran*, 38, 1957. p. 383-396.
117. Kurth, H. *Vom wildgewaechs zur Kulturpflanzensorte.* Wittenberg Lutherstadt, A. Ziemsen Verlag, 1957.
118. Lambton, A. K. S. *Landlord and peasant in Persia.* Oxford, University Press, 1953.
119. Landsberger, B. Die Jahreszeiten im Sumerisch Akkadischen. *J. N. E. Studies*, 8, 1949. p. 248-297.
120. Latron, A. *La vie rurale en Syrie et au Liban.* Beirut, 1939.
121. Lees, G. M.; Falcon, N. L. The geographical history of the Mesopotamian Plain. *Geogr. J.*, 118, 1952. p. 24-39.
122. Le Strange, G. *The lands of the Eastern Caliphate.* Cambridge, University Press, 1905.
123. Libby, W. F. *Radiocarbon dating* (2nd edition). 1955.
124. Lloyd, Seton. *Twin rivers. A brief history of Iraq from the earliest times to the present day.* 1943.
125. ——. *Early Anatolia.* Harmondsworth, Penguin Books, 1956.
126. ——; Safar, Fuad. Tell Harsuna: Excavations by the Iraq Government Directorate General of Antiquities in 1943 and 1955. *J. N. E. Studies*, 4, 1945. p. 255-289.
127. Louis, H. *Das natürliche Pflanzenkleid Anatoliens.* Stuttgart, 1939.
128. Majumbar, R. C.; Raychaudhuri, H. C.; Kalikinkar, D. *An advanced history of India, Part I. Ancient India.* London, Macmillan, 1955.
129. Malaviya, H. D. Economy of the Vedic Villages. *A.I.C.C. Economic Review*, vol. VI, no. 10, 1954. p. 8-9.
130. Mallowan, M. Mesopotamia and Syria—unity and diversity of the earliest civilizations, Part 1. *Sumer*, 5, 1949.
131. Meissner, Bruno. *Babylonien und Assyrien.* I. Heidelberg, 1920.
132. Menghin, O. *Weltgeschichte der Steinzeit.* Wien, 1931.
133. Miller, J.; Leopold, L. B. The use of soils and paleosols for interpreting geomorphic and climatic history of arid regions. *Desert Research. Proceedings International Symposium held in Jerusalem, May 1952.* Jerusalem, 1953. p. 453-462. (*Research Council of Israel Special Publication* no. 2.)
134. Moldenke, H. N.; Moldenke, A. L. *Plants of the Bible.* Waltham, Mass., Chronica Botanica Co., 1952.

135. MONOD, T. Parts respectives de l'homme et des phénomènes naturels dans la dégradation du paysage et le déclin des civilisations à travers le monde méditerranéen *lato sensu*, avec les déserts ou semi-déserts adjacents, au cours des derniers millénaires. *Colloque d'introduction. Union internationale pour la protection de la nature et de ses ressources, 6e Assemblée générale, 7e Réunion technique. Athènes-Delphi.* 1958.
136. MORELAND, W. H. *India at the Death of Akbar.* 1920.
137. MOUNAYER, N. *Le Régime foncier de la terre en Syrie.* Paris, Librairie générale de droit et de jurisprudence, 1929.
138. MOUTERDE, P. Les zones de végétation en Syrie et au Liban. *8e Congrès international de Botanique, rapports et communications, section 7,* 1954. p. 103-105.
139. MURDOCK, G. P. Culture areas of Africa. (Unpublished contribution to symposium on culture area analysis, 1957. Meetings of the American Anthropological Association.)
140. NEEDHAM, J. *Science and civilization in China.* Vol. 1 : *Introductory orientations.* Oxford, University Press, 1954.
141. OAKLEY, K. The earliest fire-makers. *Antiquity* XXX, no. 118, 1956. p. 102-107.
142. OPPENHEIMER, H. R. Summer drought and water balance of plants growing in the Near East. *J. Ecol.*, 39, 1951. p. 356-362.
143. ——. An experimental study on ecological relationships and water expenses of Mediterranean forest vegetation. *Palestine J. Bot.*, 8, 1953. p. 103-124.
144. OPPENHEIMER, H. R. Wild Emmer—its discovery by A. Aaronsohn, fifty years ago, and its importance for the origin of cultivated wheats. *Svensk. Bot., Tidskr.*, 51, 1957. p. 545-551.
144*a*. ——. The origin of the Egyptian clover with critical revision of some closely related species. *Bull. Res. Council Israel, Section D : Botany*, vol. 7 D, 1959. p. 202-221.
145. Oxford Classical Dictionary. Oxford, Clarendon Press, 1949.
146. PABOT, H. *Rapport au Gouvernement de Syrie sur l'écologie végétale et ses applications.* 1957. (FAO/ETAP *Report* no. 663.)
147. ——. *Rapport au Gouvernement d'Afghanistan sur l'amélioration des pâturages naturels.* 1959. (FAO/ETAP *Report* no. 1093.)
148. ——. *Rapport au Gouvernement du Liban sur la végétation sylvo-pastorale et son écologie.* 1959. (FAO *Report* no. 1126.)
148*a*. ——. *Report to the Khuzistan Development Service on the native vegetation and its ecology in the Khuzistan River basins.* 1960 (in the press).
149. PAN-AMERICAN UNION. *Irrigation civilizations. A comparative study.* Washington, D.C., 1955.
150. PARSONS, J. J. Irrigation civilizations. *Geogr. Rev.*, 47, 1957. p. 136-137.
151. PEAKE, H.; FLEURE, H. J. *Hunters and artists.* Oxford, 1927.
152. ——; ——. *Times and places.* Oxford, University Press, 1956.
153. PIGGOTT, S. *Prehistoric India.* London, Pelican, 1950.
154. PLANHOL, X. DE. Limites antiques et actuelles des cultures arbustives méditerranéennes en Asie Mineure. *Bull. Ass. Géogr. franc.*, 239-40, 1954. p. 4-14.
155. PLATO. *Timaeus and Critias.* (Translated by A. E. Taylor.) London, Methuen, 1929.
156. POLIAK, A. N. *Feudalism in Egypt, Syria, Palestine and Lebanon.* The Royal Asiatic Society, 1939. (Prize Publication Fund, XVII.)
157. PRZEWORSKI, S. *Die Metallindustrie Anatoliens in der Zeit von 1700-500 vor Chr.* Leiden, 1939.
158. RAWLINSON, G. *The five great monarchies of the ancient eastern world.* Vol. I-IV. London, 1867.
159. REED, C. Comments on early goats, *Antiquity*, XXXI, 1957. p. 38-39.
160. ——. Zoology. *Nat. Acad. Sci. USA., Nat. Res. Counc. Publ.*, 565, 1957. p. 43-44.
160*a*. ——. Animal domestication in the prehistoric Near East. *Science*, vol. 130, 1959. p. 1629-39.
161. REES, L. W. B. The Transjordan Desert. *Antiquity*, III, 1929. p. 389.
162. REGEL, C. Phytogéographie de l'Iraq. *8e Congrès international de botanique. Rapports et communications, section 7,* 1954. p. 51-52.
163. REIFENBERG, A. The struggle between the desert and the sown. *Desert research. Proceedings International Symposium held in Jerusalem, May 1952.* Jerusalem, 1953. p. 378-391. (*Research Council of Israel Special Publication* no. 2.)
164. ——. *The struggle between the desert and the sown. Rise and fall in the Levant.* Jerusalem, Publishing Dept. of the Jewish Agency, 1955.
165. ROSTOVTZEFF, M. *The social and economic history of the Hellenistic world.* Oxford, 1941. 3 vols.
166. RUSSEL, J. C. *Tillage practices in Iraq.* 1958. (2nd mimeograph.)
167. SAUER, C. O. *Agricultural origins and dispersals.* New York, The American Geographical Society, 1952.
168. ——. The agency of man on the earth. In : W. L. Thomas, *The role of man in changing the face of the earth.* Chicago, University Press, 1956.
169. SEARS, P. B. Environment and culture in retrospect. In : T. L. Smiley, *Climate and man in the south-west.* University of Arizona Press, 1958. p. 77-84.
170. SEMPLE, E. C. *The geography of the Mediterranean region. Its relation to ancient history.* New York, 1931.
171. SHANAN, L.; TADMOR, N.; EVENARI, M. The ancient desert agriculture of the Negev. II : Utilization of run-off from small watersheds in the Abde (Ovdat) region. *Ktavim*, 9, 1958. p. 107-129.
172. SCHIEMANN, E. Entstehung der Kulturpflanzen. *Handbuch der Vererbungswissenschaft.* Lfg. 15, 1932.
173. SCHIEMANN, E. *Weizen, Roggen, Gerste.* Jena, G. Fischer, 1948.
174. ——. New results on the history of cultivated cereals. *Heredity*, vol. 5, 1951. p. 305-320.
175. SINGER, C. *et al. A history of technology. I : from early times to fall of ancient empires.* Oxford, 1954.
176. SMILEY, T. L. Years, centuries and millennia. *Climate and Man in the south-west.* University of Arizona Press, 1958. p. 11-18.
177. SOLECKI, R. S. Dokan cave, an occupation station on the lesser Zab river in Northern Iraq. *Sumer*, vol. X, no. 1, 1954. p. 69-79.
178. SOLECKI, R. S. Shanidar cave, a paleolithic site in N. Iraq and its relationship to the stone age sequence of Iraq. *Sumer*, XI, 1955. p. 14-38.
179. STAPLETON, H. E. Origin of short-horned cattle. *Bull. Soc. Jersiaise*, XVI, part 1, 1953. p. 100-102.

180. STEBBINS, G. L. Self fertilization and population variability in the higher plants. *Amer. Nat.*, 91, 1957. p. 337-354.
181. STEKELIS, M.; HAAS, G. The Abu Usba cave (Mount Carmel). *Israel Explor. J.*, 2, 1952. p. 15-47.
182. STEWART, O. C. Fire as the first great force employed by man. In : W. L. Thomas, *The role of man in changing the face of the earth.* Chicago, University Press, 1956. p. 115-133.
183. STRABO. *The geography.* (Translated by H. C. Hamilton and W. Falconer.) London, Bell & Sons, 1906. 3 vols.
184. SYKES, P. M. *A history of Persia.* London, Macmillan, 1958. p. 563, 616.
185. TADMOR, N. H.; EVENARI, M.; SHANAN, L.; HILLEL, D. The ancient desert agriculture of the Negev. I : Gravel mounds and gravel strips near Shivta (Sbeita). *Ktavim*, 8, 1957. p. 127-151.
186. TARN, W. W. *The Greeks in Bactria and India.* (2nd edition.) Cambridge, University Press, 1951.
187. TAVERNIER, J. B. *Les six voyages de J. B. Tavernier.* Paris, 1681.
188. TAYLOR, F. H. *The destruction of the soil in Palestine.* (*Pal. Soil Conserv. Board Bull.* no. 2.)
189. THEOPHRASTUS. *Enquiry into plants.* (Translated by Sir Arthur Hort.) London, Heinemann, 1916.
190. THOMPSON, J. Joel's locusts in the light of Near Eastern parallels. *J. N. E. Studies*, 14, 1955.
191. TOYNBEE, A. J. *A study of history.* (2nd edition.) Oxford, University Press, 1935. 3 vols.
192. UNITED NATIONS. *Progress in land reform.*
193. UVAROV, B. P. The locust and grasshopper problem in relation to the development of arid lands. In : *The future of arid lands.* Washington. Amer. Assn. Advancement Sci., 1956. p. 383-389.
194. ——. The aridity factor in the ecology of locusts and grasshoppers of the old world. In : *Human and animal ecology. Reviews of research.* Paris, Unesco, 1957. p. 164-198. (*Arid zone research*, VIII.)
195. VAN BUREN, Douglas. The fauna of ancient Mesopotamia, as represented in art. *Orientalia*, 18, 1939. p.113.
196. VAVILOV, N. I. The origin, variation, immunity and breeding of cultivated plants. (Translated by K. Starr Chester.) *Chronica Botanica*, vol. 13, 1951. p. 364-?
197. VOUTE, C. C. A prehistoric site near Razzaza (Kerbela Liwa). *Sumer*, vol. 13, nos. 1 and 2, 1957. p. 135-156.
198. WAHEED, Sheikh, A. *Shat-al-Arab. An outline history of Iraq.* Jhelum City (Punjab), Pakistan, 1950.
199. WALTER, H. Vegetationsgliederung Anatoliens. *Flora*, 143, 1956. p. 295-326.
200. WALTERS, T. *Yuan-Chwang.* London, Oriental Translation Fund, Royal Asiatic Society, 1904.
201. WATTERSON, G. G. *Tree-planting and agriculture in the Near East.* 1955. (*FAO Centre on Land Problems in the Near East Paper p-8.*)
202. WEULERSSE, J. *Paysans de Syrie et du Proche Orient.* Paris, Gallimard, 1946.
203. WHEELER, Sir M. *Rome beyond the imperial frontiers.* London, Bell, 1954.
204. ——. The Indus Civilization. In : *Cambridge history of India* (Suppl. vol.), 1955.
205. ——. The first towns. *Antiquity* XXX, no. 119, 1956. p. 132-136.
206. ——. *Early India and Pakistan.* London, Thames & Hudson, 1959.
207. WHYTE, R. O. The phytogeographical zones of Palestine. *Geogr. Rev.*, 40, 1950. p. 600-614.
208. ——. Grazing resources. In : *International Arid Lands Meeting.* American Association for the Advancement of Science, 1955.
209. ——. *Plant exploration, collection and introduction.* 1958. (*FAO Agric. Study* no. 41.)
210. WILLCOCKS, W. *The restoration of ancient irrigation work on the Tigris.* Cairo, 1908.
211. ——. *The irrigation of Mesopotamia.* (2nd edition). London, 1917.
212. WILSON, A. T. *The Persian Gulf.* London, Allen & Unwin, 1954.
213. WOOLLEY, L. *Ur of the Chaldees.* London, Pelican, 1950.
214. ——. Correspondence on 'The first towns' by Sir Mortimer Wheeler. *Antiquity*, XXX, part 120, 1956. p. 224.
215. ——. *History of scientific and cultural development of mankind.* Vol. 1, part 2, Paris, Unesco, 1957. (*The Foundations of Civilization.*)
216. ——. Personal communication, 25 May 1959.
217. WRIGHT, H. E. The geological setting of four prehistoric sites in N. Iraq. *Bull. Amer. Sch. orient. Res.*, 128, 1952. p. 11-24.
218. XENOPHON. *The march of the Ten Thousand* (Translated by H. G. Dakyns). London, Macmillan, 1901.
219. ZEUNER, F. E. Domestication of animals. In : Singer, *et al. A history of technology.* Oxford, 1954. p. 327-352.
220. Cultivation of plants. In : Singer, *et al. A history of technology.* Oxford, 1954. p. 353-375.
221. ——. The radiocarbon age of Jericho. *Antiquity* XXX, 120, 1956. p. 195-197.
222. ZOHARY, M. A vegetation map of western Palestine. *J. Ecol.*, 34, 1947. p. 1-19.
223. ——. Ecological studies in the vegetation of the Near Eastern Deserts. I : Environment and vegetation classes. *Israel Explor. J.* 2, 1952. p. 201-215.
224. ——. Ecological studies in the vegetation of the Near Eastern deserts. III : Vegetation map of the central and southern Negev. *Palestine J. Bot.*, 6, 1953. p. 27-36.
225. ——. Notes on ancient agriculture in the Central Negev. *Israel Explor. J.*, 4, 1954. p. 17-25.

*Supplementary references*

226. ADDISON, H. *Land, water and food. A topical commentary on the past, present and future of irrigation, land reclamation and the food supplies they yield.* London, Chapman and Hall, 1955.
227. BRADFORD, J. *Ancient landscapes. Studies in field archaeology.* London, G. Bell & Sons Ltd., 1957.
228. BRAIDWOOD, R. J.; HOWE, B. *Prehistoric investigations in Iraqi Kurdistan.* Chicago, University Press, 1960.
229. GORDON, D. H. *The pre-historic background of Indian culture.* Bombay, M. D. Desai, 1958.
230. LORCH, J. A preliminary report on the pollen flora of Lake Hula, Israel. *Bull. Res. Counc. Israel*, 7D, 1959. p. 85-89.
231. VAN LIERE, W. J. Ager Centuriatus of the Roman colonia of Emesa (Homs). *Annales Archéologiques de Syrie*, vol. 8 and 9, 1958-9. p. 55-58.
232. ——; LAUFFRAY, J. Nouvelle prospection archéologique dans la Haute Jezireh syrienne. *Annales Archéologiques de Syrie*, vol. 4 and 5, 1954-5. p. 129-148.
233. ZOHARY, D. Studies on the origin of cultivated barley. *Bull. Res. Counc. Israel*, 9D, 1960. p. 21-42.

# EVOLUTION OF IRRIGATION AGRICULTURE IN EGYPT

*by*

G. Hamdan, Ph.D.
*Assistant Professor of Geography, Cairo University*

## INTRODUCTION

The history of land use in Egypt cannot be considered except in the closest association with the history of irrigation. In a fluvial environment, the irrigation-agriculture complex is indivisible, so much so that it is hard to tell which is cause and which is consequence. Irrigation is here the medium of interaction between men and milieu, whereby he humanizes the natural landscape, models and remodels it into a 'second-nature'—the cultural landscape.

Heat and humidity have always been abundant, but for production collective human effort was necessary in order to control them. Hence, Sun, Nile and Pharaoh [63,[1] p. 119]—all gods—symbolized undoubtedly the 'father of Egypt' [50, p. 129], Egypt the 'gift of the Nile'—specifically the Blue Nile. But it is equally the gift of the 'fellah', a truly joint architect of the land of Egypt. Despite the poet, man has here made both country and town alike. Through irrigation man assumes here the role of a geographic agent of the first order [51, p. 31].

An 'exotic' semi-oasis, Egypt may be likened to a huge 'Monsoon huerta'. The rainfall equivalent of her irrigation water supply works out at about 82 in. With only a thin coastal strip receiving an average of 5 in. of rainfall, Egypt is a typical arid zone with very low 'rain-factors'. The ecumenical pattern is thus wholly subservient to the distribution and availability of water. In Brunhes' phraseology, it is a *communauté hydrologique* [15, p. 794] that we deal with. We may look upon irrigation as part of a chapter in the works of man which may be designated 'geotechnics'[2]—the art of landscape sculpture which, like terracing in mountains, can re-create orography or hydrology. These geotechnics constituted a veritable redistribution of matter—a fourth state of matter, so to speak [80, p. 19]. Accordingly the history of land use in Egypt may be geotechnically divided into periods similar to those used by Geddes for industry [31, 62]. Thus the pristine prehistoric and predynastic phase is the 'eotechnic' period.

Basin agriculture, which spans the whole length of our history down to the nineteenth century, is the 'Palaeotechnic' period. With the introduction of perennial irrigation began the 'Neotechnic' period, while the present-day High Dam project heralds a 'Biotechnic' phase. This succession of geotechnic complexes represents a long-term process of 'sequent occupance' of the land, denoting a continuous adaptation to, or of, environment. Apart from the first period, we may conveniently consider each period from two ecological aspects: geotechnics (irrigation) and geonomics (agriculture).

## EOTECHNIC PERIOD

The opening phases in the history of land use in Egypt can be reconstructed only by speculation. The evidences of prehistoric archaeology are extremely controversial and conflicting. Only the very broad lines of this vexed question will be surveyed here. Two schools of thought can be distinguished.

### THE CLASSICAL THEORY

The orthodox view of the majority [18, p. 137; 20, p. 26; 41, p. 312 *et seq.*] is that man spread over the Sahara since the Middle Palaeolithic when, thanks to pluvial conditions, it was a vast pampa-like steppe. Hunting and food-gathering were the basic economy. The low-lying river valleys, such as the Nile, were, on the contrary, inhospitable and inaccessible marshes. The Nile is traditionally likened to the Sudd region

1. The figures in brackets refer to the bibliography at the end of the chapter.
2. A term coined by P. Geddes and V. Branford [31*a*].

of Sudan today. A post-glacial desiccation at the close of the late Upper and Final Palaeolithic reversed the habitability of both surrounding desert plateaux and the riverine strip. The former became a forbidding desert, while a reduced volume of river water and a process of degradation ameliorated conditions in the valley floor by draining the marshes, and reduced the inaccessibility of the dense aquatic jungle. This change forced the plateau hunters to descend into the valley where this was probably connected with the beginnings of both agriculture and animal domestication—at least in some of the more favoured spots. Such spots are generally taken to be the margins of the flood plain, and it is noticeable that most Palaeolithic sites in the valley were found on the 'low desert', i.e., along the borders of the alluvial plain and not inside it. In such favourable spots plants and vegetables would naturally grow after the recession of the flood, and would presumably be taken care of by these 'terminal food-gatherers' until harvesting time [4]. This would be a very rudimentary initiation into cultivation and would imply a logical gradualism.

Some have urged that wheat and barley grew spontaneously [72], that man learned to reap before he learned to sow and that the Nile, the flood, providing a yearly object-lesson in simple cultivation, was the real father of agriculture [23, p. 8; 42, p. 50]. This actually implies an autochtonous origin. Some authorities give this credit to the delta [18, p. 137], some to the valley [12]. Others rule out the fenland of the north delta as being an impossible homeland of agriculture. Others still dismiss the valley itself on account of the ultra-giantism of the flood there [42, p. 54]. Huntington argues that the tiny, easily manipulated streams at the base of the high plateau east of it, dry wadis today, might possibly have offered a more propitious nursery to nascent agriculture [39, p. 308].

All these speculations, however, clash with two serious facts. The earliest Neolithic settlements in Egypt, Merimde and Fayum, are relatively too highly developed to agree with the gradualist theory. There is a definite discontinuity in Egypt between Upper and Final Palaeolithic on the one hand and Late Neolithic on the other. This has invited theories of an allochtonous origin of agriculture; Mesopotamia, whose agricultural settlements antedate Merimde by some 2,000 years at least, being always pointed at as the probable homeland [16]. No archaeological evidence, however, is available on this theory [30, p. 11]. Yet another difficulty is the fact that between 5500 and 2500 B.C. a Neolithic wet phase took place converting the valley once again into its previous morass-like condition [41, p. 319 *et seq.*]. Such a deteriorating habitat could only be inimical to the supposed development of agriculture. Some authorities find a way out by withdrawing man, after his initial entry, from the valley during this retrograde phase to its desert fringes where he brought his newly acquired knowledge of agriculture to a higher pitch such as is found at Merimde. With the end of the wet phase the inhabitants re-descended into the valley once again [41, p. 322 *et seq.*].

## A NEWER APPROACH

The classical theory has lately come under much fire on physiographic as well as on cultural grounds. Butzer shows that Palaeolithic man moved into the valley some 10,000-20,000 years before the advent of the Neolithic and of agriculture. This is to say man stayed at least 10,000 years in the valley as hunter and food-gatherer without knowing agriculture [16, p. 79]. This would represent Keith's 'primal period' of destructive occupance [47, p. 19 and p. 298]. Again, the classical 'valley-ward' movement is shown to be a myth, man having occupied both valley and surrounding plateaux simultaneously for a long time. For the most part he concentrated near the valley during drier periods, such as after the close of the Middle Palaeolithic [16, p. 80]. Desiccation neither led to a movement into the valley nor to a transition to agriculture. Butzer points out that agriculture came to be known some 5,000 years ago, but that Merimde could neither be the earliest nor the sole Neolithic agricultural settlement in the delta and that we have to assume the existence in the delta of many such villages some 2,000 years earlier [16, p. 52]. Nor is the imputed swampy nature of the primeval valley at the beginning of agriculture tenable any more. Passarge was the first to challenge this hypothesis and to prove it fallacious: exotic river environments do not have to be influenced by direct climatic changes [16, p. 47]. Thus the valley was simply inundated annually into natural basins with the natural levee and desert margins unattained. In the southern and eastern delta also the then more extensive 'turtle-backs' were spared. (They are the gravel and sand islands representing the more solid and thick parts of the subjacent 'sub-deltaic deposits' and rising from the surrounding alluvium.) All such elevations could provide habitation for man, while in the surrounding basins there was no marsh. The assumption of artificial drainage before agriculture, of canalization as the starting point of colonization, is thus refuted. This is opposed to the view that in the valley drainage was perhaps known before irrigation [30, p. 38 and p. 43].

It will have been realized how nebulous is the picture of origins and beginnings. This 'eotechnic' period nevertheless represents the 'first agricultural revolution', the transition from food-gathering to food-producing, and is thus a crucial chapter in the history of land use in the Nile Valley.

## PALAEOTECHNIC PERIOD

### BASIN COMPLEX

#### *Geotechnics*

Without embankments the Nile would wholly overflow its valley, therefore occupance was initially restricted to the higher levees and to the desert fringes lying above the high-water mark where in pre-dynastic times populations settled in villages. Our information on this vital stage of cultural gestation is, as we have seen, conjectural, but presumably the people descended into the valley every year with their herds after the flood had receded. Gradually they practised cereal cultivation. They probably occupied the more elevated tracts within the valley itself, where they needed further protection against the flood by means of artificial circum-village banks. Perhaps this experience initiated them into the idea of embanking the river itself; Hurst surmises that this might have begun on the eastern bank where control would be easier on account of a smaller area (nearly one-tenth of the total for Upper Egypt) naturally subdivided into manageable little crescentic basins and narrow pockets [40, p. 39]. The experiment perhaps started on one of those attenuated alluvial tongues projecting into the higher desert land. A bank across its mouth, leaving a passage for an ingress of water, would be an easy undertaking for a single village. A further step would be to embank a small bay in the hills by means of a longitudinal bank run alongside the river course from headland to headland. Through a controlled water passage, floodwater could be made to stay in the basin as long as was necessary. In the more extensive bays, control would not be feasible without a subdivision into smaller compartments by means of transverse banks from river side to desert edge. Thus was evolved the traditional 'basin' system, consisting of a framework of longitudinal and transverse banks.

A socio-political organization greater than the village or locality was, however, a prerequisite for the universalization of this large-scale development. It was Menes (3400 B.C.) who first undertook such control of the river. Willcocks and Craig suggest that he probably began basining the left bank, which was for the most part the more important, being nine times the area of the right bank. The latter was left a wild jungle and a safety-valve against high floods [85, vol. 1, p. 299). It is conceivable that this view is not necessarily opposed to the concept of the left bank as a possible nursery for the art of basin irrigation. With the increasing pressure of a growing population, however, the need for basining the right bank soon arose. But the sudden restriction of the river on both sides at once brought to the fore the problem of the devastating high flood. We know that this stage was reached under the twelfth dynasty because it was then that the Fayum project was launched as a regulator of the flood. This depression, a semi-detached cup-oasis, lies lower than the level of the valley. Thus excessive floods could be diverted there where Lake Moeris would rise and extend temporarily, while in years of a deficient flood, water could be led back to the valley [85, p. 299]. It should be emphasized that the efficient running of the basin system depended entirely on a strong, centralized government, for every upstream basin could endanger the riparian rights of those downstream. Significantly, the Latin *rivalus* (rival) is a derivative of *rivus* (river) [68, p. 142].

Basins may range in size from 1,000 feddans (acres) to 40,000. They are usually arranged *en échelon* in chains of 4-5 feddans beside a shallow canal which takes off at a higher point of the river [40, p. 38]. Canals are first aligned diagonally across the basins then bear north near the desert margins in order to extend irrigation as far as possible [21, p. 3]. They have a lesser slope than the river and are regulated at their heads by earthen removable blockages. With regard to the transverse banks, the bigger the area of the basin the higher and thicker they have to be in order to stand the increased head of water behind.

It will be seen that the topography of the floodplain lends itself readily to erecting longitudinal banks. Owing to the nature of fluvial deposition, the greater part of the heavier particles of the river load is dropped immediately near the channel while the finer and lighter particles can travel laterally farther afield right to the desert foothills. Thus the river builds up alongside its course massive bermlands or natural levees whence the floodplain dips, rather irregularly, sidewards to the desert at a slope of 8 in. to the mile [40, p. 34]. In Sohag such berms are 50-90 cm. higher than the valley floor at the foot of the western escarpment [82, p. 18]. Thus 'the Nile Valley came to be cambered, something like a modern road, with the Nile running along the crest and the level of the land falling away towards the sides of the valley' [21, p. 3]. The situation in the delta is essentially the same, except that it is much more confused owing to the existence of an elaborate network of branches, old and new, each of which has its own natural levee. Therefore 'the surface of the delta is rather like the back of a leaf on which the ribs mark the higher land . . . with basins of lower land between them'.

With the advent of the flood the basins are successively filled from south to north, the whole valley turning ultimately into one vast lake. Only the high banks carrying the roads and settlements remain unsubmerged, island-like. Communication is primarily by boats. In a medium flood the river level is on average 9 m. above its bed, rising to 10 m. in high floods and falling to 7.5 m. in low floods. The beds of the main feeder basin canals lie some 4.5 m. above the river bed [85, p. 301]. If it be added that the cultivable land of the floodplain lies, on average, 9 m. above the river bed, it will be realized that the river water at the crest of the flood runs actually higher than the level of much of the plain and is only prevented from overflowing it by the giant longitudinal banks overtopping the bermlands.

The flood arrives in Egypt in July and reaches its zenith in September then subsides quickly until January. At its advent the canals are opened and the basins are submerged beginning from 20-25 August. The average depth of water in the basin varies locally according to flood volume, local elevation and the state of repair of the canals. In good years, it attained 1.25 m. in Upper Egypt, occasionally 1.50 m. In the delta, on the other hand, the depth was less, the flood arrived late and water wandered on the basins for a shorter time than in the valley. Generally speaking, water stayed 40-60 days after which the basins were drained off. This annual submergence increasingly made the basin surfaces very level, so that no ponds were left behind. In years of poor flood, basins are not drained into the river but, for economy in water utilization, into the next basin downstream [40, p. 40 *et seq.*].

Once evacuation of water is complete, land will not be watered again until the next flood. Therefore no irrigation canals or field ditches are needed [50, p. 125]. Similarly, drainage takes place naturally—essentially by the surface and escaping back to the river. Any residual water that may remain in pits and bores or infiltrate downwards in the more sandy tracts will eventually find its way to the sand-and-gravel bed underlying the alluvial layer. Since this bed is in direct communication with the river it will ultimately drain there during the low stage, thus affording a healthy drainage of the subsoil (bathydrique) [28, p. 153; 61, p. 16]. On the surface of the basins, the flood will have left a thin film of new fertilizing mud (1 mm. annually), thus continually maintaining and rejuvenating soil fertility. It is this mud that, during millennia, originally formed the floodplain—partly an unintended gift from the pastoralists of Abyssinia who helped soil erosion there by overgrazing [42, p. 46]. The use of fertilizers has thus no place in the basin system, except under rare circumstances. Sowing can start practically without ploughing since the dry, fallow season which precedes the flood will have deeply furrowed the soil and killed off parasitic weeds and micro-organisms. This was considered a natural, spontaneous ploughing —the Nile and the sun were the prime farmers of the land, or as Willcocks put it, the flood took over the present functions of the Ministry of Agriculture [83, p. 7 *et seq.*]. This evidently reduced agricultural work to a minimum. The crops remained on the field until harvesting in late spring and May, after which it lay fallow until July.

### *Geonomics*

A fundamental conclusion can be drawn from the above account. Although dependent on 'wet irrigation', basin cultivation is, paradoxically, a special type of 'dry farming' [27, p. 62]. Technically speaking, it is certainly a variant—a fluvial variant—of dry farming, therefore less rigorous and hazardous. As Mosséri [56, 60] points out, dry farming has four phases : (a) the ploughing stage when land is prepared to increase its absorptive capacity of water—this is represented in basin agriculture by the superficial, indifferent 'scraping' of the soil following flood retirement, plus the cracking which takes place during the fallow period; (b) the stage of land receiving water it has to store, this is equivalent to the flood season itself; (c) creating a pulverized, fine surface layer (the American 'mulch') [13] to counteract evaporation—a stage parallel to the slight ploughing preceding sowing; (d) the stage of cultivation proper.

As would be expected, the basin crop complex was in the first place an annual, in the second, a winter system. Cropping was seasonal because the Nile waters were utilized only seasonally : to paraphrase La Blache [48, p. 408], the Red Nile yielded cultivated or green Egypt, while for the rest of the year the Green Nile left a fallow or black Egypt temporarily a 'black desert'. Seasonal cultivation meant a basically extensive type of land use.

With crops occupying land during the cold season, they were essentially winter crops. Oddly enough, a hydrology, tropical monsoonal in origin, led to a temperate winter agriculture. This limited the range of variety in the crop complex. It inevitably meant the supremacy of cereals, whose climatic requirements are particularly adapted to the cycle of the growing season succeeding, as it does, from humidity to coolness then to a dry warmth late in spring. Apart, therefore, from the exceptional case of perennial islands, to be considered separately, winter cropping was basically a subsistence economy and could not accommodate any lucrative commercial crop. Hence cereals represented the staff of life; the Greeks significantly nicknamed Egyptians the Artophagoi [65]. While cereal production was primarily autarchic, a margin of surplus frequently allowed export—sometimes even made Egypt the 'granary of Rome', but presumably with extra effort. Josephus mentions that under Nero, Egypt provided Rome with corn for four months of the year [55]. She also supplied Philadelphus with 1.5 million *artabae* while under Justinian 8 million were dispatched annually to Constantinople [81].

We are fortunately fairly well informed on the principal crops relating to three areas, namely, ancient Egypt, the Arab period and the time of the French expedition late in the eighteenth century.

In general, the elements of the crop complex in ancient Egypt were fundamentally the same as those existing today, exception being made of the recent introduction of cotton, rice, sugarcane and Indian corn [53, p. 126]. Barley was the prime crop in the earlier times down to the end of the Classical period (until A.D. 500). Eventually wheat gained ascendancy, followed by barley [82, p. 95]. The existence of sorghum in ancient Egypt is a controversial issue. Schweinfurth denies it, while de Candolle believes millet was known [35, p. 53]. Pulses, including beans and lentils, were important and so were onions, of which mention is made in the Bible. Flax was the staple fibre for clothing. Presumably an extensive area was used as pasture, mostly cultivated, then as now, with bersim (Egyptian clover). Milne speculates that the relative acreage of these crops might have not been altogether dissimilar from what they are today —half the total being under cereals [53, p. 126]. Crop rotation was essential to alternate exacting crops such as wheat and flax with restoratives such as beans and lucerne.

Wheat [1] was raised all over Egypt excluding the northern marshes and the extreme south, where it was superseded by the hardier barley. In the Middle Ages, Middle Egypt was the seat of maximum production and quality, the same as it is today. Schweinfurth is of the opinion that both wheat and barley were introduced from Mesopotamia, according to him the cradle of agriculture. Another view is that they grew wild in prehistoric Egypt [82, p. 3]. Of a far less fastidious nature, barley was more extensively grown than wheat. Beans, introduced from the Levant during the twelfth dynasty, provided a green fertilizer in a soil poorly endowed in nitrogen compounds. The mediaeval area of main production—Upper Egypt from Minia to Sohag—coincides with its present-day counterpart.

Egypt has never possessed any worthy pasture, only some coarse, indifferent grass springing up and grazed after the flood. In years of low flood much land was uncultivated and turned into poor pasture. Egypt was therefore chronically poor in animal population and consequently in dairy products —a fact unfavourably influencing the infantile mortality in a tropical, hot climate. Fodder had to be cultivated; it comprised fenugreek, vetch, beans and bersim, the last-named being the most important since the close of the Roman period. These crops were also the sole regenerators of the soil. In the Arab period bersim was important all over the delta where artificial irrigation was easy as the level of the land is fairly near to that of the river (the difference being 4-5 m. at the head and only 1 m. near the sea). In Upper Egypt, on the other hand, the cultivation of bersim decreased progressively southwards to the vanishing point at Kena, where it was replaced by the other fodder crops which proved to have a greater yield there and needed less water in a sector of the valley which was particularly elevated. It is surprising that this is essentially the same pattern today. The French expedition estimated that, at the close of the eighteenth century, bersim accounted for one-fourth of the total cultivation in the delta, and for one-sixth of that in Upper Egypt [21, p. 22]. It is interesting to note the concentric rings of bersim round the bigger cities, such as Cairo, for feeding the transport animals [21, p. 22]—a primitive forerunner of the modern metropolitan rings of vegetable and fruit cultivation for human consumption.

Down to the end of the Middle Ages, flax had been the premier fibre of Egypt. Its cultivation was restricted to the wetter lowlands and the rich black soils, avoiding the sandy areas. This confined its production to limited areas stretching from Giza to Assyut inclusive where such places as Bosh, Delas, Bahnassa and Assyut had a special renown during the Arab period. The middle section of the delta had equally famed centres including Ibiar, Sonbat, Mahalla and Hanut. An exacting crop, flax was ordinarily fertilized in Upper Egypt with a certain marl-clay, but the quality was never good anywhere in Egypt.

## PERENNIAL COMPLEX

### *Geotechnics*

It has been seen that annual, winter cultivation constituted the base complex of basin irrigation. However, embedded within this frame was a hard core of perennial cultivation which, standing like isolated agricultural islands or enclaves, seemed more like gardens than fields. Where water could be secured constantly, cropping could be year-long, permitting the cultivation of non-winter crops. As Hurst suggests, the roots of perennial irrigation in the pristine days of pre-dynastic Egypt might be traced back to the ponds and lakelets left behind from the flood in the lower tracts [40, p. 38]. The water was usually available many months after the flood and could be lifted in buckets by hand and carried to nearby fields; all year round farming was thus possible. Lifting machines were gradually brought into use.

Two types of perennially irrigated land may be distinguished, that irrigated from riverside levees and that from underground water wells.

Riverside bermlands (Nabari lands in contrast to the basin lands or Bayadi) [35, p. 116] were higher in level than the normal flood and were inundated only every eighth or ninth year by excessive flooding of the Niles. They could scarcely be watered by basin

1. Weheiba provides the main source of information on crops in the Arab period. [See 82, p. 95-119].

overflow and water had to be perennially lifted—but the reward was perennial cropping. This class comprised both riversides in the valley as well as the fringes of the main existing and 'fossil' canals in the delta. Such 'hanging cultivation' had to be embanked against the flood. The danger, however, of its being swept by a capricious flood was ever imminent. Underlying the Nile alluvium is a pervious sand-and-gravel bed which in places comes up to or near the surface, especially in the lower areas where the thickness of alluvium is reduced. This subjacent formation is in direct contact with the river and carries a horizon of subsoil water. The spring level of this aquiferous horizon, which is derived from the river, lies, in the valley, some 4-5 m. below the surface in April and 5-7 m. in July [61, p. 13]. In the delta the depth is reduced owing to its fan-like shape. This subsoil water reservoir is well suited to irrigation, except in the extreme north of the delta where it is brackish or saline. It can be tapped by wells, lifted and run to fields. Well irrigation has always been additional to, not a substitute for, the Nile. It has the merit of preventing over-watering. In ancient Egypt it was a welcome addition to complement the flood supply and, where available, made cultivation year-long and raised the material wealth. There arose the ancient capitals such as Abydos, Memphis and Thebes, the sites of which are still characterized by the best underground water supplies in the whole valley. As Willcocks and Craig point out, underground water was the connecting nexus between basin and perennial irrigation [84, p. 299].

The area under perennial irrigation was estimated by Farid at 20 per cent of the total cultivated in Egypt [26, p. 48]. Girard, the French expedition savant, put it at 12 per cent for the valley and at 25 per cent for the delta [32]. Weheiba, however, suggests that it might have been more in the Arab period [82, p. 121]. In any case, the acute problem of such land was dual. First, it was deprived of the supposedly fertilizing 'red water'. This, together with permanent cropping, made necessary the adoption of a rotation more evolved than that used in the basins, plus the heavy application of manure. These were the lands that used animal manurials most, but *koufri* was vital. *Koufri* is the decomposed matter of extinct settlements rich in phosphates and potash found especially around the greater ancient agglomerations (such as Xois and Sakha) [59]. Drainage, too, was imperative. The second problem was the costly effort in water-lifting. Perhaps the earliest machine was the *shadoof* (pole and bucket) which features in the tomb drawings of Thebes (1250 B.C.) [40, p. 43 *et seq.*]. It can water one-fourth of an acre daily. The *tamboor* (Archimedean screw) and the *sakieh* (water wheel) were later introductions by the Greeks. The former is used for small lifts and irrigates three-fourths of an acre. The *tambusha* is a special variant of the *sakieh* (with compartments instead of vessels) used for smaller lifts. In the lower delta the *tabut* is adopted for low lifts. A sakieh irrigates 1-5 acres a day according to the depth of water. Where the elevation is great, a series of the same machine is frequently arranged *en echelon* for relay lifts. As explained above, water-lifting is easier in the delta than in the valley.

### *Crop complex*

Where perennial irrigation was possible, the range of crops was enriched by the addition of summer crops. Irrigation was, however, expensive, therefore the monopoly of the rich landowner. Foremost among the cash crops were sugarcane, rice, indigo, saffron and cotton with some onions and tobacco. The introduction of one of these crops occasionally engendered a crop struggle for land, since water too often acted as a limiting factor. Not infrequently the cultivation of some of these crops was abandoned on that account [82, p. 124]. Since their introduction by the Arabs in the Middle Ages, sugarcane and rice have been the foremost crops. The assertion that rice was introduced by the Turks [50, p. 138] is simply anachronistic. Sugarcane made great strides during the twelfth and thirteenth centuries when Egypt was apparently a leading producer-exporter. The main centres were in the valley: in Baliana, Akhmim, Assyut and the Fayum, the delta had insignificant patches [82, p. 125 *et seq.*]. Sugarcane required a score of lavish waterings, hard ploughing and good drainage. Rice was introduced immediately after the Arab conquest—whether via Syria or India is controversial. Under the Arabs, Fayum was the leading area. The French Expedition found rice most heavily concentrated around Rosetta, which is said to have derived its name from the vernacular *roz* [82, p. 132]. The fine quality Rosetta type, the *sultani*, was only for export to Istanbul. Around Damietta was found the *manzalawi* variety, also for export [66]. The predominance of rice around the two distributary mouths and in the Fayum was due to the abundance of easily lifted water.

The two dye crops saffron and indigo were restricted to Middle Egypt, particularly at Giza and Beni Suef. Unusually expensive to grow, they were the specialty of important landowners. The centre of saffron was Assyut and Isna that of indigo. Cotton was grown in both valley and delta but on a minimal scale. In the valley it was a tree cotton lasting 8-10 years, but yield was poor [21, p. 21 *et seq.*].

### *Extent of basin agriculture*

As early as Pharaonic Egypt, the limits of basin agriculture had reached the northern littoral of the delta [7, p. 219]. However, there was always a hard core of marshland and saline coastal lagoons inhabited by a fisher-folk in the extreme north. It is estimated that 6 million acres were brought under the plough in ancient Egypt [79]. Subsequently, this area sensibly oscillated. Later Arab estimates are conflicting and apparently exaggerated. Only one authentic case of land loss calls for special mention, the Beraris. Sometime in the late Roman and early Arab periods some 1.5 million acres were lost to Egyptian agriculture for good in a single stroke. This belt turned into a desolate, alkaline wilderness highly charged with salts. The cause of this Berari catastrophe is by no means clear [37, p. 189; 57]. Tradition has it that the sea frequently washed these lands, and the formation of Lake Manzaleh is only historically attested to by contemporary Arab chroniclers. It is also argued that, under the increasing weight of accumulated thick alluvium, a probable subsidence of the land fringes might have helped invasion by the sea. Others point out with good reason that untold centuries of apathy and shameful neglect of the canal network hindered regular drainage to the sea and thereby leaving excess water to wander over the land until a saline crust was formed by evaporation. In the days of the French expedition water was found to wander in the north of the delta for 8-9 months after the flood. In any case, the Berari loss was a *coup de grâce* to land use in mediaeval Egypt. The expedition found that the tilled area did not exceed 3,217,000 feddans. Late in the nineteenth century the line Dilingat-Damanhur-Shubrakhit-Disuk-Sanhur-Kallin-Mahalla-Mansura-Sinbillawein-Fakus marked the northern limits of basin irrigation proper [85, p. 368]. Across this new 'frontier' of Egyptian land use, cultivation was patchy and confined to canal and river sides, particularly around the distributary mouths of Rosetta and Damietta which had been permanently settled nuclei throughout history [7, p. 205-220].

## PALAEOTECHNIC COMPLEX: ITS PROS AND CONS

The fact that the basin complex survived unchanged and unchallenged for some seven thousand years as the backbone of land use is indication enough of its inherent merits. It was marred, however, by certain disadvantages.

### *Merits*

The basin system evolved naturally since it was well adapted to the physical pattern, especially in the valley with its sloping, slot-like nature. Technically the basin system is equivalent to the tank system in India [85, p. 299]. Economically it could be started with a meagre manpower but could eventually support a dense population. Its ecological adaptation as river control is thrown in clearer relief if compared with Iraq. A function of melting snow, the flood in Iraq took place in spring, that is when nearly all crops were standing in the field. The flood had therefore to be wholly impounded within its bed by massive banks [29, p. 358]. Hydrology and land use were in conflict, whereas in Egypt the flood season and the growing season were mutually well-timed and nicely dovetailed. The basin system was clearly symbiotic.

It also solved the problem of salinization, the real foe of arid land agriculture, as well as the problem of soil exhaustion, so characteristic of fixed agriculture. This was due to the principles of free inundation and forced fallow. Whether or not Nile silt is fertilizing is a moot question, but it stands to reason that it supplies the soil with a modicum of fresh plant food. The fellah as well as many writers ascribe the proverbial fertility of Egypt to silt. Others, however, find the secret in the *sharaki*—that beneficial fallow period. This allows the land to rest; plant and animal parasites are weeded out and the soil interior receives a thorough aeration and insolation through its deep interstices. Not least is that it allows a searching process of washing and draining thus cleaning both surface and sub-surface of their accumulated salts and precluding salinization [60, p. 21-61; 61, p. 9-19]. There can thus be no doubt that either through its silt deposit or fallow period, the basin system is biologically sound, making for soil conservation and regeneration. It has survived through millennia because it maintained the 'ecological balance' of the soil and provided a 'workable connexion' [44] with the natural environment. Since it needed few main canals and no field ditches or drains, it was likewise in tune with the principle of space economy, so imperious in such a limited, 'finite universe' as the land of Egypt.

### *Demerits*

If biologically sound, the basin system was technically primitive and economically wasteful in a large measure. It was an adaptation to, rather than of, nature. It was a passive adaptation, only a very partial use of the land was made while it let the bulk of the Nile water run to waste in the sea. It limited agriculture to one-third of the year and did not permit of any substantial extension of the cultivated area [50, p. 123]. The historians' concept of the 'amazing productivity' of Egypt, while basically true, was partly overrated either because travellers saw only the richer perennially irrigated riversides [49] or were unduly influenced by the contrast with a poor desert homeland [49] as in the case of the Arabs. Furthermore, population and land use were left at the mercy of the flood vagaries. Agricultural production proceeded, in effect, under marginal conditions due to inefficient river control. There has always been a secular rise in the level of the river bed and the valley floor owing to progressive sedimentation of the bottom load, rendering misleading the long-term comparison of Nilometer readings[1] [11, p. 120]. But apart from this the river revealed a high variability and a periodicity which has not been satisfactorily explained. Sometimes the flood came too late and the sole winter cultivation was adversely affected. It would start plentiful but suddenly subside. The greatest danger, however, was for it to be too low or too high. The former meant a proportional shrinkage of the cultivated area—sometimes to one-half or even less. The corollary was *al-shidda* (the crisis, e.g., the famous Fatimid *al-Shidda al-Mustansiriya*);[2] or famine—an all too recurrent dark spot in the history of fluvial Egypt and immortalized in the descriptions of Abullatif.[3] Excessive floods swept away the *nabari* crops, but left the basins a pestilential morass. It was then the 'plague' which gained the upper hand—another stubborn feature of mediaeval Egypt. In the early Arab period 16 cubits were just the margin of safety—'the angels of death'; 18 marked plenty—it was a *sultani* flood; it was the deluge *al-lugga al-kubra* when it exceeded 20 cubits. It has been found that, within five centuries (from the fourteenth to the eighteenth) 50 plagues and epidemics ravaged Egypt—a rate of one every 11 years [34, p. 164].

It is apparent that the cultivated area was a direct function of the flood volume. However, flood effectiveness was actually a function of two variables: flood volume and human control. Hence the inflated role of centralized government in Egypt. The canal and dyke system was by its very nature short-lived and tended to silt up quickly, making necessary ceaseless clearance and maintenance. Any neglect aggravated the evils of an abnormal flood. Periods of political stability and power were therefore periods of efficient river control, extended land use, reclamation and re-population. Retreat of agriculture, increased wasteland and depopulation were concomitant with political weakness and chaos. It was found that, in particular, the most vulnerable and sensitive parts were the peripheral margins of the ecumene. Here the two endemic enemies of tropical oasis agriculture, namely salinity and invading sands, made for a pronounced 'marginal vibrancy' [34, p. 188] in occupance and land use. Slight and temporary encroachment of desert on the western and eastern flanks of the delta synchronized with periods of cultural degeneracy, while evidence exists of similar episodes in the valley west of Dairut and elsewhere in Middle Egypt [16, p. 66; 40, p. 19]. But salinity was by far the most serious danger, the Berari of the northern delta being the chief example.

Staunch conservatism was yet another drawback of basin agriculture. After a good early start it became associated with unimaginative inertia. Some urge that such continuity was a healthy sign of ecological equilibrium and efficiency, and contend that this imputed conservatism has been unduly exaggerated: besides the old survivals, new arrivals were introduced in the way of crops and farm machinery. Considering, however, the great extent of Egypt in latitude—she spans ten degrees representing a full climatic traverse—it is perhaps fair to say that the basin system partly thwarted the potential agricultural personality of the country.

## NEOTECHNIC PERIOD

### DEVELOPMENT

The novelty of this period is that it completely revolutionized the geotechnic system and universalized its geonomic complex. Perennial irrigation and agriculture were respectively the parallels of the mechanical and industrial revolutions in Europe [34, p. 9 and p. 65]. With a badly depopulated Egypt (2.5 millions), the change, to quote Farid, was only artificially wrought by a needy ruler. Perhaps it was also an early response and attempt to catch up with the epoch-making changes in a newly created industrial world abroad. The prime motivation was to gear Egyptian economy to the world market by producing valuable commercial crops, i.e., summer crops. The crux of the problem was that the summer water was too far below the level of the land and mechanical lifting from the old flood (*nili*) canals proved no answer. Two solutions were successively resorted to [21, p. 54-57].

From 1820: The floor of the flood canals in the delta was lowered at their heads to a considerable depth (6 m. and more), so as to enable the low summer supply to enter. In order to allow easy flow irrigation these canals were run at a lesser slope than the land, over which they therefore gained slowly northwards. This *seifi* (summer) canals experiment proved a failure. Costly and hard lifting of water by machines had still to be resorted to. Worse still, a whole army of corvée labour had annually to work on the clearance of the ever-silting canals in order to maintain the requisite depth.

From 1825: Instead of lowering the canal beds, the reverse procedure was adopted, namely, to raise their water level by barraging. Series of regulators were thrown across the delta canals. However, silting above the regulators soon strangled their action and reduced intake. Again, clearance by a 400,000-strong corvée army for four months annually was merely a palliative. This procedure persisted

1. Makrizi, *Khitat*, vol. 1, p. 95-98 (in Arabic).
2. Makrizi, ibid., vol. 2, p. 137 *et seq.*
3. *Abdollatiphi Historiae Aegypti*, Oxford, p. 210 *et seq.*

until 1843 when construction of the Delta Barrages began at the hydrologically strategic position of the bifurcation. The impounded, raised water was to supply three arterial feeder canals (*rayahs*), each commanding a triangle of the delta. Completed in 1861, the barrages functioned imperfectly until put back in order in 1890 when they could hold up water 4 m. above its normal summer level.

The full conversion of the delta to perennial irrigation, which started earlier in the south than in the north, was thus achieved. It was effected through a whole network of *seifi* canals pivoted on the three *rayahs* from which they took off and not from the Nile branches. This network assumes the shape of a fan or a bunch spread from the apex of the delta and closely following the old channels, thus running along the higher contours and tongues so as to command the adjacent low-lying areas. It represents an intricate hierarchy of graduated channels ranging from main carrier canals to branch canals, distributaries and field ditches (*miskas*).

In the valley, perennial irrigation gradually proceeded from north to south, the starting point for all Egypt being the apex of the delta. The Ibrahimiya was the first summer canal in Middle Egypt (1873) where it carried water to the sugarcane plantations of Ismail and a summer supply to the Fayum. It ran on land 1 m. higher than its surroundings [50, p. 124].

It will have been noticed that until the close of the century, conversion to perennial irrigation depended on merely raising the immediately available summer supply. The inadequacy of this partial utilization was soon manifest and a new era was ushered in when the floodwaters were stored for summer irrigation. This was effected by the erection of Aswan Dam (1902). Such is the basic distinction between barrages like those of the delta and a dam like Aswan. It was only natural for the position of the dam to be at the southernmost part of the river so as to benefit the whole country. This was true also of its site at a solid constriction in the river—the First Cataract. The dam (capacity 1 milliard $m.^3$) provided more water for the extension of perennial irrigation and was also a guaranty against low summer supplies. For the efficient distribution of the new reserve, a series of barrages like those of the delta, but on a smaller scale, were built: Assyut (1902), Zifta (1903), Isna (1909), Nag Hamadi (1930). Carrier canals from each were likewise dug. With increasing water requirements the Aswan Dam had to be twice heightened: 1912 (2.5 milliards $m.^3$) and 1933 (5.7 milliards $m.^3$). The opening decades of the century may well be designated the 'era of dams and barrages'.

In 1925 the perennial to basin ratio was 4 million to 1.2 million feddans. Today four-fifths of the cultivated area is perennial, the basins being confined to Upper Egypt. In the last few decades, however, summer lift irrigation has been increasingly practised. Such areas attain 70 per cent of the cultivated land in Assyut province and 50 per cent in Sohag province [40, p. 41].

The crux of perennial irrigation is the relative level of land and water. Perennial geotechnics—dams, barrages and canals—are therefore tantamount, in effect, to a virtually re-created orography. Landscape is now more man-made than ever before. While under the basin system the land was wholly inundated, the river is now absolutely imprisoned in its channel. The old basin embankments were ploughed up and a colossal protective bank *(gisr al-tarrad)* was built on both sides of the river from Jebel Silsilah in the far south to the Mediterranean [21, p. 57]. Whereas the valley in its entirety was converted into a seasonal vast lake from which only the slim banks emerged, the situation is now reversed: a dry valley punctuated with hundreds of canals—a drastically 'inverted hydrology'. Instead of one copious and prolonged watering, many waterings throughout the year are now applied at intervals. The greatest significance, however, was the changed danger of the flood. Under the basin system the dangers of too high floods were relatively slight—only sweeping the nabari crops, the basins themselves being naturally submerged. Indeed, thanks to the unusual quantity of silt, the drowning of the nabari meant an abundant crop in the ensuing years. The real danger was the defective flood. Now during the Nile flood period, summer crops are standing in the field and everything is done to confine the river to its channel. If allowed to overflow, it would ruin the whole crop. Geotechnically, perennial irrigation, imprisoning as it does the flood within its channel while the summer crops are still standing on both sides, has artificially put Egypt in the unenviable situation of Iraq where seasons of flood and cultivation are diametrically opposed.

Perennial irrigation meant an extended land use, both horizontally and vertically, to roughly 3 million feddans in 1820, to 3.5 million in 1830, to 4.1 million in 1852, to 4.9 million in 1889 and, with the completion of the Delta Barrages in 1890, it rose to 5.495 million feddans in 1899, then to 5.658 million in 1911. The actually cultivated area, however, was less: 4.805 million feddans in 1893-1894; 5.403 million in 1904-1905; 5.282 million in 1913 [21, p. 58]. Horizontal expansion has since been slower, the cultivated area being 5.698 million feddans in 1955-1956.

Growth of the crop area has been more spectacular. Cropping being year-long, the land now gives two or three crops—sometimes even more per year. This intensified use is like a change from a *vega* to a *huerta*, and makes the farmer rather a gardener. Until the turn of the century, the crop area was nearly 7 million feddans. It reached 8 million in about 1920, 9 million in about 1945 and in 1957 it surpassed the 10-million mark for the first time. The density of cropping is now nearly 177 per cent on the national level.

The increase of crop area compared to actual area is all the more significant because it has been essentially directed towards the more important summer and flood crops.

TABLE 1. Changing values of crop area by seasons [21, p. 153; 22]

| Year | Winter | % | Summer | % | Flood | % | Total |
|---|---|---|---|---|---|---|---|
| 1879 | 3 139 228 | 65.9 | 813 012 | 16.9 | 809 938 | 16.8 | 4 762 178 |
| 1899 | 3 906 299 | 55.5 | 1 712 276 | 24.3 | 1 414 136 | 20.1 | 7 032 711 |
| 1913 | 3 728 761 | 48.3 | 2 205 959 | 28.6 | 1 777 692 | 23.0 | 7 712 412 |
| 1957 | 4 698 621 | 46.7 | 3 364 404 | 33.4 | 1 881 064 | 18.7 | 10 054 681 |

All three groups have steadily gained in absolute acreage, the winter increase specifically denoting horizontal expansion. Although still first the winter crop area has relatively dropped from two-thirds of the total to less than one-half. The flood crop area again is relatively negligible; while the real change is that shown by the summer crop area—now nearly one-third of the total.

Clearly then Egyptian agriculture has become intensive as well as a truly 'wet agriculture'. This, however, has been vitiated by many drawbacks inherent in perennial irrigation.

## WEAKNESS OF PERENNIAL AGRICULTURE

For a few years after the advent of perennial irrigation a rise in average yield was marked for most crops [21, p. 154], thanks no doubt to the millennial reserve of fertility in the soil maintained under basin agriculture. Soon, however, yields seriously declined and have since continued to do so, although in the last few years the downward trend has been arrested and partly reversed.

Four main reasons attendant upon perennial irrigation account for this.

*Insects.* Wet agriculture, by increasing moisture in soil as well as in atmosphere, has created an ecologically favourable habitat for both plant and animal parasites. To cite only one example, the increased summer supply after the erection of the Aswan Dam in 1902 was immediately followed in 1904 by failure of the cotton crop through the devastating worm [21, p. 155-156]. The boll-weevil is the most publicised of the field pests, but the evil is common to most other crops and the over-all loss is enormous.

*The 'red water famine'.* Perennial irrigation has materially deprived the soil of the silt-laden red water. A basin-irrigated acre receives annually much more mud than a perennially irrigated one because all the gates and sluices of dams and barrages are left wide open in flood lest the mud would choke up the system or silt up the reservoirs. On the other hand when the flood is strictly canalized out to the sea within its banks, only 'anaemic' water is allowed to reach the fields. The greatest danger that jeopardizes soil fertility in Egypt, many authorities maintain, is a 'red water famine'—a downright 'suicidal policy' [85, vol. 2, p. 456]. Another school of thought would deny the special value of silt and claim that fertility is due to the Nile water itself whether or not charged with silt [50, p. 129]. In any case, to make good the diminished fertility, recourse to ample chemical fertilizers has, since 1900, increasingly become an essential feature of Egyptian agriculture. However despite the increasing doses of artificial fertilizers, yields are much greater on basin lands. Today the average consumption per acre far exceeds any norms known in other agricultural countries [29, p. 464]. Imported nitrates and super-phosphates are the main items, with consumption greater in the valley than in the delta [4, p. 39]. Reduction of imports during the last war was immediately reflected in an alarming drop in average yields.

*Overcropping.* Perennial cultivation, with its suppression of *sharaki* (fallow) is synonymous with overcropping. The new crops have actually inherited the sharaki. Two main rotations, pivoted on cotton, are practised—the biennial and the triennial. The latter, more rational, practice permits the cultivation of cotton in one-third of the area and the longer fallow and rest give yields exceeding by as much as 20 per cent those of the biennial. However, this practice is followed only by a minority. The biennial gives more crops, but exhausts fertility. Overcropping joins forces with the 'red water famine' in raising inordinately the consumption of fertilizers.

*Waterlogging and salinity.* To ensure flush irrigation, the perennial canals were run at high levels throughout the year. Frequently they ran at the same level as the land—indeed occasionally higher. There was serious over-watering. It was maintained at the end of the century that Egypt's problem was one of water, and clamour was everywhere for more summer flush water. However, the presence of water continually in the soil hindered its natural drainage downwards and a quantity of water began to accumulate every year in the soil near the surface. Thus, an artificial water table, quite different from and independent of the natural water table, came into existence [28, p. 153-156; 52]. In places it was not more than 1 m. deep, and asphyxiation from waterlogging menaced the crop roots. In 1884 the level at which water was held up at the Delta Barrages was raised from R.L. 12 m. to 13 m., and in 1889 a rise of 1 m. in the subsoil water was recorded everywhere in southern Munufiya [85, vol. 1, p. 100]. Since then the level has been persistently increased, with a corresponding rise of subsoil water.

Progressive salinization, too, began. The Nile waters contain much soluble salt, and under perennial irrigation an acre is estimated to receive 96 kg. of salts mostly sodium chlorides [37, vol. 1, p. 183]. The annual flooding under the basin system took care of washing away these salts. But since perennial irrigation Egyptian agriculture has become more than ever a 'constant struggle with salt' [37, vol. 1, p. 183]. This evil was more menacing to the lighter sandy soils where infiltration is quicker than in the denser clayey soils, but it is fairly easily remediable in the former whereas in the latter, once established, it is extremely difficult to treat. Since the heavier sandy particles are deposited nearer to a channel and earlier in its course than are the fine clay particles, the dangers of the rising water table were first manifest in the southern, more sandy, delta rather than in the more clayey north and along canals rather than away from them [85, vol. 1, p. 397]. For crops, the danger is more disastrous to the longer rooted ones—mainly the all-too-important cotton—and less serious to cereals and bersim. Signs of soil sterility began earlier in the middle reaches of the delta, the south being of relatively higher elevation and the north more clayey. There some of the choicest cotton lands in Egypt lost their fertility [85, vol. 1, p. 411 *et seq.*]. Soon, however, it was the turn of the south and Munufiya, of age-old renown for its fertility, began to suffer and 'radishes and cucumber paid more than cotton' [84]. In the north, exceptionally high floods induced a good rice crop, but the following year the cotton crop would be a complete failure [6]. Naturally, the valley, more elevated, was less vulnerable, but was not ultimately spared. Such, too, was the story of the Wadi Tumeilat, ruined by the high level Ismailiya canal, and the lands adjacent to the Ibrahimiya in Middle Egypt.

These developments gave rise at the end of the century to the alarmist view that perennial irrigation would ultimately ruin the fertility of Egypt [50, p. 133]. We now know enough to take a more moderate view. Artificial irrigation means artificial drainage. Until World War I, drainage was a very secondary question, but has since leapt into the forefront. Everywhere, the fellah now asks for a drain. After laborious experimentation, the optimum depth of drains has been fixed, with an eye to the length of cotton roots, at 1.25 to 1.50 m. below land level [58]. In the delta a network of drains similar in hierarchy to that of irrigation canals has come into being, ending at the Mediterranean or the northern lakes. The network is carefully interdigitated with the canals, each main drain being parallel to and lying between two main canals, thus occupying the lower tongues of land leaving the higher stretches to carry irrigation [85, vol. II, p. 451]. Similarly, the smaller drains are interposed between canals of respective rank. A serious problem in the delta is the feeble slope while substantial sections in the north are well below sea level, so that drainage by gravitation is precluded and electric pumping stations have had to be installed to discharge water out into the sea. Drains, too, take up much valuable land. Since the system is hardly effective if not connected to every field, as much as one-tenth of the total area may be claimed by drains [21, p. 245]—a staggering ratio where land is so precious. The answer lies with covered, piped drains, but this has hardly been put into effect so far. The rising water table has been further controlled by eliminating high level canals and lift water has been supplied by electric pumps to those high tracts, such as occur in Kaliubiya, that cannot be commanded by canals of reasonable level. Indeed, many deprecate the fetish of flush irrigation and recommend instead the universalization of lift irrigation. Irrigation rotations have also been adopted so that water is alternately run high and low, canals thus turning into drains during their low water season [67].

## CHANGING VALUES IN LAND USE

Perennial irrigation has given to Egypt the wide range of crops appropriate to the protracted thermal traverse she represents. Partly tropical, subtropical and warm temperate, the only limiting factor in the past was water. Now she has been converted from a monsoon semi-oasis into a perennial monsoon—and contradicts the contradiction. Here, as Selim puts it, 'the wheat, the maize, the cotton and the rice belts of the vast Mississippi basin are all rolled into one . . .' [5, p. 69]—a unique case of compressed gradient.

However, the extended and varied crop complex did not really mean the introduction of new crops as much as the effective expansion of already existing but previously unimportant ones. This is true of cotton, which is erroneously considered by some to have been introduced by Mohammed Ali [5]. Known from very early times in Egypt, it has been a rediscovery. So it is with rice and sugarcane. Indeed, perennial irrigation has synchronized with the decline or suppression of certain traditional crops, e.g., indigo and saffron, due to the advent of aniline dyes and kerosene. Tobacco was suppressed on account of fiscal policy [21, p. 64]. Flax has also declined considerably with the increased cultivation of cotton. The only new crop has been Indian maize. A flood crop, introduced via Syria (whence the Arabic name) its history in Egypt does not cover more than 150 years. It has rapidly become a major crop, the staple cereal of the masses—a change for the worse in the opinion of some as wheat was once the staple cereal in Egypt. Anyway, the novelty of the new crop complex lies not in absolute innovation but rather in changed relative proportions and values. This, however, was a mighty enough revolution. The dominance of the new summer crops, particularly cotton, has put an end to the cultural endemism and historical hibernation of mediaeval Egypt, brought her into the cockpit of the world market and supplied a medium of exchange for modern culture. In fact cotton has meant acculturation. It has created new needs as well as new means, and evolved agricultural methods and techniques—summer crops alone receive the maximum attention of the farmer. This, however, has been at the expense of food crops : Egypt today—the classical agricultural example of the textbook—does not produce enough food for her population. 'From food to fibre' has been the keynote of change, leaving the country under the sway of world markets. Egyptian agriculture is now monoculture by cash value, but on the basis of acreage is definitely polyculture.

## ELEMENTS OF THE MODERN CROP COMPLEX

On the basis of acreage, three categories of crops may be distinguished : primary, secondary and tertiary.

### *Primary crops*

This is the maize-bersim-cotton-wheat quartet. Together they occupy at least three-fourths of the cultivated as well as of the crop area—sometimes more. The areas given over to maize and bersim have been the more constant and those for cotton and wheat rather more variable; since the end of the last century their crop area very rarely fell below 20 per cent for each crop. They progressively gain in area at the expense of other crops and while maize and bersim have long contested for first place in acreage, the former has tended to lead in the past few decades. As the base of the crop-pyramid, they significantly represent the staple food of man and animal respectively. Maize is the food of the fellah and, in order to guarantee his daily bread, is the first item in his rotation. The importance of bersim is due to the absence of natural pasture. The allegation that the animal population has decreased since and because of perennial irrigation [50, p. 132] is not supported by the facts and is rightly refuted by Farid and Thomas [26, p. 138; 77, p. 200]. The increasing bersim area has been in harmony with a growing animal population. Issawi argues that Egyptian agriculture is wasteful in its use of bersim as fodder and that the soil of Egypt is much too valuable for maize which might conceivably be imported. However, bersim is essential for an animal population—so valuable in farm work and in its manurials and dairy products, though the value of the last item has been found to be less than the value of the fodder offered. Yet bersim, a green nitrogen fertilizer in a depleted soil initially poor in nitrogen compounds, is primarily the safety valve of Egyptian agriculture, an antidote to perennial cropping of the typically exhausting maize, cotton and wheat.

Cotton and wheat rank lower in acreage than maize and bersim. While cotton sometimes attained 24 per cent of the crop area, wheat has never reached 20 per cent, the average being 16-17 per cent. While cotton fell, however, occasionally to 12.5 per cent (1931), wheat has scarcely ever dropped below 15 per cent. Cotton is thus more fluctuating and variable than wheat; it is perhaps the most variable of all our crops. Introduced seriously only in 1890 [77, p. 156], its area is a function of the world market. Pivot and master of Egyptian agriculture, it is nevertheless a slave of world prices which, with her small production, Egypt can never hope to control. Hence the failure of all restrictive policies on its acreage. The relative value of cotton with respect to other crops has visibly declined : in 1924 its value was five times that of wheat and three times that of maize. In 1932 it was one and a half times the value of wheat [43, p. 64]. Lately, however, its relative value has been mounting, and cotton is still 'king'. It is more popular with the big landowners in view of its profitability and possibilities. Also, it lends itself readily to a system of hiring, it being unconsumable by the tenants [43, p. 64]. Cotton acreage shrinks in world wars and crises, expands in periods of strategic stockpiling such as that of the Korean War. Self-sufficiency in food becomes an imperative national policy in wartime; the gainers are usually cereal crops, particularly wheat. To some extent the movement of cotton and wheat vary inversely in area. The story of cotton in Egypt has invariably been the introduction of new varieties and strains, which in turn soon deteriorate as a result of mixing (winds being a potent factor), and then a new variety is again introduced.

Wheat, a staple of the urbanites, has lately been expanding with growing urbanization—itself a product of cultural changes ultimately wrought by cotton. The urban contingent stands now at one-third the total population [34, p. 13]. The rather stationary wheat area has necessitated the importation of considerable quantities of wheaten-flour. It is to be noted that until before the second world war there had been a margin of surplus for export.

### *Secondary crops*

On the national plane, this class should not exceed 10 per cent of the total crop area nor be less than 1 per cent. This is admittedly a wide range and the minor members may conceivably be considered in the tertiary group. However, this category comprises six crops totalling 18 per cent in 1957 and ranking then as follows :

| Rice | Beans | Vegetables | Barley | Cane | Fruit |
|---|---|---|---|---|---|
| 7.3 | 3.5 | 3.4 | 1.3 | 1.1 | 1.1 |

They fall into two groups: declining and growing. The declining crops had until recently an important place. Beans occupied one-tenth of the total area at the end of the last century. It is the main summer fodder, besides being an important protein-rich fodder. Barley, once 7 per cent of the crop area, has dwindled with the rise of rice and millet, the optimum use always having first claim on the land.

The growing group is headed by rice. Its water requirements are insatiable, the 'water duty' being more than twice as much as that allocated to cotton. Its expansion, therefore, had to await the summer supply schemes. It is still directly dependent on the state of the flood, its acreage being annually decided by edict in accordance with that determinant. The first claim on water goes naturally to the standing crops, and rice has to be satisfied with the residue [40, p. 60]. Undoubtedly 'riziculture' has been the most important revolution in Egyptian agriculture since cotton [73]. It now occupies as much as half the land devoted to cotton or wheat, and has therefore become a vital export crop. In 'vegeculture' there has been virtually a silent revolution. Vegetables, together with fruit, occupied in 1900 some 18-19 thousand feddans only and 29 thousand in 1914-1915;[1] and today they alone rank with beans in area—and nearly half that occupied by rice. Vegeculture as well as horticulture and arboriculture are all related to growing urbanization and its attendant rising standard of living. Fruit does not occupy as great an area as do vegetables. Similarly with sugarcane, which, though very minor in terms of area, is of primary standing in terms of value and because it is the oldest industrial crop of Egypt—earlier than cotton. Its systematic cultivation began after the cessation of the American Civil War as a substitute for the fall in the price of cotton. This piece of speculation, however, proved a failure and a decline in area set in, until the trend was reversed in the last few decades.

### Tertiary crops

This category includes seven crops totalling 3 per cent of the crop area in 1957; each one occupies less than 1 per cent.

| Lupins | Lentils | Fenugreek | Chick-peas | Onions | Sesame | Groundnuts |
|---|---|---|---|---|---|---|
| 0.1 | 0.8 | 0.6 | 0.4 | 0.4 | 0.4 | 0.3 |

Onions, an export crop, are the most important, and the area of cultivation is determined, like cotton, by the foreign market. Some of the tertiary crops are substitutes for bersim, e.g., fenugreek, lupins, and chick-peas. Others are vegetable oil crops, e.g., sesame and groundnuts.

## ECOLOGICAL CONTROLS OF AGRICULTURAL LAND USE

A major distinction between primary crops on the one hand and secondary and tertiary crops on the other is that the former are almost universally grown all over Egypt, while the latter are highly localized in their distribution. So much is this so that one may divide Egyptian crops into universals and locals, the former providing a general matrix, the latter embedded in the background as distinct pockets and enclaves. This basic pattern is due to the interplay of various controls, physical and human.

### Physical controls

Of the two climatic conditions of humidity and temperature, irrigation has practically neutralized the former. Apart from the basin-irrigated sector in Upper Egypt (where cotton is considerably reduced), the effect of modern geotechnics has been to reduce regional inequalities with regard to water supply. Yet the flood still arrives later and has a shorter duration in the delta than in the valley. This may retard the cultivation of maize with adverse results to the crop. Again the slight winter rains of the northern strip of the delta may harm the growth of cotton. In general, however, it may be said that the real differential influence of water and hydrology is conditioned by some such factors as elevation and soil.

Temperature is probably a more effective differential. It generally drops northwards, while relative atmospheric humidity increases. Since bersim, maize and cotton require moderate temperature and a humid atmosphere, they are more important in the delta than in the valley. Even within the delta, bersim and cotton progressively decrease southwards. This is also true of the valley, so that all over the country these two crops systematically decline in ratio and density from north to south. In particular, the better qualities (long staple) of cotton are sharply restricted to the humid, cooler north, while the coarser and shorter types are relegated to the south. Maize, with its considerable vegetative growth, is more adapted to the north, hence the decrease in percentage of cropping southwards. It is noticeable that wheat, the transitional, intermediate crop *par excellence* with the widest range in distribution the world over, is the most regularly distributed crop in Egypt.

Most secondary crops reveal strong localization,[2]

1. *Ann. Stat.*, 1915, p. 121.
2. Figures worked out from *Monthly Bulletin, Agric. Statistics*, 1958.

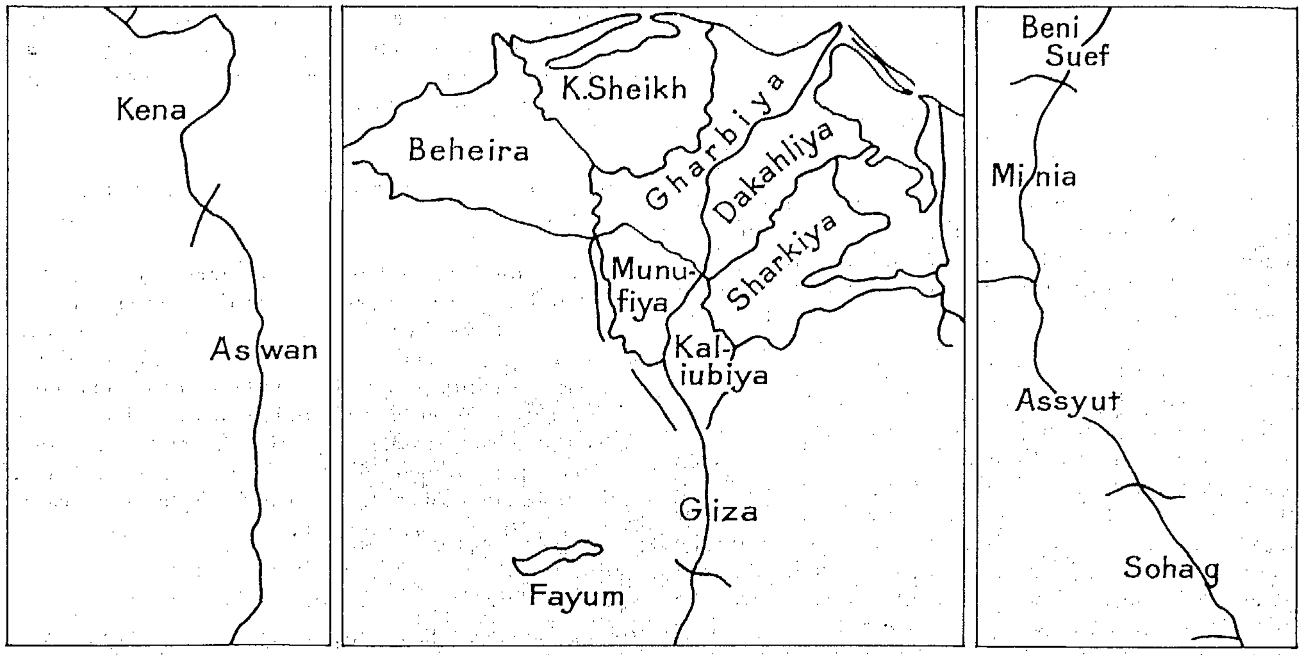



FIG. 1. 'Pioneer fringe' of reclamation of Egypt.

mainly because of the temperature. Some 93.6 per cent of the total crop area of sugarcane is concentrated in Upper Egypt, where two pockets (Minia and Kena-Aswan) account for 85 per cent of the national total. Kena alone accounts for 53 per cent. In the last century sugarcane culture was centred in Minia, but now a definite shift has taken place towards the Far South—no doubt in search of higher temperatures. Nearly 68.2 per cent of the area given over to onions belongs to Beni Suef-Minia-Assyut-Sohag—the 'onion pocket'. Similarly lentils, which were previously grown in both delta and valley, have, as pointed out by Farid [26, p. 138], experienced a definite migration to the valley; they are never grown in the delta today. A concentration of 99 per cent of the total national acreage of lentils in Kena and Assiut (71 and 27.7 per cent respectively) forms a definite 'lentil enclave' there. Again lupins form essentially a valley crop, where 96 per cent of the total acreage belongs to Minia-Assyut-Kena. Fenugreek too, is a valley crop : 92 per cent of its total area; with 86 per cent in Fayum-Minia-Assyut-Sohag-Kena, the centre of gravity being in the south. On the other hand, such little flax as is grown in Egypt belongs entirely to the delta, where 70 per cent of the total area is monopolized by the cooler, wetter north (Beheira, Gharbiya and Dakahliya). It is certain that all these cases of narrow localization are related to temperature. This is attested also by the fact that yields in these areas are invariably the highest, denoting optimum habitats.

*Soil*

This potent control has two aspects : mechanical structure and salinity. Chemical composition may be dismissed as being essentially homogeneous all over the country, genetically belonging, as it does, to the same source, the Nile deposits [37, p. 181 *et seq.*].

*Mechanical structure.* Extremely changeable, even within one and the same field, the pattern of soil structure in Egypt is hopelessly complicated. The broader lineaments of Egyptian agrogeology, however, can be identified. The proportion of sand decreases while that of clay increases northwards throughout the whole length of the country.

The valley is thus more sandy than the delta where, apart from the hard section, a thick black clayey soil *(ard soda)* predominates, reaching its maximum development south of Lake Brullos. There clay constitutes 80-90 per cent of the soil composition, giving it an extremely tough plastic impermeable, therefore retentive, texture. Arenaceous soil predominates again in the east and west fringes of the delta *(ard sofra)*.

This general pattern is a basic control of crop distribution. Despite their farming difficulties, the sedimentary argilaceous dense black soils are rich in nutrients and are admirably suited to exhausting, long-rooted cotton which is adversely affected by the poor sandy soils. Cotton therefore increasingly thrives and preponderates within the delta from south to north with the increasing prevalence of black soil. The same type of soil is necessary for maize; this is partly the reason why it is more widespread in the delta than in the valley where the proportion of sand rises steadily southwards. The sandy, rather saline, soils along the fringes of the delta account for the localization of sesame and groundnuts in Sharkiya in the first place and Beheira in the second (37 per cent of the crop area is devoted to each in both provinces). It explains too, the concentration of henna in Sharkiya and Kaliubiya (76 per cent of the total crop area of that plant). Fruit growing is likewise related to the sandy soils of Kaliubiya, Sharkiya and Beheira which together account for 52 per cent of the orchard area in Egypt. Hardy barley replaces wheat in the poorer, saline sandy soils along the margins of the delta and in the tail-end of the valley. Thus Beheira and Sharkiya in the north and Kena and Aswan in the south monopolize 66.8 per cent of the barley area in Egypt.

*Salinity*. In the northern half of the delta as well as in the Fayum, the salt content of the soil exerts a major restrictive influence on cultivation. It is related in the latter to inadequate internal drainage to Lake Karun which lies below sea level. In the former it is connected with the formation of the Berari, the low contour and the perennial irrigation. In fact throughout the delta the fertility factor is the salt quantum [46]. Good land has an average salt content of about 0.3 per cent, medium land 0.5 per cent while land rated poor has 0.8 per cent and barren land may contain anything up to 25 per cent. The gradual transition from good land in the south through medium to bad and barren in the north is a fundamental feature. The less porous and permeable black soil favours capillary attraction more than the sandy soils, hence the rise of the artificial water-table (connected with perennial irrigation and neglected drainage) is accompanied by more salt efflorescence and salinization in the former. The salt content is therefore a function of the degree of subsoil water infiltration and of drainage, themselves partly functions of altitude above sea level. Contour and fertility are closely interdependent. Thus the general division between good and medium lands follow roughly the 6-m. contour, while that between poor and barren is in the vicinity of the 5-m. contour. Through the control of salinity, the micro-relief of the delta assumes undue influence on fertility. Thus up to the 1.5-m. contour the soil has frequently been washed by the sea, and in lands in immediate contiguity to Lake Brullos and the littoral the salt content varies from 5 to 8 per cent of sodium chloride and from 1 to 2 per cent of magnesia. Between the 0.50-m. and 1-m. contours it decreases to 2-2.5 per cent for both salts and is 1 per cent of sodium chloride and 0.5 per cent of magnesia for lands above the 1-m. contour. In local cases, however, these limits are ignored; and in general soils with more than 3 per cent of salts are uncultivable.[1] In fact, below the 7-m. contour bad drainage is always accompanied by salt efflorescence and below the 3-m. contour salt is everywhere in excess [85, vol. 1, p. 32]. Two grades of salinization are noticeable. Where relatively fresh subsoil water is nearest to the surface, 'black alkali' prevails, while 'gypsum-veined' soils in Egypt occur in localities where subsoil water is deeper. Some humus-less types of the black alkali soils are actually solonshaks, while forms of solonetz also exist [11, p. 166; 24].

From the standpoint of agriculture, this physical pattern of the Berari belt makes it at once synonymous with rice. Although rice actually thrives better on good land as in the south of the delta, it has essentially come to be the reclamation crop *par excellence*. Lavish in its water requirements (4 m.$^3$/day/acre), it permits of abundant washings which dissolve the surface salts from the soil. There is, generally, a cycle of reclamation here. If salinity is 3.0 per cent nothing but wild weed would grow, but if reduced to 2.0 per cent a rough species of low grade millet *(deneiba)* can be raised, and it is not until it has been reduced to 0.5 per cent that rice can be grown. Bersim usually follows in order to nitrify the soil and generate humus in it. Cotton can then follow. It has been found that if the subsoil water level in the northern delta can be maintained permanently at a depth of 70-80 cm. from ground level, cotton can be safely grown and would yield 5-6 kantars (250-300 kg.) per feddan—provided rice alternates with it every third year. The recurrence frequency of rice cultivation is proportionate to the depth of the subsoil water, i.e., dependent upon the stage of reclamation. Again, on both sides of a drain effective amelioration of land is confined to an immediate small width, beyond which drainage efficiency diminishes progressively to vanishing point, and here recourse to rice cultivation is imperative at short intervals while the favoured strips along the drain can grow cotton more frequently. Hence it is noticeable in the north of the delta that rice tends to preponderate in the lower-lying ill-drained stretches while the more favourable strips nearer to drains are given over to cotton [17; 58, p. 99-101].

South of the Berari proper, salt exists, but in proportion not very harmful to cotton which seems to tolerate a slightly salty soil. Maize is, on the contrary, very sensitive to any salt in the soil since its roots are shallower than those of cotton. Therefore where subsoil water has risen, maize will be confined to the higher parts, which are still free of salts, while cotton and rice will be sown in rotation in the lower-lying parts.

1. H. Sirry, *Science of Irrigation*, Cairo, vol. II, p. 32 (in Arabic).

### *Human controls*

Human factors may go counter to the physical controls as discussed above. As Hume points out the principle of adaptation in Egyptian agriculture is not always strictly observed. Owing to the universal desire of the fellah to guarantee his own food, and if possible ready cash, maize and cotton are too generally grown—partly irrespective of physical optimum conditions.

The demographic factor, too, is a prime control of land use. The pattern of density in Egypt is fairly simple: proceeding from both extreme north and south, it rises quickly and steadily until the summit densities are reached at the head of the delta. A basic feature of rural economy in Egypt is that in every locality the local demands for grains, pulses and foodstuffs must be satisfied in the first place and the proportions of other crops are subordinate to, and conditional upon, their acreage. Hence the demographic differential looms large in the crop combinations of the land use equation. This explains why the maize area goes hand in hand with density, in the valley as well as in the delta where it substantially increases from north to south.

The pattern of land tenure has also its repercussions on land use. Such commercial, costly crops as cotton, fruit and sugarcane are closely related to big landownership which predominated in the northern delta and in certain enclaves in Upper Egypt.

Finally urbanization may be regarded as one of the really potent determinants of land use, though in a rather patchy manner. With accelerated urbanization and the rise of metropolitan super-cities, concentric rings of what may conveniently be designated 'urban crops', vegetables, dairy products and fruit are already well developed. Particularly around the two conurbations of Cairo and Alexandria and the Canal towns, as well as the major urban centres of the delta, agricultural geography is clearly subordinate to urban geography.

## AGRICULTURAL REGIONS

It is not easy to define distinct and clear-cut land use regions in the Nile Valley since in one sense it may all be regarded as one vast single region of mixed agriculture. Yet with a proper sense of proportion, minor regional associations and typologies can be identified within such a region. The snag is always that the main crops are too general, while the specifically local crops are of minor weight in area as well as in cash value. A possible way out is to recognize main types on the basis of the principal primary crops —the base complex. Internal ranking within this complex should also be a useful guide. Sub-types can then be identified within them by reference to secondary and tertiary crops. The national crop area percentage can always be used as a norm from which local and regional deviations are assessed. Agricultural regional personalities would thus emerge. For regional purposes, however, the statistical basis of distinction between primary, secondary and tertiary crops must differ from their national basis. The

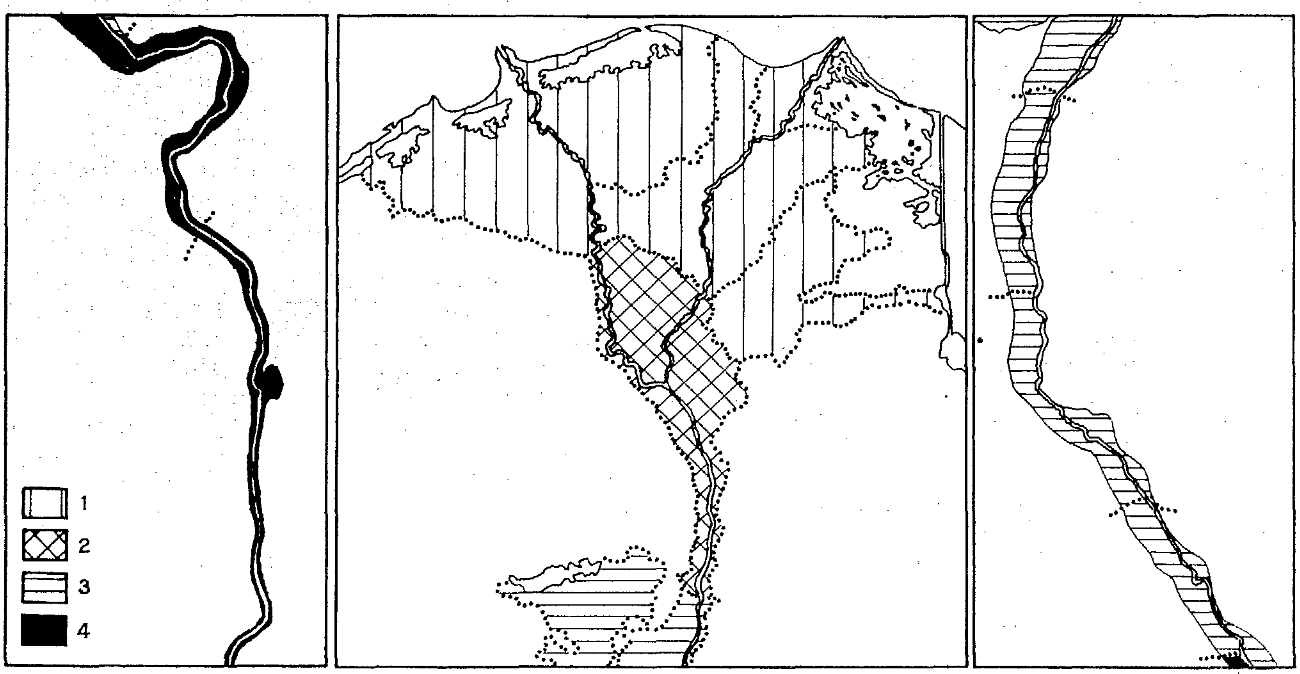



FIG. 2. Agricultural regions: 1. Northland; 2. Metropolitan Triangle; 3. Middle Egypt; 4. Far South.

following limits have been found practical : primary, +10 per cent; secondary, 10-5 per cent; tertiary, 5 per cent—reference being always to crop area as of 1956-1957.[1] It is once again necessary to insist that the resultant regions are not first order, that they all have a basic common denominator and merge gradually into one another without hard and fast limits.

On these bases four agricultural regions are discernible within the Nile Valley in Egypt, namely the Northland, the Metropolitan Triangle, Middle Egypt and the Far South (see Fig. 2).

*Northland*

Essentially the 'pioneer fringe' of reclamation of Egypt, the belt includes the provinces of Behiera, Kafr El-Sheikh, Gharbiya, Dakahliya and Sharkiya (see Fig. 1). It comprises the Berari and the rice belts in their entirety, as well as the sandy east and west margins of the delta, where it monopolizes a series of nearly whole pockets of minor crops like barley, sesame, henna and groundnuts. A sparsely populated region, it is distinctively extensive in land use, with predominantly commercialized stereotyped production.

The four primary crops of the base complex (maize, bersim, cotton and wheat) occupy together a crop area similar in general to their national value (i.e. 78 per cent). Beheira, however, is a serious deviation (59.5 per cent). Apart from the very peculiar Far South, it is the only province in Egypt where the ratio of the base quartet drops far below its national average. The reason is that here rice rises to the rank of a primary crop nearly equal to wheat (12.8 per cent and 12.9 per cent respectively). The base complex thus includes five not four crops.

The elements of the base complex in Northland are characterized by a specific order of importance. Bersim occupies a greater area than maize, cotton than wheat, the order thus being bersim, maize, cotton and then wheat. This is the only region where bersim persistently outweighs maize in acreage. The main explanation lies in the fact that the real potentialities of these new lands rest with animal husbandry and dairy products rather than with traditional farming. Again the supremacy of bersim and cotton over maize and wheat respectively reflect that the accent is here laid on commercial rather than food production. A sparse population, and a prevalence of big land holdings together with a suitable soil and climate jointly account for this. The former order, however, is offset in Kafr El-Sheikh and Dakahliya, where rice takes the rank of maize. These are in fact the two nuclei of 'rice-land'. Bersim, however, remains the first crop as elsewhere in the region.

A rise in rice cultivation so marked as that in Kafr El-Sheikh and Dakahliya is achieved at the expense not only of the primary crops but also of the secondary which are in turn demoted to tertiary. This applies particularly to beans and vegetables. In Beheira where rice is only reasonably prominent these two crops are of secondary order and vegetables, in particular, attain their highest percentage of the crop-area in the delta. In the remainder of the region, the secondary rank is represented by rice, the third by vegetables and beans. Sharkiya is characterized by its wide diversity of tertiary crops owing to the localization of certain specialities, e.g., groundnuts and sesame. Both western and eastern peripheries of the region in Beheira and Sharkiya have in common a sandy soil and a metropolitan orientation (towards Alexandria and the Canal towns respectively). Hence they are both distinguished by barley and fruit growing.

Synoptically then, the region falls into four sub-regions or sectors : (a) The core, Gharbiya, focus of cotton, (b) the distributory sectors, flanking the core in (c) Kafr El-Sheikh and Dakahliya, representing the foci of rice, and (d) the terminal sectors, Beheira and Sharkiya, generally more diversified.

*Metropolitan Triangle*

This region comprises Munufiya and Kaliubiya in the south of the delta together with Giza at the head of the valley. This old, settled, very densely populated region further differs from Northland by its higher elevations and more sandy soils. Agriculturally intensive, this region is primarily one of food production, the pressure of population being of paramount importance. It is distinguished from Northland by a marked preponderance of the traditional base complex, its percentage of crop area being, with the exception of Giza, far above the national average. Traditional agriculture is typical, and rice is absent. In contrast to Northland, the area occupied by the four main crops is in the following order, maize, bersim, wheat, cotton.

The accent is already on subsistence and food crops rather than on commercial crops. The importance of cotton is reduced to below the national average. The metropolitan agglomeration of Cairo results in an emphasis on vegetables and fruit. In Giza, vegetables occupy 15 per cent of the total crop area, thus replacing cotton in fourth place.

The region has thus a traditional rural economy, modified by urban influences. Its component sectors exhibit further specialization. Munufiya is primarily the traditional purveyor of milk products and therefore has a high density of animal population, which goes with an exceptionally high percentage of bersim and maize cultivation. Kaliubiya has a long-standing reputation for fruit. The orchard percentage is five-fold the national norm. This is explained by the

1. Calculated from the *Monthly Bulletin, Agric. Statistics*, 1958.

sandy soil and relatively high elevation which afford good drainage together with the historical factors. Giza is the vegetable sector *par excellence;* here vege-culture ranks in acreage as a primary use of the land, with a crop-area percentage nearly five-fold the national average.

### Middle Egypt

This region of the valley includes the Fayum, Beni Suef, Minia, Assyut and Sohag. It is a region of traditional agriculture with the usual base crops and a special development of pulses. Maize is as usual the first crop—a fact explained by the very high population density. Bersim is no longer necessarily the second crop as in the Metropolitan Triangle. In one case it drops to the fourth position. This is a reflection of the diminishing importance of bersim southwards throughout Egypt. It is generally the second crop except in the Minia-Assyut sector where a definite, old-established concentration of medium-stapled cotton exists. Wheat finds propitious conditions in the mild, almost warm, winter of Middle Egypt and is elevated from its traditional fourth or even lower place to be the third.

Beans represent a common denominator all over the region, but in the Beni Suef-Minia-Assyut-Sohag sector they rise to secondary rank. This is actually the most important area of bean cultivation in Egypt.

Minor crops exhibit a considerable localization. Rice and fruit in the Fayum are historically famous and reflect its peculiar topography—fruit on the terraced slopes with rice in the bottom marshes of this depression. In Assyut it is lentils and sesame; while Minia features the more commercial sugar-cane and onions. Fenugreek and sesame are more typical of Sohag.

### Far South

Like Northland, this is a very distinctive region. As in Northland, the explanation lies in a marginal position, a marginal temperature, marginal soils as well as in marginal human conditions.

The traditional crop complex falls far below the national average, accounting for less than half the total crop area. The reason is that its elements are radically turned upside-down. Maize with millet remains the leading crop; wheat is second. Bersim and cotton become minor crops. Temperature and vestigial basin irrigation are the main determinants. Instead, sugarcane, lentils and barley feature in the primary complex—the last as a poor substitute for wheat, sugarcane and lentils reach their highest importance in this region, replacing cotton as cash crops. Minor crops assume a greater importance than elsewhere. They include beans, bersim, cotton, barley and fenugreek.

## LAND USE REGIONS IN EGYPT

Having depicted the land use picture of the Nile Valley proper in some detail, we may attempt a synoptic survey of the land use types in and outside the valley. The basis of classification will be the dominant land use, following the system devised by the World Land Use Commission set up by the International Geographical Congress, Lisbon, 1949. Four main areas can be distinguished (see also Fig. 3).

### Nile Valley

The alluvial flood land of the Nile in Egypt is only 35,000 km.$^2$ or 3.5 per cent of the total territory. It assumes the shape of a lotus—with the valley as the stem, the delta the flower and the Fayum the bud [11, p. 3]. Small as it is, it is nevertheless the greatest, densest and most ancient human agglomeration—or island—in the continent. In occupancy and land use it is more like a segment of a China than of a Java. In particular, it recalls the lower Yangtze, whose delta has been termed the 'Holland of China'. Translating its water requirements in terms of rainfall equivalent (55 milliard m.$^3$ on a cultivated area of approximately 6 million feddans), we get 82 in.—the norm of monsoon or equatorial lands. The Nile would be more logically located alongside, say, the Irrawaddy than alongside the Red Sea. Herein lies a basic contrast with fluvial Iraq. Both are semi-oases; but Egypt lies in a desert, Iraq in a dry steppe. Land use in Iraq shades off gradually from river to desert; in Egypt the change is abrupt and definite.

Neither is the whole area of the Nile Valley cultivated, nor is land use uniform throughout. According to the standard system adopted by the World Land Use Commission, several categories of dominant land use can be recognized.

Category 1, settlements and associated non-agricultural land, including 'public utilities' land, occupies an area of 955,000 feddans in 1954, out of a total cadastrated land of 8,316,000 feddans.[1] Of the urban areas, the Cairo conurbation (3.5 million) and Alexandria alone can be satisfactorily represented on small-scale maps.

Category 2, horticulture, covers 1.1 per cent of the total crop area, but is scattered and diffuse. Fairly extensive orchards are found in Sharkiya and Kaliubiya but cannot be delineated on maps. Much interculture is practised in this category.

Category 3, perennial or tree crops, is represented particularly by groves of palm trees, but these are

1. *Ann. Stat.*, 1954-56, p. 143.

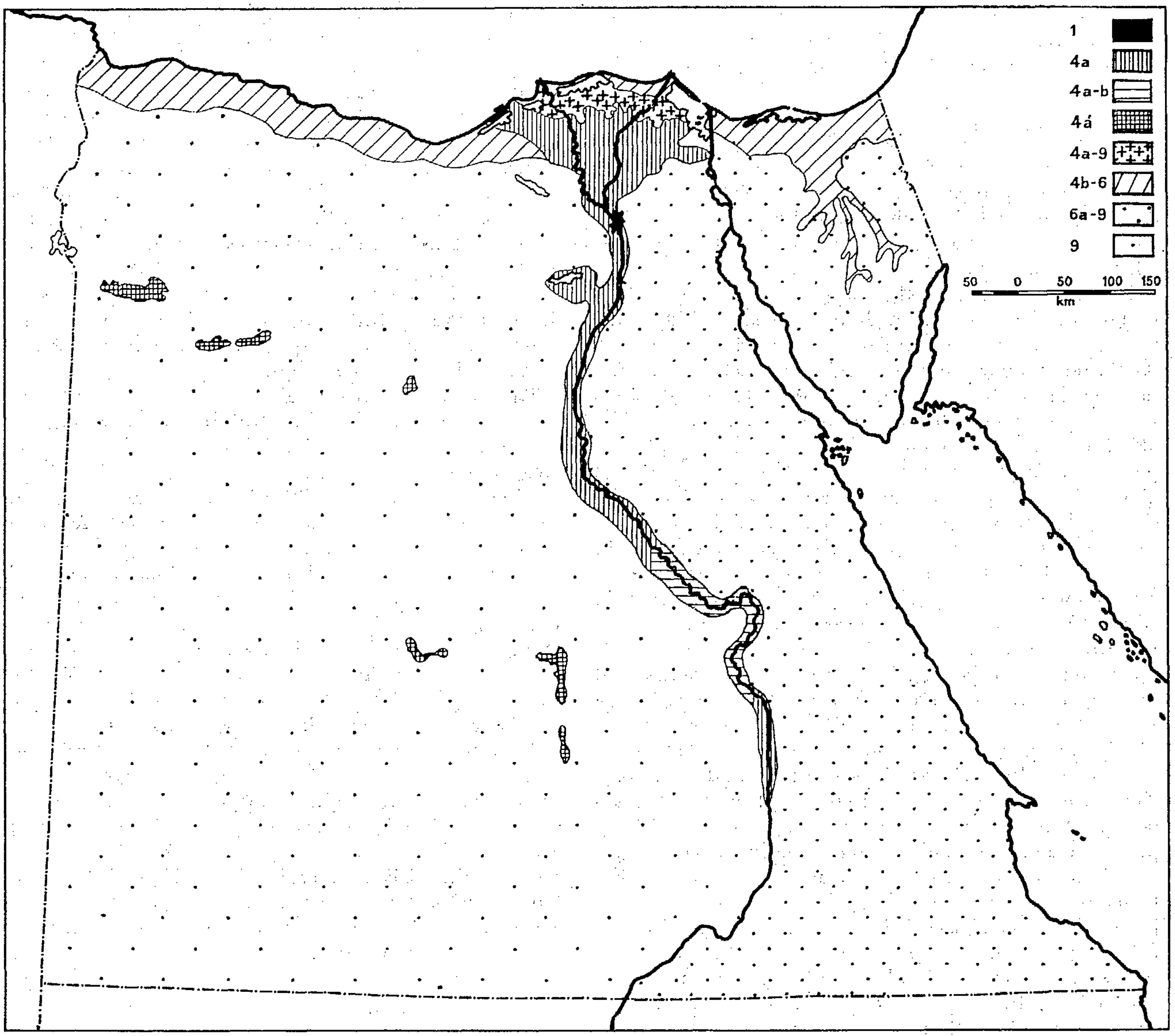



FIG. 3. Dominant land use category according to nomenclature of the World Land Use Survey.
Key : 1, settlements and associated non-agricultural; 4a, continental and rotation cropping; 4a-b, basin land rotation; 4á, oasis continual and rotation cropping; 4a-9, berari unproductive; potentially continual cropping; 4b-6, land rotation with used unimproved grazing; 6a-9, mainly unproductive desert with very little used, improved grazing; 9, unproductive desert land.

widespread all over the valley, especially along the desert front east and west of the delta and in the valley. Some outstanding clusters may be recognized in individual spots such as the Damietta and Rosetta triangles, Katia in northern Sinai and al-Marg near Cairo, but none are large enough to be plotted on 1 : 1 m. maps.

Category 4a, permanently cultivated cropland, is the dominant land use type in the major part of the valley where perennial irrigation is practised, i.e., in the cultivated delta and the greater part of the valley.

The basin-irrigated sector of Upper Egypt should be separated as a local subcategory since basin irrigation is technically a fluvial version of dry farming, cultivation being annual.

The Berari land in the north of the delta, including some 1.5 million feddans, is unproductive—category 9. Swamps and marshes around the lakes belong to category 8, but are potential cropland, awaiting reclamation.

The northernmost tip of the delta is a sand dune belt of grazing and dry farming. It is better considered with the coastal belt of Egypt outside the delta.

*Sandy north littoral*

The narrow coastal ribbon, from Marmaraica in the west across Brullosia in the north of the delta to Sinai in the east, is a single land use unit. Physical conditions differ along the different sectors of this fringe, but the whole is broadly homogeneous.

In Marmaraica and Maraeotis a belt from 40 km. to 60 km. wide of oölitic limestone and sandy soils extends west of Alexandria to the Libyan border. In the east, more or less fixed dunes cover the surface leaving in between narrow, elongated depressions with clayey soils. The belt receives about 5-8 inches of winter rains. A good deal percolates through the porous surfaces and is stored in the dunes. Rainfall gives rise to pasture and grazing, especially for sheep, also to a type of dry farming which is aided by the underground supply. To avoid loss of rain water, soil is frequently hoed and loosened into a semblance of 'mulch', thus reducing evaporation [76, p. 1]. Underground water increases in salinity westwards away from the influence of the Nile subterranean water [38]. It is tapped by wells and wind pumps, but tanks, cisterns and aqueducts have been renowned in the area since the Romans. This belt was highly prosperous and productive in classical times and had excellent vines, olives, orchards and grainland. The water system was eventually neglected and desolation set in. Many cisterns and wells have now been put in order and cultivation of barley, vegetables and fruit such as melons and tomatoes as well as tree fruit (figs, olives, almonds and vine) constitutes the basic type of land use. With a very low 'rain factor', denoting extremely dry climatic and edaphic conditions, and a high rainfall variability, this marginal type of dry farming is precarious. Nor is the underground supply illimitable: over-pumping induces invasion by sea water. Population is therefore sparse, mostly nomadic *(Awlad'Ali)*, with few settled nuclei along the coast. With a mixed economy of dry farming, horticulture and grazing, this area falls mainly into categories 4b-6a.

The tongue of land between Lake Brullos and the Mediterranean in the north of the delta is an extensive belt of sand dunes composed of sands most probably derived from the river rather than from the sea [37, vol. 1, p. 57-61]. Consisting of the finest material carried down by the Nile, these diffuse dunes are the land continuation of shallow sand bars formed parallel to the coast by the action of sea currents. The prevailing north-west winds helped drift them inland. Some dunes are 10-15 m. high and 100 m. long. In an area which is the rainiest in all Egypt, these dunes act as the main reservoirs of water on which the few inhabitants rely. It has been estimated that an average-sized dune would receive 7,000 $m.^3$ of water during the rainy season. Water is tapped by scooping holes at the foot of the dune and even sometimes at the top [76, p. 2]. The method of agriculture is essentially similar to that in Maraeotis. With a mean annual rainfall of 240 mm. and a mean annual temperature of 21° C., the rain factor is only 11, while rainfall variability is very high [14, p. 145]. Water-melons, barley, tomatoes, pomegranates, figs and grapes, together with some 200,000 palm trees scattered in the low-lying pockets among the sand dunes, make up the land use of this isolated 'island' [78]. The palm tree is especially valuable as a fixing agent of the ever-mobile dunes.

The northern strip of Sinai, the Jeffar, is likewise covered with sand dunes. Rainfall is more scanty. The coastline has occasional lagoons and wadis, the most important of which is Wadi al-Arish, with a ramified valley system. This is again a nomad's land with patches of wheat and barley dry farming, garden plots and palm groves. Here is gathered the greater part of the small population (50,000) of Sinai. Sand dune reservoirs again afford many wells, some worked by windmills. This type of land use is extended inland along the Wadi al-Arish which is dammed at intervals to impound water for irrigation of limited patches [2]. An interesting technique of direct tapping of underground water instead of boring wells is to plant trees in hollows dug so deep in the sandy soil as to approach the water spring as near as possible [9, p. 202]. This original method is reminiscent on a minor scale of the *jardins d'excavation* of the Souf of south Algeria. According to Makrizi, the Jeffar of Sinai was a fairly rich, arable land [15, p. 581-582] of much horticultural importance.[1] Schemes are now being considered to extend Nile water to this fringe by a syphon under the Suez Canal.

*Libyan Desert oases*

Some five or six major oases dot the face of the north-dipping plateau of the Libyan Desert. Situated far apart, the four southern oases lie roughly along a line parallel to the Nile some 200 km. west. In the desert but not of it, they are probably aeolian in origin. They lose in altitude northwards, until the northernmost two, Siwa and Natrun, are below sea level. Artesian wells, fed by underground water originating in the Sudan highlands and travelling northwards through permeable sandstone strata, form the basis of life in these oases. This 'fossil' underground water supply is probably affected by lateral seepage from the Nile, while along the north coast it is unfortunately partly invaded by sea water. Hence salinity increases in the northern group where a brine crust is found in Wadi

1. Makrizi, *Khitat*, vol. 1. p. 297 *et seq.* (in Arabic).

Natrun while the maximum salinity (ten times the other oases) is recorded in Siwa [54]. The depth of the aquiferous strata generally decreases northwards, the range being between 120 m. in Kharga and 20 m. in Siwa.

Of local origin, soil in the oases differs according to the type of underlying rock formation. Standing on the limestone plateau, Siwa has a sand-and-lime soil, while the Bahriya is mainly sandy. The Dakhla and Kharga are situated on the sandstone plateau, but enjoy a far richer clayey soil derived from the lacustrine deposits of ancient prehistoric lakes. This good soil resembles that of the Nile Valley, with the difference that it is not annually renovated and also there is a greater mixture of blown sand.

The total cultivated area of the oases is only some 30,000 feddans, but presumably there was more in the past. The Libyan oases had a brilliant history under the Romans when they were a noteworthy source of grain and fruit. Thanks to an excellent system of well-kept wells and even underground aqueducts of the *foggara* type, still in existence in Bahariya and Farafra [9, p. 202], they supported a considerable population. Exaggerated estimates running into millions however, are simply untenable. The water system eventually fell into disrepair and many wells were left to choke up through neglect. Arable land shrank and population dwindled.

The type of land use prevailing in the oases is 4a, intensive continual and rotation cropping based on well irrigation, with a high proportion of horticulture and tree and perennial crops (categories 2 and 3). Grains for local consumption and fruit for export to the valley (mainly figs, pomegranates and olives) are grown as interculture under the shade of the date palms. While in the valley the problem of land use is soil conservation, here it is water conservation, as in the northern littoral. The two most crucial problems are sand and salt—much the same as in the valley but on a maximized scale. The encroaching sand dunes as well as blown sands from the north are met by wind screens of palm groves and long-rooted shrubs, especially along the northern margins of the oasis. Well pits, canals and even settlements are frequently buried. In Kharga, every few years some houses have to be relocated in a more southernly position [1]. Salinization is induced by excessive temperature, by overwatering and the absence of adequate drainage. The lower parts of the depression are especially affected and salt efflorescences steadily accumulate; because it is easy to sink the wells here it is the part most often selected. Such areas soon become malarial and derelict, and need surface drains for reclamation. Pump drainage from the low-lying parts on to the higher fringes, where palms could then be grown, is advocated. Heat and evaporation are again enemies of water supply, hence the value of ancient underground aqueducts and *foggaras*—now better replaced by less costly and more durable pipes [69]. This also explains the universal palm—the oasis 'umbrella'—which, as is sometimes said, truly makes it the 'forest of the desert'.

Water economy is reflected in legislation. Contrary to usage in the valley where there is no 'water tax', land here is State-owned and water is the most cherished individual property, alienable, to be hired and can be hypothecated—all independent of land and of standing crop [9, p. 202]. Most existing wells are a revivification of some ancient Roman wells rather than entirely new ones. Overpumping in the lower-lying tracts of the depression leads to depletion of wells in the higher parts—a source of much bitter friction. Contrary to the riparian situation in the valley, here it is the lower altitude that can endanger the water interests of the higher. The over-all inadequacy of the water supply in the oasis has, however, occasioned an exodus to the valley and consequently much land has been abandoned.

### *The deserts*

Apart from the littoral margin and the oases, the Libyan Desert itself is unproductive (category 9). It is perhaps the most desolate part of the Sahara. On the other hand, thanks to a high, rugged surface and a solid impervious structure, the Eastern Desert experiences a modicum of rain—mostly of the torrential, downpour type. The deeply incised wadis therefore afford some poor grazing to the nomadic tribes which range over southern Sinai and the Eastern Desert essentially south of Wadi Kena [10; 16, p. 78]. These stretches belong thus to category 6a-9.

## A BIOTECHNIC ERA OF LAND USE?

As an epilogue to the history of Egyptian land use, an outline of possible future trends is only an extrapolation of past lessons and present problems and experience.

The real challenge to Egyptian land use is to devise a system whereby the economic efficiency of perennial irrigation shall be married to the organic soundness of basin irrigation. The universalization of the triennial crop rotation has been evoked by many as the only answer. However, already Egypt has demographically and culturally reached the point of no return to a lowered productivity. The triennial rotation would reduce the area of cotton from one-half to one-third, thus allowing soil more repose and cereals an increased acreage. But these gains fall short of offsetting the serious cash loss entailed in the curtailment of cotton cultivation [3, p. 522]. Others envisage the day when fallow periods might be imposed by legislation [21, p. 241]. It has also been suggested to inundate the land periodically or to trap, at the fringes of the delta, the silt wasted in the sea in order to create rich, new land [21, p. 244].

The major problem, however, has remained the inadequate use of the river water. The pronounced variability of the total river supply has resulted in a similar variability of agricultural output—particularly of rice. It is estimated that agricultural production in Egypt fluctuates within 10 units either side around its index figure of 100. While the average annual discharge of the river at Aswan is roughly 82 milliard $m.^3$, the maximum recorded reached as much as 129 milliard $m.^3$ (1879) and the minimum was barely 44 milliard $m.^3$ (1913). Again two-thirds of the total discharge goes to waste in the sea during the flood seasons [21, p. 243]. Hence the paradox of a 'water famine' in Egypt. Moreover, its régime renders the river particularly parsimonious at the 'critical period' of the low-stage, as the monthly rainfall equivalents (in inches) reveal [26, p. 21]:

| Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5.8 | 4.4 | 4.0 | 3.6 | 4.1 | 5.1 | 8.8 | 33.0 | 39.0 | 28.4 | 14.1 | 7.7 |

Thus while the present requirements are 52 milliard $m.^3$, 22 milliard $m.^3$ are needed during the critical period, but the total stored then available is barely 7.5 milliard $m.^3$. With the increasing water needs of Sudan for the proposed Roseires reservoir and the Managel extension of the Gezira, these supplies could no longer guarantee the filling of the Upper Egypt basins or the full functioning of the Aswan Dam.

The recent launching of the High Dam [8] project has therefore been most opportune. The most colossal dam of its type in the world, it will stand 6 km. upstream of the Aswan Dam and will hold up water at a height of 180 m. above sea level. The storage capacity will be 130 milliard $m.^3$. While the Aswan Dam annually stored only a fraction of the flood water, the High Dam will perennially store the whole river supply, i.e., the so-called 'century storage'. This would mean the maximum of river control: not a drop will reach the sea as waste. Nor will there be a Nile 'flood' any longer; the tamed river will simply become a huge feeder canal. On the other hand, the silt load will be reduced—a miniature higher delta should begin to develop upstream of the dam. That the dam will revolutionize the physical and human landscape as never before in the history of Egypt is only too obvious. It will provide ample waters for all the agricultural needs of Egypt, as well as for 2 million feddans of agricultural expansion, including the conversion of 700,000 feddans from basin to perennial irrigation with an estimated 30 per cent net increase in productivity. It will likewise annually guarantee a minimum rice area of 700,000 feddans. Through the related hydro-electric projects, agriculture will benefit from the home-produced chemical fertilizers and from an improved drainage—the latter increasing general productivity by nearly 20 per cent.

The final removal of water as the endemic limiting factor of Egyptian land use will enable the realization of such vital principles as maximum use, optimum and multiple use [74] and is likely to have far-reaching effects on the traditional structure of land use in Egypt. This may well prove the beginning of a new era in the history of our land use—the 'biotechnic' period. Three aspects may be briefly treated here: horizontal expansion, vertical expansion and re-patterning the land use complex.

The forecast of Willcocks in 1902 that 'fifty years hence the word *Berari* . . . will have died out of Egypt' [83, p. 7-8] has proved mere wishful thinking. Owing to lack of water and to sociological factors (land tenure, inertia, etc.), only a few thousand feddans on average have annually been reclaimed since the thirties.[1] This situation will be radically altered after the completion of the High Dam. It is also proposed to reclaim half the total area of the northern lakes or nearly 0.3 million feddans leaving the other half for fisheries. Since it is estimated that the cultivable area within the valley is 7.6 million feddans, this would bring up the total cultivable to 7.9 million feddans.[2] The only shrinkage of area due to the dam will be the tail end of the valley in Nubia; it will be truncated for good as part of the resultant artificial lake that will extend 500 km. upstream of the dam.

Extension of agriculture along the desert margins of the valley should also be feasible. Cheap power should make lift irrigation an easy proposition and it is estimated that a 20-m. lift would add some 2.1 million feddans to the cultivable area, while a 40-m. lift would increase this to 4.5 million.[3] This, however, would naturally mean increasingly marginal conditions and output. Outside the valley proper, reclamation in the oases, based on a fuller use of their subterranean water supplies and along the north littoral afford further possibilities for expansion of agriculture and grazing respectively. The realization of these schemes would be nothing else than a human thrust—a robust, modern case of the old phenomenon of 'marginal vibrancy' observed earlier.

Other measures for maximum use and horizontal expansion can also be explored. It is perhaps too late to save valuable agricultural land from suburbanism, particularly metropolitan suburbanism. But sound town-planning in the future could conserve much land that is now a potential prey to the erosive forces of suburbanism. Resiting in the case of marginal settlements might be possible [19]. The substitution, where soil structure allows, of covered for open

1. *The State Domains Department*, Cairo, Ministry of Finance, 1949, p. 18-19 (in Arabic).
2. *Report of the Permanent Council for the Development of National Production*, Cairo, 1955.
3. Ibid.

drains can be very valuable. Finally, although burial habits in Egypt are adapted to soil structure, being mostly communal on the black land and individual on the marginal sands [70], there are cases where the dead chase the living off valuable land and there is generally a need for greater economy. Modern Egypt cannot afford to be less wise than ancient Egypt where the rule was rigidly *chemi* : the black land for the living, sand for the dead [64, p. 56].

As to vertical expansion, it is evident that, in small-sized Egypt, it is quality rather than quantity that matters in the final analysis [83, p. 15]. Despite the present high norms of fertilizers, the availability of cheap home-produced fertilizers will go a long way to counteract overcropping and the effect of the reduced silt coating. Improved techniques and selected strains can give greater average yields. In this respect the remark of Professor Stamp, that it is a contradiction to refer popularly to the poorer backward states as 'underdeveloped' while they make a more intensive use of their lands than do many western countries [75, p. 81], may not apply particularly to Egyptian agriculture, for there is much scope for a more efficient and intensive use. Regional planning of crops and land use can also be effectively explored.

To realize optimum use, the question of breaking up the traditional pattern of the fellah's farming is difficult but should be no deterrent [36, p. 156]. Two lines of development are often quoted—truck-farming and animal production. Some imaginative planners would envisage an Egypt turning into a California of Europe. They urge that at least some 200,000 feddans should be diverted from cotton and wheat to produce fresh fruit and vegetables for the European market, especially in winter (*primeurs*) [43, p. 71]. Thanks to the High Dam, truck farming could expand without cotton or wheat having necessarily to shrink. As to developing the animal wealth of the country, some recommend a minor repetition of the bold shift by Denmark from grain to livestock production [71], especially because the potentialities of the Berari are not so much in farming as in animal production. This would mean more land under bersim, therefore the whole system of crop allocation is bound to be considerably influenced. The criticism levelled against bersim and maize in Egyptian land use should not be overlooked. Diversification and the introduction of new crops (e.g., soya beans, beetroot, medicinal plants, etc. [45, p. 45 *et seq.*] may make for optimum and multiple use.

## BIBLIOGRAPHY


1. Abu Zeid, A. *Man and environment in the Khanga oasis.* Cairo, Société de Géographie d'Égypte, 1958. p. 69-71. [In Arabic.]
2. Ammar, A. *Eastern gateway to Egypt.* Cairo, 1946. p. 143-144. [In Arabic.]
3. Anhoury, J. Les grandes lignes de l'économie agricole de l'Égypte. *Égypte contemporaine*, May 1941. p. 520-521.
4. ——. Les engrais chimiques et leur rôle dans l'économie de l'Égypte. *Égypte contemporaine*, 1942. p. 39.
5. Arminjon, P. *La situation économique et financière de l'Égypte.* Paris, 1911. p. 69.
6. Audebeau, Ch. Études hydrographique et agricole sur la région des Bararis. *Bull. Inst. égypt.*, vol. III, 1909. p. 113.
7. ——. Terres du Bas Delta restées fertiles à la suite de l'abandon de la culture dans le nord de l'Égypte, etc . . . *Bull. Inst. égypt.*, vol. VII, 1924-25. p. 219.
8. Awad, H. Le Sadd El-Ali, le plus grand réservoir du monde . . . *Bull. Soc. Géogr. Égypte*, vol. XXX, 1957. p. 5 *et seq.*
9. ——. L'eau et la géographie humaine dans la zone aride. *Bull. Soc. Géogr. Égypte*, vol. XXXI, 1958, p. 202.
10. Awad, M. Settlement of nomadic and semi-nomadic tribal groups in the Middle East. *Bull. Soc. Géogr. Égypte*, 1959. p. 25-26.
11. Ball, J. *Contributions to the geography of Egypt.* Cairo, 1939.
12. Baumgärtel, Elise J. *Cultures of prehistoric Egypt.* Oxford, University Press, 1947. p. 1 *et seq.*
13. Bernard, A. Le dry-farming et ses applications dans l'Afrique du Nord. *Ann. Géogr.*, no. 114, November 1911.
14. Bonné, A. *State and economics in the Middle East: a society in transition.* London, Routledge, 1948. p. 145.
15. Brunhes, J. *La géographie humaine.* Vol. II, Paris, Alcan, 1934.
16. Butzer, K. Environment and human ecology in Egypt during predynastic and early dynastic times. *Bull. Soc. Géogr. Égypte*, vol. XXXII, 1959.
17. Catzeilis, E. Le drainage des terres humides et salées du delta égyptien. *Égypte contemporaine*, 1916. p. 330.
18. Childe, V. G. *Social evolution.* London, Nelson, 1951.
19. Cleland, W. A population plan for Egypt. *Égypte contemporaine*, vol. XXX, no. 185, May 1939. p. 473.
20. Coon, C. S. *Caravan. The story of the Middle East.* New York, Holt, 1951.
21. Crouchley, A. E. *Economic development of modern Egypt.* London, Longman's, 1938.
22. ——. *Monthly Bulletin, Agricultural Statistics*, Cairo, 1958. p. 5.
23. Davison, Dorothy. *The story of prehistoric civilizations. Egypt.* London, Watts, 1947. p. 1 *et seq.*
24. Demolon, A. *La génétique des sols.* Paris, Presses universitaires de France, 1949. p. 99. *(Collection 'Que sais-je?')*
25. El-Gritly, A. A. Structure of modern industry in Egypt. *Égypte contemporaine*, Nov.-Dec. 1947. p. 577.

26. FARID, I. A. Introduction of perennial irrigation in Egypt. Its effects on rural economy and population problems. Thesis, London University, 1937. [Typescript.]
27. FAUCHER, D. *Géographie agraire.* Paris, 1949.
28. FERRAR, H. T. On the creation of an artificial water table in Egypt. *Surv. Notes, Cairo,* July 1910. p. 153.
29. FISHER, W. B. *Middle East: a physical, social and regional geography.* London, Methuen, 1950. p. 358.
30. FRANKFORT, H. *Birth of civilization in the Near East.* London, Williams and Norgate, 1951.
31. GEDDES, P. *Cities in evolution.* London, 1915.
31*a.* ——; BRANDFORD, V. Rural and urban thought. *Sociological Review,* Jan. 1929.
32. GIRARD, M. *Mémoires sur l'agriculture, l'industrie et le commerce de l'Égypte. Description de l Égypte, état moderne.* Vol. 11. p. 557 *et seq.*
33. HAMDAN, G. Population of the Nile mid-delta. Past and present. PH.D. thesis, Reading University, 1953. Vol. 1, p. 164. [Typescript.]
34. ——. *Studies of Egyptian urbanism.* Cairo, 1959.
35. HARTMANN, F. *L'agriculture dans l'ancienne Égypte.* Paris, 1923. p. 53.
36. HINDUS, M. *In search of a future.* London, Gollancz, 1949. p. 156.
37. HUME, W. F. *Geology of Egypt.* Cairo. Vol. 1.
38. ——; HUGHES, F. *Soils and water supply of the Maryut District.* Cairo, 1925. p. 18 *et seq.*
39. HUNTINGTON, E. *Mainsprings of civilization.* New York, Wiley, 1945.
40. HURST, H. E. *The Nile: a general account of the river and the utilization of its waters.* London, Constable, 1952.
41. HUZAYYIN, S. A. *The place of Egypt in prehistory.* Cairo, 1941.
42. HYAMS, Edward. *Soil and civilization.* London, Thames, 1952.
43. ISSAWI, Ch. *Egypt. An economic and social analysis.* Oxford, 1946.
44. JAMES, P.; KLINE, H. V. B. *A geography of Man.* Boston, Ginn, 1949. p. 48-49.
45. JUNGFLEISCH, M. Cultiverons-nous le soja en Égypte? *Égypte contemporaine,* Jan. 1940. p. 45 *et seq.*
46. KEELING, B. The fertility map of the Delta. *Cairo Scientific Journal,* Jan. 1914. p. 1-3.
47. KEITH, Sir Arthur. *A new theory of human evolution.* London, Watts, 1948. p. 19 and p. 298.
48. LA BLACHE, V. *Principles of human geography.* London, 1926. p. 408.
49. LACROIX, A.; DARESSY, G. Dolomieu en Égypte. *Mém. Inst. égypt. (d'Égypte),* vol. III, 1922. p. 79-82.
50. LORIN, H. *L'Égypte d'aujourd'hui.* Cairo, 1926.
51. LOZACH, H. *Le delta du Nil.* Cairo, 1935. p. 31-32.
52. LUCAS, A. An artificial water table. *Surv. Notes, Cairo,* vol. VI, August 1910. p. 198-199.
53. MILNE, L. G. *A history of Egypt under Roman rule.* London, 1898. p. 126.
54. MITWALLI, M. Water supply of Egyptian oases. *Bull. Fac. Arts, Alex. Univ.,* vol. II, 1944. p. 60 *et seq.*
55. MOMMSEN, Th. *History of Rome.* Vol. II, London, 1886. p. 239.
56. MOSSÉRI, V. Note sur les dépôts nilotiques des gazayers et saouahels d'Égypte. *Bull. Inst. égypt.,* vol. I, 1918-19. p. 154.
57. ——. Note sur l'affaissement de la Basse Égypte. *Bull. Inst. égypt.,* vol. I, 1918-19. p. 117-130.
58. ——. Note sur l'assainissement des terres de la Basse Égypte. *Bull. Inst. égypt.,* vol. II, 1919-20. p. 113.
59. ——. Le sebakh des Koms ou sebakh Kufri. *Bull. Inst. égypt.,* vol. III, 1920-21. p. 76 *et seq.*
60. ——. Du sol égyptien sous le régime de l'arrosage par inondation. *Bull. Inst. égypt.,* vol. V, 1922-23. p. 24.
61. ——; AUDEBEAU, Ch. Du rôle des crevasses du sol dans le dessalement et l'assainissement permanents des terres d'Égypte. *Bull. Inst. égypt.,* vol. V, 1922-23.
62. MUMFORD, L. *Culture of cities.* New York, Harcourt, 1946.
63. PERAIN, Ch. *La Méditerranée.* Paris, 1936. p. 119-120.
64. PHILLIPPS, L. M. *Works of man.* London, Duckworth, 1932. p. 56.
65. RUFFER, M. A. Food in Egypt. *Mém. Inst. égypt. (d'Égypte),* 1919. p. 45.
66. SAVARY, M. *Lettres sur l'Égypte.* Vol. I, Paris, 1786. p. 57-58.
67. SELIM, H. K. *Twenty years of agricultural development in Egypt, 1919-1939.* Cairo, 1940. p. 12-14.
68. SEMPLE, E. C. Irrigation and reclamation in the ancient Mediterranean region. *Ann. Ass. Amer. Geogr.,* Sept. 1929. p. 142.
69. SHAFEI, E. C. Problems of irrigation in arid zones. *Bull. Soc. Géogr. Égypte,* vol. XXXII, 1959. p. 153.
70. SHEPPARD, V.; RICHARDS, F. S. Egyptian cemeteries. *Égypte contemporaine,* vol. XIV, no. 70, Feb. 1923. p. 120-131.
71. SIDKY, H. *Animal breeding improvement in Egypt.* Cairo, 1948.
72. SMITH, G. Elliott. *In the beginning: the origin of civilization.* London, Howe, 1928.
73. SOCIÉTÉ D'ENTREPRISES COMMERCIALES EN ÉGYPTE. *Le riz dans l'économie égyptienne.* Alexandria, 1949. p. 9.
74. STAMP, L. Dudley. Land use surveys with special reference to Britain. In: G. Taylor (ed.) *Geography in the twentieth century.* London, Methuen, 1951. p. 391-392.
75. ——. *Land for to-morrow. The underdeveloped world.* Bloomington, Indiana University Press, 1952; London, Faber, 1953.
76. SUTTON, L. J. *Rainfall in Egypt.* Cairo, 1949. p. 1.
77. THOMAS, G. H. Changing values in Egyptian agriculture from 1800. M.A. thesis, London University, 1939. p. 200-201.
78. T.J.C. Notes on Burollos. *Surv. Notes, Cairo,* Jan. 1907. p. 159.
79. TOUSSOUN, O. Mémoire sur les finances de l'Égypte depuis les Pharaons jusqu'à nos jours. *Mém. Inst. égypt. (d'Égypte),* vol. VI, 1924. p. 71.
80. VALLAUX, C. *Les sciences géographiques.* Paris, 1925. p. 19.
81. WALLACE, S. L. *Taxation in Egypt from Augustus to Diocletian.* Princeton, University Press, 1938. p. 336-338. (*Princeton University studies in papyrology,* no. 2.)
82. WEHEIBA, A. F. Agriculture of Egypt during the Arab Period. M.A. thesis, London University, 1952. (Typescript.)
83. WILLCOCKS, W. Egypt fifty years hence. 1902. p. 7 *et seq.* (Paper presented to the Institute of Egypt.)
84. ——. Egyptian irrigation and public health. 1927. p. 7. (Paper presented to the Institute of Egypt.)
85. ——; CRAIG, J. I. *Egyptian irrigation.* London, 1913.

# THE ARID ZONE OF INDIA AND PAKISTAN

*by*

O. P. BHARADWAJ

*Professor of Geography, Punjab University, Ludhiana, India*

## INTRODUCTION

For the purpose of this study the arid zone of India and Pakistan has been defined by the isoline of —40 moisture index—an index calculated on the basis of Thornthwaite's formula. This zone is bounded on the east by the Aravalli Hills and extends, on the west, to the western border of West Pakistan. On the south, the desert reaches the coast, whereas on the north it runs through the southern part of the Punjab. In all, it covers a vast area of nearly 300,000 square miles with about 24 million inhabitants. Thus, while covering nearly one-fifth of the total area of the Indian subcontinent, the arid zone supports only one-eighteenth of the population of India and Pakistan together. The average density of population in the whole zone is about 80 persons per square mile. However, there are great intraregional variations in the actual density. It is as low as 4 in parts of Baluchistan and 6 in Jaisalmer and as high as 95 in Sind. The average density in the dry area of Rajasthan west of the Aravallis is 61 persons per square mile.

The object of this study is to make an evaluation of the physical resource base and the agricultural land use in the arid zone of India and Pakistan from the earliest times. It will bear emphasis that the value of the physical resource base changes from time to time according to the capabilities of man to make use of these resources.

In the making of such an historical study numerous difficulties have been experienced. The information available on agricultural land use and climatic conditions in the past is both irregular and meagre and there are many gaps. In the circumstances it becomes very hazardous to attempt to reconstruct the past. Even the data for the modern period are far from satisfactory. There are many areas within the dry zone which were formerly native princely states in which no systematic attempt was ever made to collect statistical information. Furthermore the boundaries of the administrative units have changed considerably in the last decade thus making the earlier figures non-comparable with those of the present. Comparable agricultural data for the dry areas in India and Pakistan for a longer period are not available. In addition, maps showing district and *tahsil* boundaries for the entire zone do not exist so that it becomes impossible to prepare detailed distribution maps to serve as the basis of a detailed regional analysis.

To make a precise assessment of the economic potentialities of the zone, sample surveys of various types are urgently needed. The subjects of study in such sample surveys should include land forms, soils, underground water, climatic elements, agricultural land use, yields, mineral resources, industrial potential and population and their characteristics, etc. It must be emphasized that such work cannot fall entirely within the scope of one field. Instead, it has to be interdisciplinary and teams of workers should be available from each field of study.

## GEOLOGY AND LAND FORMS

The subcontinent of India and Pakistan may be divided into three broad geological regions : the stable block of peninsular India; the young folded Himalayas with their eastern and western continuing ranges; and the intervening Indo-Gangetic plain. In the arid zone of India and Pakistan all the three divisions are represented. Western Rajasthan which has resisted all orogenic forces during later geological periods is a representative of the peninsular block; Suleman, Kirthar and Mekran ranges represent the young fold mountains; and the third division is represented by the Indus Plain. It is noteworthy, however, that whereas western Rajasthan has, on the one hand, resisted the orogenic forces like the Deccan

Plateau, it has, on the other hand, been subjected to Mesozoic and Early Tertiary marine transgressions as were the extrapeninsular areas. The Baluchistan hills are formed of folded Tertiary rocks. The Indus Plain is built up of the alluvial deposits of the rivers of the Indus system. In the west the boundary of the Indus Plain is sharply defined by the Suleman and Kirthar ranges. In the east, on the other hand, the plain imperceptibly merges into western Rajasthan.

## GEOLOGICAL HISTORY

The Indus Plain which forms a downwarp has dominated the palaeogeography of the arid zone from Mesozoic times onwards. The sag which it occupies is the final position of a trough which oscillated east and west from Mesozoic times as is indicated by marine transgressions. The varying positions of the marine transgressions have been depicted by Dr. K. Jacob in five maps. The following paragraphs give a brief account of the geological history of the area since Archaean times.

The Archaean period is represented in this region by three types of rock observed in Rajasthan: Bundelkhand gneiss, the Aravalli series and the Raialo series. The Bundelkhand gneiss is a very old rock and forms the uneven floor on which the Aravallis were laid down by mature streams. The Aravallis are overlaid by the Raialo series which were deposited in the eroded channels of the Aravallis. The Raialo series is related in point of time to the Eparchaean quiescence during which the Raialos suffered prolonged erosion.

After the Eparchaean interval the Aravalli geosynclinal basin seemed to have deepened and in it were laid down the Delhi system by torrential streams as is indicated by the vast quantity of conglomerate and sand with impure calcareous sediments. The Aravalli Range was upheaved by orogenic forces in pre-Vindhyan times, and thereafter the Vindhyan sediments were deposited on either side of it. The Vindhyan rocks are nearly three hundred feet thick in western Rajasthan [10, p. 104].[1] The geological history of Rajasthan is obscure from Vindhyan times to Middle Carboniferous times and it is not known for certain whether the Aravalli Range underwent peneplanation or was slowly upheaved.

At the close of the Carboniferous period the Aravalli Range was occupied by an ice sheet which stretched as far north as the Salt Range via Bap [10, p. 105]. Boulder beds are found in the Salt Range with boulders whose source was undoubtedly Rajputana in part [13, p. 277]. During Permo-Carboniferous times a large sea covered the Himalayan area, Salt Range, Baluchistan and Sind, and an arm of sea stretched from the Punjab area, through Cutch into the Narbada Valley. It is difficult however to know the exact boundaries and shape of the Permo-carboniferous sea.

The early Mesozoic period in Rajasthan is marked by earth movements which created the great Boundary Fault and rejuvenated the Aravalli mountains. Information about the Triassic period in western Rajasthan is very scanty and in Cutch the eruption of the Deccan lavas has covered much of the geology and it is not known whether there are Triassic rocks under the richly developed Jurassics. In the Jurassic period western Rajasthan was peneplained and was invaded by the sea. The presence of marine Jurassic rocks in Cutch and Kathiawar, western Rajasthan and Baluchistan gives clear evidence that in Jurassic times most of the present arid zone was under the sea. The estuarine facies of the Umia plant beds of Cutch, Idar and Barmer indicate that the sea regressed from western Rajasthan in early Cretaceous times but that Baluchistan was still under water. The Umia plant beds are overlaid by marine sediments from which it may be inferred that the sea transgressed again in middle Cretaceous times. A sea connexion was established between the arm of the Tethys and the Narbada Valley across the north of Kathiawar via Baluchistan during Upper Cretaceous times. Cretaceous marine transgression was followed by a huge outpouring of Deccan lava which continued into the early Tertiary.

The Eocene period in the arid zone of India and Pakistan is marked by an extensive marine transgression which covered Sind, Baluchistan, southwestern Punjab and western Rajasthan. The widespread Eocene transgression was apparently connected with the final large-scale foundering of Gondwanaland [10, p. 111].

During the Oligocene and Miocene periods a continuous downwarp took place in front of the Himalayas and the Suleman and Kirthar ranges owing to compression [13, p. 23], while the sea withdrew from western Rajasthan into the foredeep. An arm of the sea may have extended into the Indus and Luni valleys. Oligocene-Miocene calcareous rocks developed in Sind and Baluchistan are found on the eastern side of the Eocene beds and it may be inferred that the sea regressed toward the east of Suleman and Kirthar ranges.

In the Pliocene period the sea withdrew into a narrow channel occupying the Indus and Luni valleys. The Manchher and Mekran series deposited in estuarine to marine conditions indicate that the sea was becoming shallow in Baluchistan. In Pleistocene times the sea extended through the Rann of Cutch into the Indus, Saraswati and Luni valleys. Sedimentation has continued in the Indus basin from the Pleistocene to the present day but it is

1. The figures in brackets refer to the bibliography at the end of the chapter.

not known when the foredeep actually became dry land.

### REGIONAL GEOLOGY AND LAND FORMS

As a result of this geological history in the arid zone of India and Pakistan Archaean rocks occur mostly in Rajasthan; Mesozoic rocks are exposed in a few patches in western Rajasthan and in the central axes of the Suleman and Kirthar ranges; Tertiary rocks are well exhibited in the mountain ranges of Baluchistan, as well as being exposed in a few patches in Rajasthan near Jaisalmer. All the Indus Valley and considerable parts of western Rajasthan are covered with recent deposits.

As there is a very intimate causal relationship between relief and geological structure, the land forms of the three main geological divisions mentioned above are in extreme contrast. The youthful relief of the folded Baluchistan hills discloses a complicated picture of anticlines and synclines. The Indus Plain with flat and featureless aggradational surfaces contrasts sharply both with the Baluchistan hills and western Rajasthan with its peneplained surfaces.

#### *Western Rajasthan*

Western Rajasthan, delimited by the Aravalli Range on the east, forms the north-western part of the stable block of the Deccan Peninsula. Its underlying geology is complex but most of western Rajasthan is covered by sand which has concealed the solid geology of this area. The Aeolian deposits belong to Pleistocene and recent times. Wadia thinks that the sand in Rajasthan originated from long continued aridity, with sand-drifting caused by the southwest monsoons which blow with considerable force the material derived from atmospheric weathering of rocky outcrops. The sand consists predominantly of quartz with grains of felspar and hornblende which are uniformly rounded by attrition. [30, p. 395].

In its land forms western Rajasthan is mostly a sand-covered peneplain in which rocky outcrops appear locally through the sand. The most striking topographic feature is the Aravalli Range which extends from the northern Gujarat Plain northeastward to Delhi over a distance of 400 miles. The Aravalli Range boldly defines the eastern limit of the sand-covered Thar. Probably the range has acted as a great check to the advancement of the sand into Central India and the Ganges Valley, and it is noteworthy that, wherever there are gaps in the range, sand has advanced to the east of it. In the heart of the sand-covered area, the bare dune-free country of Barmer, Jaisalmer and Bikaner presents an anomaly and is a problem that warrants investigation. In this central dune-free area, Jurassic to Eocene marine deposits are exposed.

Western Rajasthan may be divided into three land form regions: the predominantly sand-covered Thar; plains with hills including the central dunefree country; and hills. With these interruptions the sand-covered Thar stretches from the irrigated Indus Plain on the west to the Aravalli Range on the east and from the southern Punjab Plain in the north to the Rann of Cutch in the south. It is a desolate country where sand is piled up into huge windblown dunes, where human settlements are few and agriculture extremely precarious. Three types of sand-dune characterize the Thar—longitudinal, transverse and barkhans. Longitudinal sand dunes which develop where the wind is strong, are confined to the southern part of the Thar. Their direction is parallel to the prevailing south-west winds. Transverse sand dunes predominate in eastern and northern portions of the Thar. The longitudinal axes of these sand dunes are transverse to the direction of the prevailing south-west winds and develop where wind strength is less. In central Thar barkhans are developed. On the whole, the Thar desert slopes imperceptibly towards the Indus Plain and surface unevenness is mainly due to sand dunes. The dunes in the south are higher, rising sometimes to 500 ft., whereas in the north they are lower and rise at the most to 50 ft. above the local ground. Plains with hills mainly occur in the north-eastern and south-eastern parts of western Rajasthan. In the northern section the Aravalli Range is broken into ridges and encloses plains. In this region local relief is large and the rocky hills rise steeply from the plain. In the south-east of the Thar in Jodhpur the plains are dotted with hills. In the south the Aravalli Range is continuous and forms a hilly country which culminates in Mount Abu rising to over 5,000 feet. All the hilly country is most uninviting for agriculture.

#### *Baluchistan*

The desolate country of Baluchistan with its arid basins and hills forms the western part of the arid zone. Three zones are recognized in the mountain ranges: the zone of calcareous rocks of Triassic to Oligocene Age is the outermost zone bordering the Indus Plain; the middle zone predominantly formed of 'flysch' facies of the Oligocene Age; and the lower zone to the west consisting of a variety of rocks ranging in age from Archaean to Tertiary [13, p. 64-65].

The outer zone is characterized by a succession of sharp anticlinal folds mostly composed of Eocene and Oligocene limestones, with sandy Siwalik sediments in the intervening synclines and on the outer border. The middle zone with 'flysch' facies rocks is formed of highly folded sandstones, shales and clays in close-set parallel ridges. The rocks of the middle zone are mostly of Oligocene Age, often hard and less subject to erosion, the chief exception being the friable clay of the hills near the Mekran coast. The inner zone of Baluchistan is formed of ridges of various rocks, including volcanics, separated by desert basins.

Baluchistan is an uninviting barren and hilly country. The hills are rugged, sun-scorched, with steep narrow ridges alternating with valleys. The Suleman and Kirthar ranges rise steeply from the Indus Plain and clearly define the Baluchi hill country with steep slopes and great local relief, where level land is at a premium. The main mountain ranges of Baluchistan merge in the Quetta node: north-east of the node are the Toba Kakar and Suleman ranges; south of it radiate the Kirthar and Siahan ranges; towards the west are the Chagai hills. The parallel mountain ranges of Baluchistan enclose valleys whose bottoms are covered with recent and sub-recent deposits of hill-wash and alluvium derived from the adjoining ridges. Because of the prevalence of arid conditions degradational forces have not been very active in this region. Consequently the ridges of bare rock occupy large parts of the whole.

### *Indus Plain*

The geology of the Indus Plain is simple: it is formed of Pleistocene and recent alluvial deposits in layers

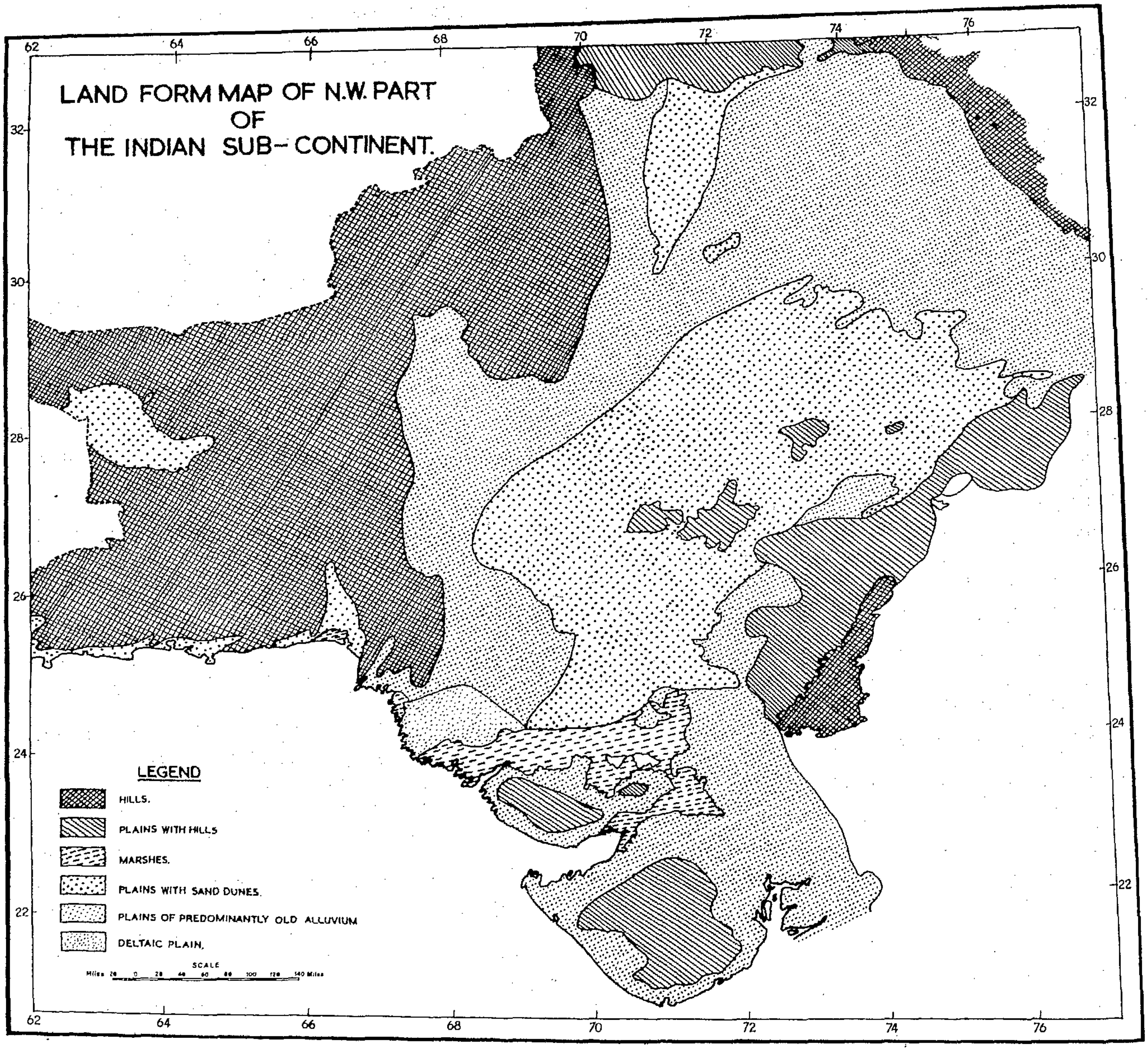



FIG. 1. Land form map of the north-western part of the Indian sub-continent.

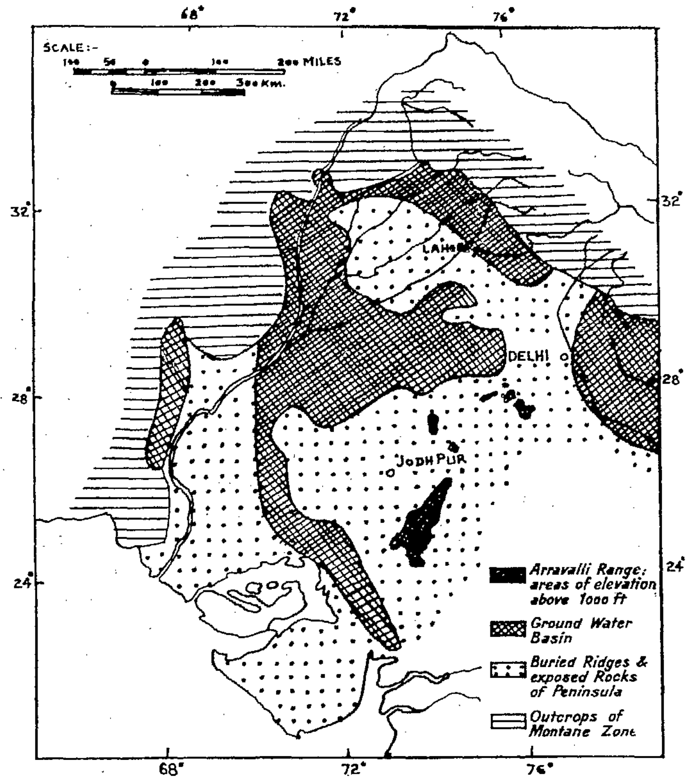



FIG. 2. The groundwater basins of North-West India and Pakistan. (Modified from Auden [2].)

conformable with the flat surface. The deposits vary considerably with some massive beds of clay and sand, sometimes with calcareous concretions, and silts. Blown-sand occupies a considerable part of the Sind Sagar Doab and occurs also in a narrow belt along the foot of the Suleman and Kirthar ranges. These sand deposits are loessic in origin and were deposited for the most part after the Pleistocene.

The Indus Valley remained under sea up to Sub-Recent times and the plain originated from the unfilling of the foredeep. Geodetic surveys have revealed that much of the plain is underlain by concealed ridges.

The Indus Plain slopes imperceptibly towards the Arabian Sea. Any unevenness of the surface is due to older banks and deserted channels of the rivers; otherwise local relief is insignificant. Empirically the Indus Plain can be divided into three sub-regions: nearly flat land of the Indus Delta; plains predominantly formed of older alluvium; and plains covered with loessic deposits.

The delta is formed of new alluvium and is characterized by numerous deserted channels whilst along the coast are abandoned creeks and inlets. The greater part has long remained a waste land with a few patches under cultivation. However, it is now being brought under vast new irrigation works. The second sub-region of the Indus Plain includes alluvial plains along the valleys that are dune-free. In these plains older alluvium is predominant away from the channels in the higher doabs. Along the channels of the rivers there are narrow strips of floodplains which are subject to annual flooding. The third sub-region of the Indus Plain, which coincides largely with the Sind Sagar Doab is covered by a continuous spread of sand-dunes. The sand of these dunes is derived from the ever-renewed banks of the rivers and the barren hills of Baluchistan (see also Figs. 1 and 2).

## CLIMATE THROUGH THE AGES

Climate has been subject to change since earliest geological times. In view of the very meagre information available, however, the reconstruction of past climates is a very difficult and hazardous task. A perusal of the geological records indicates alternative prevalence of 'normal' and 'glacial' climates in the past. The glacial climate is characterized by frozen Polar seas and ice-capped land masses. When the glacial climate is at its climax ice extends to temperate latitudes and high altitudes in the tropics. 'Normal' climate, on the other hand, comes to prevail when ice disappears even from the Poles. During normal climates sharp zonal contrasts are absent [26, p. 75].

Although there is a coincidence between crustal upheaval and glaciation the two do not provide an exclusive causal relationship. Ice caps in the higher latitudes were formed when there was north-south exchange of air-masses in the general atmospheric circulation. The northward thrust of a moist, mild air-mass, accompanied by cloud cover, is supposed to have created congenial conditions for ice formation. It is generally believed that the present arid lands experienced pluvial conditions during glacial periods. On the other hand, the periods of quiescence experienced normal climate which was characterized by a rise in temperature. However, the existence of arid climates during 'normal' times is a controversial matter. It seems likely that rather mild desert conditions existed in continental interiors and that intense aridity was restricted to times of revolutions [26, p. 77].

The geological record in India suggests several alternations of arid and pluvial conditions in pre-Cambrian times. In Carboniferous times a glacial climate prevailed over what is now the arid zone of Indo-Pakistan. The Aravalli Range at this time was occupied by an ice-sheet which extended northwards to the Salt Range and the Permian period is characterized by Glossopteris flora which flourished in a warm humid climate. In the Damodar Valley where the best coal seams are found, climate was definitely humid; westwards the coal seams occur in cycles which were formed in humid and dry conditions occurring alternately. It is probable that during the Permian period desiccation started in the area under inquiry. That the Permo-Trias also experienced a dry climate can be inferred from the presence of red tints in rocks and from the remains of reptiles and amphibians. This dry period was followed by a humid period and the *Pitophyllum* flora developed extensively at the close of the Gondwana period. During the rest of the Mesozoic period normal climatic conditions seem to have prevailed.

From the Middle Miocene to the close of the Pliocene the climate was humid and warm. The rich Siwalik fauna which flourished during this time must have required a warm and humid climate. The Siwalik fauna becomes extremely meagre in the succeeding deposits indicating the replacement of the warm conditions by Pleistocene glacial climate.

## CLIMATE SINCE THE CLOSE OF THE PLIOCENE

Study of the Pleistocene climatic changes is of vital significance. It is during this period that man appeared on the scene in the Potwar Plateau and was subjected to the changes of climate. The warm humid Pliocene climate was replaced by distinctly cooler conditions in the Pleistocene. The beginning of the Pleistocene was heralded by a lowering of temperature and, in consequence, the formation of ice in higher temperate latitudes and on high mountains in the tropics. During Pleistocene times the Himalayas underwent glaciation, the effects of which are discernible from the glacial features. These features in Kashmir and the pluvial river terraces in north-western Punjab (Pakistan) provide important information with which the succession of Pleistocene climate can be reconstructed fairly well. During the Pleistocene it is generally believed that the westerlies expanded southwards extending their influence to the arid zone. As a result of the extension of the westerlies the winters in the arid zone received more precipitation. Because of extensive glaciation over the Himalayas down to lower altitudes the summers in the present arid zone became cool and evaporation was less. Under these circumstances, therefore, the possibilities are that the arid climate was much more restricted in areal extent than at present. The existing salt lakes of Rajasthan might have been formed in the Pleistocene pluvials when precipitation was greater than evaporation.

Two important studies have been made of the climatic succession of the Pleistocene in the north-western Indian subcontinent : de Terra and Paterson investigated the Himalayan glaciation and deduced climatic conditions and associated human culture in Potwar and Kashmir [7]; Zeuner examined the Pleistocene deposits of Sabarmati and Mahi streams and reconstructed the climatic succession of northern Gujarat [33]. Both the areas investigated lie on the fringe of the arid zone and the two studies afford evidence on what might have happened in the arid zone itself.

De Terra succeeded in correlating the river terraces on the Indus and Sohan with moraines of Himalayan glaciers. It seems clear from his correlation that when the ice advanced down the Himalayas, pluvial conditions were experienced in the region south of the Himalayas. But it is not known how far south in the present arid zone the pluvial conditions extended.

Four glacial and three interglacial phases have been recorded from the glacial features of the north-western Himalayas. The glacial phases are indicated by moraines and till-sheets, and interglacial by the alluvium and sediments deposited in the lakes. De Terra and Paterson on the basis of the study of alluvium, river terraces, erosion of valleys and human culture have recognized a three-fold Pleistocene sequence in the Punjab (Table 1) : the Lower Pleistocene comprising the First Glacial Phase and the First Interglacial Phase; the Middle Pleistocene with its Second Glacial Phase and the Second Interglacial Phase; and the Upper Pleistocene consisting of the Third Glacial Phase, Third Interglacial Phase and the Fourth Glacial Phase. A brief summary of the characteristics of each phase in the sequence is given below.

The Lower Pleistocene is divided into two stages by de Terra : Tatrot and Pinjor. The Tatrot zone is correlated with the First Himalayan Glacial Phase and the Pinjor zone with the First Interglacial Phase.

*First Glacial Phase (Tatrot stage).* Ice accumulated over the Himalayas and a pluvial climate was established during this phase. Evidence of pluvial climate is found in the sediments of the Tatrot zone which are composed of coarse but soft sandstones with bands of conglomerate. These sediments must have required rapid river deposition to fill the existing lowlands in the Potwar. It is evident that such a rapid accumulation of almost a thousand feet of sand must have involved very powerful streams and abundant rainfall [7, p. 260]. The sediments of the Tatrot zone show a total absence of chemical weathering which indicates the prevalence of a cool climate with glacial conditions. The palaeontological records found in the fossil remains of elephants, pigs, hippopotamuses, bovines, turtles and crocodiles also strongly indicate a moist climate.

*First Interglacial Phase.* Deposits of the Pinjor stage are correlated by de Terra with this phase. The Tatrot deposits are grey whereas the Pinjor deposits are pink. This change of colour has been taken to indicate a change of climate. In this zone there is a rich faunal assemblage which indicates better climatic conditions. The glaciers are supposed

TABLE 1. Pleistocene sequence in Northern Punjab, Pakistan, and Kashmir (according to de Terra and Paterson [7])

| Stratigraphic units | Northern Punjab (Pakistan) | | | | Kashmir |
|---|---|---|---|---|---|
| | Deposits | Stone Age Culture | | Climate | Glacial sequence |
| | | Chalcolithic Mohanjodaro | | | |
| Post-Pleistocene | Post-glacial silt Deposition: Terrace 5 | Neolithic | Uchali in Potwar | Present conditions | Post-glacial ice advance |
| | | Proto-Neolithic Sukkur, Rohi | Chitta industry Microlithic industry | | |
| Upper Pleistocene | Pink clay, sand and gravel Deposition: Terrace 4 | Dhak, Pathan, Pindi, Gheb | Evolved Sohan | Cool temperate pluvial | Fourth Glacial Phase |
| | Redeposited Potwar silt Second loess Erosion: Terrace 3 | | | Interpluvial | Third Interglacial Phase |
| | Potwar loess Potwar basal gravel | | Late Sohan B | Cool temperate; pluvial | Third Glacial Phase |
| | Deposition: Terrace 2 | Late Acheuleam | Late Sohan A | | |
| Middle Pleistocene | Redeposited Boulder Conglomerate | Abbevillio-Early Sohan Acheulean | | Interpluvial; long dry period | Second Interglacial Phase |
| | Erosion: Terrace 1 | Hand axe; chopper flakes | | | |
| | Boulder Conglomerate zone, fans and terraces; gravel with erratics | Pre-Sohan Worked flakes Pre-Abbevillian | | Torrential rains; pluvial | Second Glacial Phase |
| Lower Pleistocene | Pinjor zone Pink silt, sand and concretionary clay | ? | | Warm temperate; Interpluvial | First Interglacial Phase |
| | Tatrot zone Grey Conglomerate sand and silt | ? | | Cool temperate; chemical weathering absent; pluvial | First Glacial Phase |

to have retreated thus making the climate warm. The Pinjor deposits, like Karewas of Kashmir, contain loessic material which must have required a climate in which a part of the year was dry. It is possible that the monsoonal climate may have been established during this phase. There were fluctuations of climate; dry periods alternated with rain, as is indicated by wind-blown sand and fluviatile silt in the Pinjor zone.

*Second Glacial Phase.* This phase corresponds with the Boulder Conglomerate zone. Intensive pluvial conditions were established in the Punjab plains during this phase. It is associated with widespread fan formation in the foothill plains with thick deposits of Boulder Conglomerate which must have required heavy rainfall. The Potwar landscape was dominated by wide flood plains. The plains were sufficiently covered with vegetation to provide abundant grazing grounds for elephants, horses and buffaloes. All evidence tends to indicate that during this phase the climate was moist and cool. It was favourable for early man in Potwar, but in Kashmir it was too cold for him.

*Second Interglacial Phase.* This phase is correlated with Terrace I which is cut into the tilted Boulder Conglomerate zone. In this terrace early Palaeolithic implements are found which de Terra and Paterson named the Sohan culture. It is the only archaeological record and on this basis de Terra believes the climate was relatively dry and warm during this phase.

*Third Glacial Phase.* This phase is represented by Terrace 2 which is aggradational in origin and contains two stratigraphic horizons: basal gravel; and the overlying Potwar loess. The third glaciation was weak compared with the first and second. As a result the climate was less pluvial during the third glaciation. Basal gravel was deposited in humid conditions as is substantiated by the presence of abundant fossil remains. The fossil remains in the Potwar loess, on the other hand, are meagre and consist of such animals as horses, bisons, camels and wolves. It is probable that when the loess was formed in this period the climate was becoming drier. But vegetation must still have been sufficient in the Punjab plains on which the animals roamed for 'Palaeolithic man would hardly have left so abundant records of his manual skill unless hunting gave him an initiative for the manufacture of tools and weapons whereby he secured his maintenance' [7, p. 230].

*Third Interglacial Phase.* Terrace 3 in Potwar is correlated with this period. Over the Himalayas the glaciers retreated during this phase and Potwar experienced a long erosion. The climate became warm and dry as is indicated by the presence of Aeolian deposits in Terrace 3.

*Fourth Glacial Phase.* This phase in the Potwar is represented by Terrace 4. Its advance over the Himalayas was the feeblest of all the Pleistocene ice advances. During this phase ice remained at 11,000 ft. Because of the very feeble nature of this glacial phase, the climate could not have been as moist and cool as in the earlier glacial phases. Instead it was rather dry and warm. The varying stages of terminal moraines and snouts indicate fluctuations in climatic conditions. During this period dry conditions must have spread over wider areas as compared with earlier glacial phases.

*Postglacial Ice Advance.* Terrace 5 in Potwar is correlated with a postglacial ice advance. This terrace is aggradational in origin, and is formed of silt. Climate during this period was warmer and drier than the Fourth Glacial Phase but was less dry than the interglacial phases. The recession of glaciers during the postglacial period over the Himalayas points towards increasing aridity. The marks of recession-terraces, due to aridity, in the highland glacial lakes of Ladakh and western Tibet also indicate increasing desiccation.

Out of the four glacial phases of the Himalayas, the first and second were intensive, the third and fourth being feebler. The progressive decline in the intensity of the glacial phases tends to indicate that the climate, on the whole, has followed a trend toward drier and drier conditions in the north-western part of the Indian subcontinent.

The climatic succession of northern Gujarat has been reconstructed by Zeuner [34] on the basis of his findings in his investigation of the deposits in the valleys of Sabarmati and Mahi streams. The deposits investigated lie over the Deccan Trap. Zeuner has divided the deposits into eleven phases and he infers the climatic sequence from the nature of the deposits. His results may be summarized as follows:

(P) Lateritic Phase. During this phase lateritic crusts were formed and allitic weathering was also present. This supports the contention that the climate was more humid than now, because laterite formation must have required humid conditions. The Lateritic phase may in time be correlated with the first glacial advance over the Himalayas because during this very period pluvial conditions prevailed in northern Gujarat.

(Q) Lateritic deposits are succeeded by deposits of mottled clay in river basins. The absence of laterite postulates a drier climate.

(R) Phase of Cemented Gravel. Coarse pebbles deposited in sheets by the rivers dominate this phase. This evidence tends to indicate that precipitation was heavier than at present and seasonal floods were common.

(S) Silt Phase. Continued deposition of sand and silt during this phase raised the beds of rivers. Apparently there was a decrease in run-off and the climate was relatively drier.

(T) Red Soil Phase. A flat surface was formed due to continued aggradation. Over the newly formed surface red soil was developed which suggests that the climate was more humid than that of the (S) Silt Phase but the lack of laterite indicates that climate during this phase was less humid than during the Lateritic Phase.

(U) Main Dry Phase. Once again aggradation took place and rivers raised their beds by deposition of silt. In the beginning of this phase wind-blown sand derived from the dry surface was deposited away from the rivers. In the later part of the phase aeolian deposits gradually dominated the river deposits. From these evidences it seems as if the climate during this phase gradually became dry and finally culminated in an arid period.

(V) After the Main Dry Phase (U) Zeuner thinks that climatic conditions were getting humid. Zeuner draws his evidence from the Mahi stream where the soils are supposed to have been formed under humid conditions.

(W) Dune Phase. During this phase the climate was dry and favoured the formation of dunes. The dunes were deposited over the surface of (V) phase.

(X) Pre-Pottery Microlithic Phase. Soil was formed over the dunes of (W) phase. Active soil formation indicates the existence of humid climate.

(Y) Latest Dry Phase. Climate during this period became drier. Aeolian deposits dominated the landscape. Zeuner thinks that the arid conditions were due either to decreasing rainfall or to the destruction of natural vegetation by man.

(Z) Modern Phase. Climate of this period was humid as is indicated by soil formation; it resembled that of (X) phase.

The above analysis of the climatic succession in northern Gujarat reveals alternating phases of damper and drier conditions but on the whole suggests a trend towards drier and drier conditions as one approaches the present day. [34, p. 24.] It is interesting that though the works of de Terra and Zeuner were on different areas and were based upon different approaches, the conclusions of both the authors regarding the trends of climate are similar.

Of all the phases discussed above only the Lateritic Phase (P) had humid climate with heavier rainfall than the present. 'It is the only period which could legitimately be called pluvial, although it too must have had a dry season.' [34, p. 24.] In the Himalayas also the First Glacial Phase was the most intensive during which glaciers descended below 6,000 ft. The Lateritic Phase (P) of Sabarmati might be related to the Himalayan First Glacial Phase when, because of the intensity of glaciation, the belt of cyclonic storms of the westerlies is supposed to have been pushed southwards. Thus as a result of the prevalence of the westerly winds over the present arid zone conditions are believed to have become humid. Subsequent glaciations became feebler and feebler and as a consequence the westerlies again retreated northwards so as to occupy only the northern part of the arid zone. The southern part of the arid zone thus deprived of the influence of westerlies attained dry conditions.

## CLIMATE DURING PREHISTORIC TIMES

Evidence which indicates climatic conditions during prehistoric times in the Indus Valley and Baluchistan is conflicting and highly controversial. A great civilization developed in the Indus and Saraswati valleys, and in Baluchistan agricultural villages flourished. At present, both of these areas are arid; bare, desolate and arid, the Baluchistan hills now support a meagre agriculture with nomadic herding as the dominant occupation. Numerous high mounds of Chalcolithic settlements in the Baluchistan hills reveal a different environment during prehistoric times. It is thought that the agricultural conditions were stable and the settlements permanent during that period. The 'relatively stable' conditions have been taken to imply a moister climate with fairly reliable rainfall and flourishing agriculture. In Baluchistan several ruined stone-dams locally called *gabarbands* are found near many Chalcolithic sites. These dams indicate that the rainfall was sufficient to store water but, on the other hand, it must have been sufficiently precarious and seasonal to necessitate controlled storage and irrigation. Thus the evidence in Baluchistan indicates that during prehistoric times rainfall was somewhat more than at present.

When we consider the evidence of climatic conditions in the Indus Valley difficulties accumulate. There are some indications of the prevalence of humid conditions whereas others suggest dry conditions. It is often pointed out that millions of kiln-burnt bricks were used in the construction of houses in Mohanjodaro, Harappa and Sutkagendor which must have required an enormous amount of wood for fuel; on this basis it is conjectured that abundant forests flourished in the Indus Valley and that the climate was humid. But the available evidence is not conclusive; kiln-burnt bricks are used only in those sites which were accessible to the rivers. Wood might have been floated down the rivers from the Himalayan forests to the sites. The sites which were away from the rivers had houses only of sun-dried bricks or local stones. It is likely that in Chalcolithic times the Indus Valley lacked forests. It is also pointed out that kiln-burnt bricks were used for durability of buildings in the moist climate of those times. But what about the durability of the houses of those sites which did not use kiln-burnt bricks at all? It is suggested, therefore, that use of kiln-burnt bricks may have been only a cultural advancement.

An elaborate system of drains was developed in Harappa-culture cities; it is argued that the drainage system must have been constructed because of increased rainfall. Representation of animals—tiger, rhinoceros, buffalo, elephant, etc.—on Harappa seals, supported by evidence of actual remains of bones discovered, indicate that in the Chalcolithic period these marsh or forest animals were present. The existence of these animals from a more humid climate indicates that the climate was moist. Absence of camels also supports the same point.

The Indus civilization was characterized by large cities. These cities must have required a considerable agricultural population with surplus production accruing from a highly developed agriculture. It is argued that such a prosperous agriculture must have required a more dependable and increased rainfall than that of the present. However, this evidence is not decisive: agriculture could have depended on irrigation in Chalcolithic times [21]. No traces of the irrigation system are found now, although it is possible they were obliterated by recent sedimentation. Development of cities in the Indus civilization was probably due to large-scale irrigation which was also necessary for agriculture in the dry climate. Large-scale irrigation works must have required, for their control and management, some sort of government agencies, and they must also have needed protective works to check the damage by floods. Such a complex irrigation system must have necessitated a large non-agricultural population living in central places or 'urban centres'. The growth of cities in the Indus Valley has, therefore, been intimately related to the development of an extensive irrigation system. This type of civilization has been termed hydraulic by Wittfogel [33]. The broken terrain in Baluchistan did not permit the development of large-scale irrigation works. Thus, due to the handicap of environment only small scale dam-irrigation developed there during prehistoric times. This system of irrigation was handled locally by small groups of the agricultural population. It is recognized by many that the prosperity of the Indus civilization was dependent on irrigation and not so much on rainfall.

The roofs of houses in Harappa and Mohanjodaro were flat and were covered with bamboo and rush matting coated with mud and earth to form solid and waterproof layers. The flat mud roofs suggest that the climate was not a wet one, but it may not have been as arid as it is today. 'A certain degree of climatic change is beyond dispute, but how far that change is due to natural causes and how far to sheer human improvidence ... is less easy to say.' [31, p. 6.]

Finally, the causes of deterioration of the Indus civilization should be sought partly in the changes of river courses damaging the irrigation works and thus the entire economy and partly in the attacks of the Aryans.

It is often suggested that the small decrease in rainfall that has occurred since the third millennium B.C. is partly due either to an eastward shift of the south-west monsoon or to a northward shift of the belt of western depressions. According to the first view, which is supported by Piggot [21], the south-west monsoon reached Baluchistan and the present arid zone received sufficient monsoonal rainfall during the Chalcolithic times. However, Piggot fails to give any reason for the subsequent eastward shift of the south-west monsoon and the consequent aridity of Baluchistan. The other reason advanced to explain the decrease in rainfall and the consequent desiccation of the zone suffers from similar uncertainties. Leighly, however, is inclined to accept the northward shift of the westerlies as the cause of the decrease in rainfall in the present arid areas in general [15].

It is thought by many that climatic changes within the historic times have been slight, if any. There are historical evidences which tend to indicate that at the time of Alexander's invasion arid conditions existed throughout Baluchistan.

## PRESENT CLIMATIC CONDITIONS

In dry climates potential evaporation exceeds precipitation during the course of the year. Several climatologists have tried to define precisely the arid climates. In recent years Thornthwaite [29] has evolved an empirical formula with the help of which arid climates can be delimited by the moisture index of −40. Following this index, Bhatia [5] delimited the arid zone of India and Pakistan by drawing the isoline of −40 moisture index. The arid zone thus delimited includes Sind, Baluchistan, almost all of western Rajasthan (west of the Aravallis), the south-western tip of Punjab (India), south-western Punjab (Pakistan) and the North-West Frontier Province excepting its extreme northern part (Fig. 3).

In the Indo-Pakistan arid zone the moist monsoon layer, in which there is no subsidence, is normally confined to the lower 2 km. of the atmosphere. Above this height the air is dry and subsiding as elsewhere in comparable latitudes. This fact, together with low moisture content of the air and high temperatures, are mainly held responsible for the aridity of the Indo-Pakistan arid zone. The region is thus situated below the subtropical high pressure existing at an altitude of about 2 km. It has been observed in July and August that over Rajasthan, Sind and adjoining parts of the Punjab the monsoon air extends only up to 1 km. but east of Bikaner and Jodhpur it goes to a height of 3 km. West of Bikaner and Jodhpur anticyclonic conditions exist in the upper air. This high pressure belt in the upper air suppresses the monsoon currents and keeps them from ascending beyond 2 km. Thus condensation is retarded and the area receives only meagre rainfall.

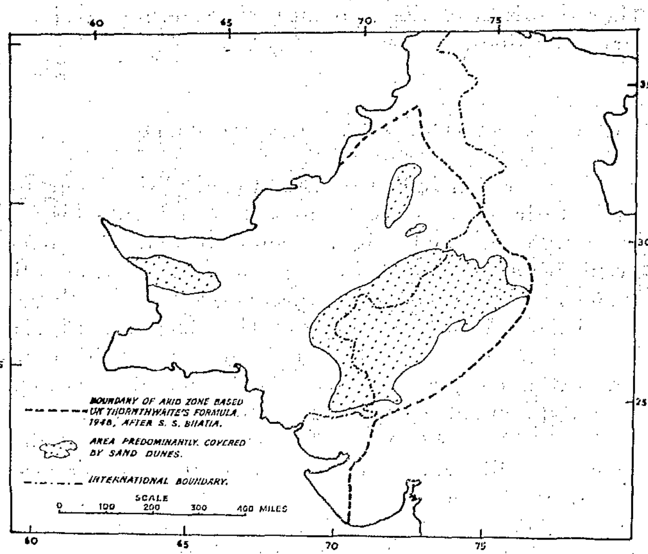



FIG. 3. Arid zone of India and Pakistan.

The arid zone of India and Pakistan occurs, as do almost all the tropical deserts of the world, in the zone between the tropical rainy climates and the rainy belt of the westerlies. Only the northern and western parts of the arid zone receive an appreciable amount of rainfall from the western depressions which lose most of their moisture in the long journey from the Mediterranean.

Climographs of various stations of this region prepared on the grid classification [8, p. 54] depict the intensity of the Indian Desert. A comparison of these graphs reveals that complete aridity prevails in central Sind which is best exemplified by the climograph of Jacobabad. This station has an annual deficiency of more than 150 cm. As we proceed outward from this central region the water deficiency decreases. Consequently there is a decrease in the intensity of aridity. Jodhpur in central Rajasthan has a water deficiency of 114 cm. The climograph of this station indicates semi-arid to humid conditions during the monsoon period. The intensity of aridity in other directions also decreases. Multan has a water deficiency of 126.6 cm. and Lahore 83.99 cm. These two stations also experience humid conditions in the rainy season. In the extreme north-west and west, i.e., at Peshawar and Quetta, subhumid conditions are experienced during the months of western disturbances. Temperatures are high throughout the desert and warm to hot conditions prevail for the most part of the year.

*Temperature conditions*

Winter is cool and January is the coldest month of the year. At some places temperature falls below freezing point. On the other hand, scorching, unbearable heat is the rule of the summer months. The hottest month is June when the day temperatures at many places are as high as 120° F. With occasional heat waves the day temperature exceeds even this figure. The rise of temperature from the coldest to the hottest month is not uniform over the whole of the desert; instead it varies from area to area within the arid zone. It is more or less steady over southern Sind and Rajasthan while in the northern tracts the rise is irregular. Thus in northern Sind and southern Punjab there is a steep rise in February and March, somewhat smaller in April but sudden in May. In southern Sind the highest temperature is reached in May while in the rest of the region the highest is in June. Temperature remains almost constant in May and June or until the arrival of the monsoon winds. Owing to clear skies, bare ground and low humidity insolation is greatest during this season. The burning heat coupled with scanty water supply makes life very hard.

The temperature falls slightly with the monsoon showers. June temperature in Jodhpur is 95.9° F. and drops to 89° F. in July and 85° F. in August. The comparable figures for Jacobabad are 99.4° F., 96.5° F., and 93.2° F. respectively. The monsoon winds retreat by mid-September lowering the humidity of the atmosphere; but the insolation does not decrease at the same rate as the humidity. This results in another rise of temperature, for example: the temperature at Bikaner is 97° F. in August and 98° F. in September; in Jodhpur it is 91.8° F. in August and 94.2° F. in September. The temperature again decreases from mid-October, this time steadily so as to reach its lowest point in the second half of December or the first half of January.

Due to the clear skies and the low relative humidity insolation is greatest in summer so that temperatures tend to be very high for the latitude, resulting in a great annual as well as a great daily range of temperature. Central Sind experiences an annual range of mean monthly temperatures of about 40° F. This range is, however, narrowed near the coast due to the onshore winds. The annual range at Karachi is only 20° F., but proceeding to the north, the range increases to 40° F. at Multan and 45° F. at Jacobabad.

The same factors—clear sky, small amount of water vapour and bare ground—that explain the receipt of maximum insolation during the day are responsible for the rapid loss of this energy by night resulting in a wide diurnal range of temperature which is higher than the mean annual range. As in the case of the annual range, the diurnal range of temperature is much higher in the interior areas than on the coast. At Karachi the daily range is 35° F., at Hyderabad 40° F. and at Jacobabad it is as high as 45° F.

*Rainfall*

The normal annual rainfall over the Indo-Pakistan desert nowhere exceeds 15 in. (Fig. 4). It is only 6 in. in Sind, 10 in. in south-western Punjab and 11 in. in western Rajasthan. This rainfall is extremely seasonal and more than 90 per cent of it falls during the monsoon period which is also a season of high evaporation. The upper air anticyclonic conditions permit only a shallow current of the monsoon to penetrate the arid zone. Furthermore, they effectively check the rise of the moisture-laden winds so that saturation level is seldom reached and rainfall remains extremely low.

The rainfall due to the Arabian Sea branch of the monsoon decreases considerably as it proceeds northwards from the tip of the peninsula. It is very meagre beyond the gulf of Cambay. Ahmedabad receives 29 in., Bhuj 15 in., Nagar Parak 14 in., Karachi 7 in. and Sukkar only 3 in. annually. Except in the coastal areas of Mekran, most of the rainfall of the arid zone is associated with the Bay of Bengal branch of the monsoon. When this air enters the desert it is already

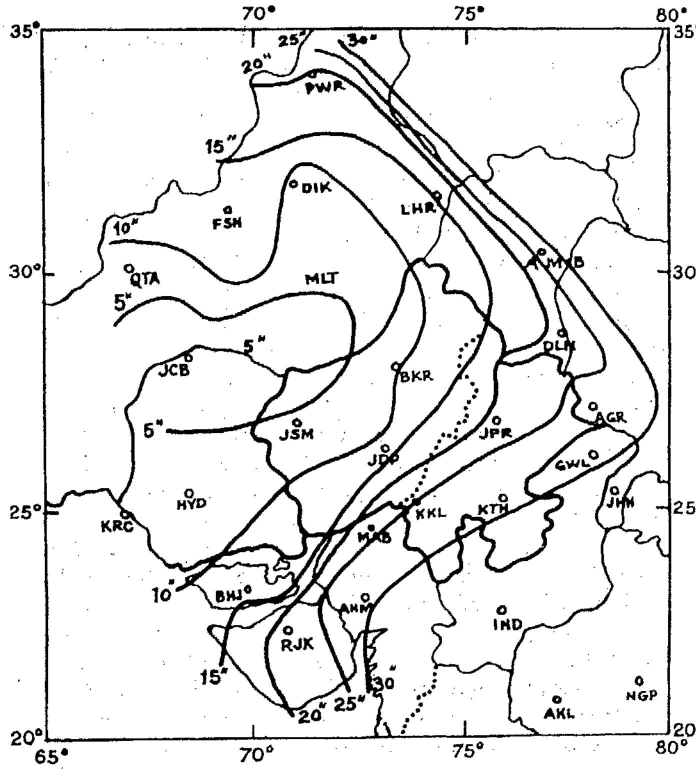



FIG. 4. Normal annual rainfall (in inches) of Rajasthan and neighbouring tracts (based on records up to 1940). (After Ramdas.)

deprived of most of its moisture because of its long journey over the Gangetic plains. Although the stream is heated up and rises vertically condensation fails to take place because of the presence of high temperatures and low humidity up to a considerable altitude. During this season the rainfall decreases rapidly from east to west over the entire region.

During the winter months the north-western desert area is traversed by feeble cyclones from the west. Quetta, on the western fringe of the desert, receives 1.94 in. of rainfall in January and 1.98 in. in February. Peshawar receives 1.44 in. in January. This rainfall decreases rapidly east and south-eastwards. Lahore and Multan have 1.04 in. and 0.37 in. respectively in the month of January. Jacobabad which is in the heart of the desert receives only 0.23 in. in January and 0.33 in. in February.

The Indo-Pakistan desert is not only handicapped by the meagreness of rainfall but, like the other deserts of the world, the rainfall is also highly variable both in space and time. Some stations may have no rainfall for a whole year. In another year much more than the normal annual total may fall in a few hours in sudden downpours. The mean annual rainfall at Hyderabad is 7 in. but in August 1865 the rainfall of three consecutive days amounted to 13 in. of which 10 in. occurred in one day. Doorbaji whose mean annual rainfall is 5 in. had 34 in. on one occasion. A study of rainfall at various stations in Rajasthan and adjacent regions reveals that the variability is maximum 'between years'; it is considerably higher 'between stations'; but it is smaller 'between the days' of the rainiest month i.e., July. Charts of rainfall, prepared by T. S. Govindaswamy, for Sind and west Rajasthan, show that within the rainy season the distribution of rainfall is highly erratic. Some weeks of the rainy season may experience either floods or severe droughts. The comparison of these charts further reveals that the intensity of the droughts varies inversely with the amount of total rainfall as well as the length of the rainy season, i.e., as we proceed from east to west in the desert region the amount of rainfall as also the length of the rainy season decreases. During the normal rainy season only 32 per cent of the weeks in Sind have normal rainfall. The percentage is 27 for western Rajasthan and 44 for eastern Rajasthan. The percentage of drought weeks in the normal rainy season is 51 in Sind, 53 in western Rajasthan and 37 in eastern Rajasthan. The percentage of flood weeks is 16, 20 and 18 in Sind, western Rajasthan and eastern Rajasthan respectively. A chart showing the percentage departure of rainfall from the normal thus makes it clear that the rainfall of western Rajasthan is extremely irregular—this is true of the entire desert region. In general, droughts are a rule but the floods are few and far between.

Graphs of 5-year and 10-year means of rainfall of those stations for which the data of long periods are available reveal that there has been no appreciable upward or downward trend in the rainfall. However, in the case of some stations (Jodhpur, Kotah, Barmer, Agra and Neemuch) there has been a definite tendency for the rainfall to increase in recent years. It is only in the case of three stations (Jacobabad, Ajmer and Hissar) that some tendency for decrease in the rainfall is noticed. Lower Sind has also shown an increasing tendency.

### *Cold season*

During the months of December and January a comparatively high pressure area is created over Kashmir and Punjab and a moderate gradient is established between this area and the low pressure area which has shifted beyond the equator in this season. It is this high pressure which influences the direction of the winds. The winds are light and variable on the whole, but north-westerly or northerly winds are most frequent. The stability of air and its dryness in the cold season are not favourable factors for condensation. The only chance of rainfall is from wave disturbances of the strong overlying westerlies, which sometimes produce cyclonic circulation at

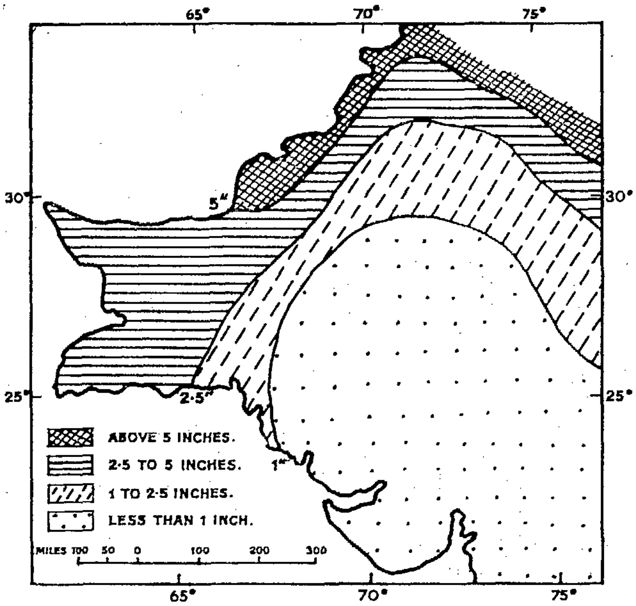



FIG. 5. Arid zone of India and Pakistan. Winter rainfall (December to March). (Record up to 1940.)

low levels over Indo-Pakistan. Their journey eastward from the Mediterranean is accompanied by a decrease in the vapour content and any significant amount of rainfall is in the extreme north-western tip of the desert as revealed by the winter rainfall map (Fig. 5). From this area rainfall decreases gradually to the south. The winter rainfall over southern and north-western Baluchistan and most of North West Frontier Province ranges between 2.5 in. and 5 in. Western Sind and Punjab receive 1-2.5 in. while over the rest of the desert the amount of rainfall is less than 1 in.

In Rajasthan, the relative humidity during December to February is generally 50-60 per cent in morning hours and 25-30 per cent in the evening hours. These values are, however, higher at those places where canal irrigation is provided (Sri Ganganagar has 78 per cent in the morning and 42 per cent in the evening). The humidity figures are lowest in the most arid tracts such as in the areas around Jacobabad and Jodhpur.

The temperature rises often to 90° F. during the day in January while frosts at night are common. Fires are lit evening and morning right up to February. With the approach of cold waves, which occur on many occasions, the night temperature goes below the freezing point.

### *Hot season*

From January onward the sun continues its northward journey and the temperature begins to rise. This gradual rise of temperature breaks down the high pressure of Punjab and by April it entirely disappears and its place is taken by a low pressure area throughout north-western India. By May there is a deep low of 29.6 in. centring around Multan. At this time the air circulation, though feeble, is certainly cyclonic and the conditions are favourable for local thunderstorms. The winds are locally controlled but are generally south-west and west over most of Rajasthan, and they are hot and dusty except near the coast where a sea breeze blows during the day.

The real hot season begins from early April, but March is already so warm that the *rabi* crop is harvested at the end of this month. The rise of temperature from January onward is very steady. Jodhpur, for example, records a mean monthly average of 80° F. in February, 90° F. in March, 99° F. in April and 105° F. in May. A similar rise is found over most of Rajasthan, Punjab and northern Sind. Jacobabad, which has the evil reputation of being the hottest station in the Indian subcontinent records a mean daily maximum of over 110° F. The heat and glare of the sun reflected from the bare ground make man's movement in the open fields very difficult.

Relative humidity decreases with the rise of temperature in this season and is the lowest compared with the months in other seasons. If we exclude the values for June, it is in general from 35 to 60 per cent in morning hours and from 10 to 30 per cent in the evening. Jodhpur has 35 per cent in the morning and 11 per cent in the evening during the month of May. This decrease in relative humidity is attributed to the rise of air temperature which has consequently increased its vapour-holding capacity. The relative humidity along the coastal tracts is higher because of the sea breeze.

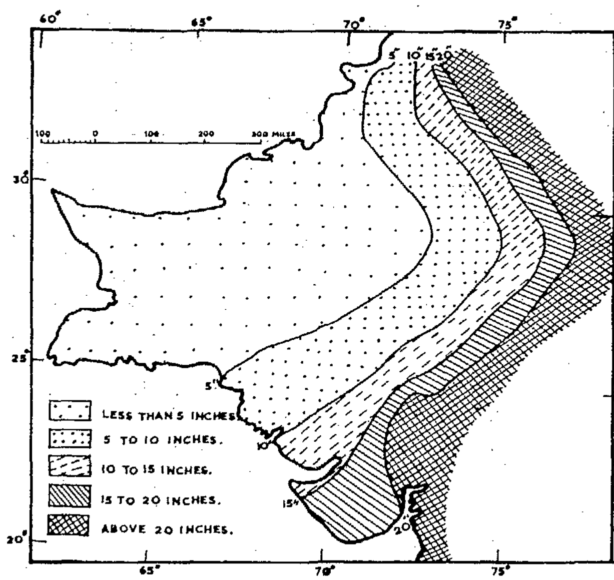



FIG. 6. Arid zone of India and Pakistan. Monsoon rainfall (June to September).

*Rainy season*

During the month of June the monsoon currents invade the Indo-Pakistan subcontinent. The monsoon current from the Bay of Bengal reaches eastern Rajasthan by the middle of June and covers the whole of the desert within one month of its arrival in eastern Rajasthan. As this current proceeds westwards it becomes more and more deficient in water content. Moreover, condensation of this ascending monsoon, as also of that coming from over the Arabian Sea, is hampered by the hot and dry air present in the upper layers of the troposphere. Figure 6 shows the amount of rainfall from June to September and indicates a decrease in rainfall from east to west. The decrease is particularly rapid west of the Aravallis. Jaipur receives 24 in., Bikaner 11 in., Jaisalmer 7 in. and Jacobabad only 4 in. annually. A major part of this rainfall occurs during the period of monsoon winds. For example, Jodhpur receives 0.65 in. in March, April and May but in the next three months receives 10.23 in. This trend is true of the whole desert excepting the extreme western side where the winter cyclonic rainfall exceeds the monsoonal rainfall.

The amount of rainfall over the desert is small; nonetheless the air is fairly humid. There is a marked increase in the relative humidity over a period of a month. The mean relative humidity at Jodhpur in May is 30 per cent rising to 48 per cent in June and 60 per cent in July. The increase in relative humidity is less to the west and north-west.

There is a slight depression in the crests of the curves of temperature when the rain comes: the mean maximum day temperature at Ajmer is 100° F. in June and drops to 91° F. in July. This is accompanied by a corresponding increase in the relative humidity. As the increase in relative humidity is less and less due west the rate of the fall in temperature also declines. At Quetta there is hardly any increase in the relative humidity from June to July, with the result that there is no decrease of temperature in the month of July. Here the moist heat during this season is more oppressive than that of the hot season.

With the retreat of the monsoon in September there is a fall in the relative humidity of the atmosphere. The fall in relative humidity is accompanied by rise in temperature. Thus the temperature in September is slightly higher than that of August. The mean maximum temperature at Jaisalmer in August is 94° F. and in September it is 99° F. From October onward there is again a fall in temperature which gradually reaches its minimum in January.

## DEVELOPMENT OF LAND TENURE

A study of the development of the various types of land tenure, and the processes which bring about changes in them, is necessary for the understanding of the past social and economic conditions of an area where agriculture has been the main occupation of the people. One thing must, however, be made clear at the outset that there has never been consistent and continuous evolution of any system of land tenure. Instead, different periods in the past are marked by important changes in the tenure of the land. In most cases such changes have been brought about by political and social forces.

Time after time in the past large groups of migrants or invaders have poured into the north-western part of the Indian subcontinent. And every time they have caused important changes or modifications in the prevailing land tenure of the region. Thus the roots of the systems of land tenure existing at present in the area under inquiry lie in the remote past.

Palaeolithic man seems to have inhabited Peninsular India first and then to have migrated to the Sohan valley in the Punjab [16]. He was a hunter and a food-gatherer. He hunted and followed the contemporary fauna and roamed about in search of roots and fruits, as far as the environment permitted him. He lived in small family groups and in temporary dwellings. His life was unsettled. It may be argued that at this stage of low human intelligence no sense of private landed property had developed. A significant change in man's attitude towards property in land occurred when he learnt the art of agriculture and became a settled tiller of the soil and the sense of private landed property was developed first when men settled in fixed dwellings; each family or a member (probably the woman) of the family cleared a piece of the land in the vicinity of the dwelling and started cultivation. After long association with the cultivated fields, a sense of ownership developed. The waste land around the dwellings was probably jointly claimed by the clan. The tendency to live in groups and so in dwellings grouped around a nucleus probably developed early, partly to provide a joint protection of crops against predators and robbers.

Settled agricultural communities were established in Baluchistan at the beginning of the third millennium B.C. [21, p. 67]. Archaeological evidence tells us nothing about landed property; one can only surmise that at this stage each family cultivated the fields which were cleared from the primeval jungle, and after long association with the cultivated land ownership rights in it grew naturally. Small dams were constructed to impound water for irrigation. The individual or family which participated in the construction and maintenance of the dams must have had rights in the irrigation water.

A great civilization flourished in the Indus Valley during the Chalcolithic period. The Indus civilization was based on prosperous irrigation-agriculture. Tillers of the land probably had ownership rights in the fields they cultivated. They paid a share of the produce as land revenue and water charges to the 'State'. The huge granaries uncovered at Harappa indicate that land revenue was paid in kind [21, p. 170].

The Aryans conquered the Indus civilization in the second millennium B.C., and forcibly acquired the land. Ownership of the land was thus vested in the conquerors. The Harappa civilization was pure Dravidian and matriarchal [1, p. 326]. The Aryans, on the other hand, were patriarchal; they met the matriarchal societies of the Dravidians in the Punjab. Man was dominant in the Aryan societies and the land was owned by him. The Aryans were primarily pastoral people, they brought dairying and cattle culture with them that blended and fused with the agriculture farming culture of Harappa; later on they took to farming.

The earliest document giving information on India is the *Rig Veda* which was composed during 1500 to 1000 B.C. The Rig Vedic Age was one of great landowners, and the king was considered as the supreme landowner. This being so, the wealth and prestige of the farmer were reckoned in land and cattle. Each individual family owned its cultivated land and the head of the family was owner of the landed property. The arable land lay around the village and each family cultivated land according to its ability. The peasants were allowed to make use of the waste land for grazing and fuel. The chief was the owner of the waste land and he made grants to new settlers from it.

In Rajasthan the present land-tenure is modified from the ancient Aryan system. Waste or uncultivated land was held to be the property of the crown (raja); the rajas made grants from it to their chiefs. Later, the chiefs acquired ownership rights in the granted land and became landlords, locally termed *Bhumiyas*. Thus the land was held either as the property of the crown or as the estate of the *Bhumiyas*.

From ancient times, however, it has been the custom in the Khalsaland (land owned by the crown) of Ajmer that those who permanently improved the land by providing irrigation facilities, by sinking wells or construction of embankments for storage of water, acquired certain rights in the land. The cultivator of the improved land could not be ejected so long as he paid land taxes. His successors inherited the land and the right of ownership thus gradually grew up in permanently improved land. In arid and semi-arid areas, such as Ajmer, land has no value without irrigation; consequently water for irrigation has greatly influenced the land tenure. This system of land tenure created landlords and tenants. The landlords took the cultivators as their tenants.

After the Rig Vedic period the Aryans left the Punjab and settled in the Ganges Valley. According to Baden-Powell, Jat and Gujar tribes invaded north-western India—independently of course [3, p. 611]. They came in large number and in sufficient force, settled in the north-west of the Indian subcontinent and formed a large network of villages. The chiefs of these tribes forcibly acquired the whole of the land and established their rule. The chiefs then made land-grants to other members of the clan and partitioned the land among themselves. Thus the chiefs and members of the clans gained the position of landlords over the village lands. Later the descendents of the chiefs and other members of the clan multiplied and thus established *pattidari* village communities. The character of the Gujar and Jat tribes is important in shaping the system of land tenure in which land is jointly held by the peasants of the village. They like to maintain independence and show unequal sharing of the landed property.

In the Punjab the present land tenure came into being in a manner different from that of the Aryan system, and no trace of the Aryan system of land tenure has survived. The village community is not an aggregate of separate cultivators but the peasants, at least theoretically, have a strong joint claim over the cultivated village land as well as the waste. But it should be noted that the holdings are separately held by individuals or families. Cultivated land is equally divided among the sons who are virtual heirs and here the law of pre-emption is strong.

During later historical periods, neither the Muslim nor the Pathan conquerors, nor the later Sikh rulers, ever allowed the local chiefs to acquire *zamindari* powers; consequently landlords as a rule are absent in the Punjab. Instead almost all land is now owned by small peasant proprietors who cultivate it in part or whole; the institution of peasant proprietors has existed since 1000 B.C. It is noteworthy that the institution of peasant proprietors is not the result of the measures adopted either by the British Government or earlier governments [3]. The prosperous agriculture of the Punjab is due in part at least, to the system of peasant ownership and the evils attendant elsewhere on a tenancy system are absent.

Village communities as such did not exist in the arid 'bars' of southern Punjab (Pakistan) until the introduction of canal irrigation during British rule. Only in the fertile riverine tracts, which benefit from annual flooding, did compact villages with joint claims over land develop. Nomadic herding remained a dominant occupation in the harsh environment of the 'bars' of the Punjab. The nomads had indefinite joint claim over the waste land. Private landed property in the 'bars' came into being when a family sank a well in the plot where the water level was near the ground and cleared the land for cultivation around the well. Instead of villages, hamlets grew up, individual families owning patches of the cultivated land. The absence of village communities is due to the harshness of the arid environment. Irrigation water has played an important part in shaping the land-tenure system of the southern Punjab. Here a class of proprietors, distinct from landowners, has developed. They are owners of wells and sometimes of irrigation channels constructed at their own expense on another's land, possessing hereditary and transferable right in them. Either they received a share of the produce from the cultivators as water charges or they arranged for cultivation and paid a fixed share to the owner of the land.

The North-West Frontier Province was inhabited by Muslim tribes who came in large waves along with Pathan, Afghan and, in some cases, Mogul conquerors. They forcibly acquired the land from the Jats and Gujars. In some cases these nomads occupied the land for grazing their herds, in others the tillers held it and divided it among their families for cultivation. The influential man in the clan had the privilege of headship for which he was paid a share of the produce. But the head man had no claim over the soil.

Holdings were frequently exchanged among the proprietors of the same village and sometimes among the proprietors of different villages in the North-West Frontier Province. The system of exchange of holdings was common, particularly in areas which lay along the rivers and were subjected to erosion. The character of the land and the tribal sentiments of the people induced the exchange of holdings. When each family became conscious of the improvement in the land it cultivated, objections to the exchange of holdings were raised.

In the arid climate of the North-West Frontier Province, as in southern Punjab (Pakistan) and Sind, property rights are also held in irrigation water. In Baluchistan and the North-West Frontier Province one or more families dig *Karez* and acquire a proportionate share in the land in return for the supply of irrigation water.

The Hindu Rajput and Jat tribes occupied Sind before the Arab conquest. The Hindu tribes had a system of chiefs subordinate to the raja. Land in Sind was originally allotted in separate holdings for every family of the clan. In Sind the zamindars had no ownership rights in the soil but their authority over the clan was supreme. The zamindar collected land revenue for the raja and for his services he was entitled to claim a share of the produce. The chief had indefinite rights over the waste land. He induced new settlers to cultivate the waste land by digging irrigation channels or sinking wells. 'In this way a privileged class of tenants grew up in Upper Sind.' [3.] In later historical times the chiefs tempted the Baluchi settlers to dig irrigation channels in the waste land. The channel diggers supplied water for irrigation and in turn were given a share of the produce. The Arab and later conquerors found the system of chiefs prevalent; they readily adopted it and authorized the zamindars to collect land taxes. The authority of the zamindar was so firmly established that theoretically he became the owner of the land. In the absence of the zamindar, the government was supposed to act as zamindar, and to take its share of the produce. The zamindars still have fairly definite claims for certain dues from the landholders, and they have indefinite claims over the waste land. The holdings are owned by individuals or families.

Thus, in conclusion, it may be pointed out that the present systems of land tenure are deeply rooted in the past history of the region. In addition to physical factors, political and social forces brought about important changes in the way the land is held and cultivated. It is not surprising that the resultant systems of land tenure have great social and economic implications.

## HISTORY OF THE DEVELOPMENT OF IRRIGATION

The seed-hearths of the old world are located in areas where part of the year is dry. Due to the handicap of aridity in these regions irrigation is likely to have been developed quite early.

In Rana Ghundai the development of irrigation in a very early period seems fairly certain. Without the aid of irrigation the arid Baluchi region could not have supported such a large population as is indicated by the size and number of archaeological sites. Bull pottery indicates that cultivation was carried on with the help of irrigation works very similar to those of the present day [25, p. 311]. That the agricultural communities in Baluchistan practised irrigation is substantiated by the fact that a large series of artificial stone-built dams and terraces designed for irrigation was identified by Aurel Stein near the Chalcolithic tills. These dams clearly indicate that irrigation in Baluchistan was important in prehistoric times.

In the arid climate of Sind, cultivation without irrigation was impossible. The Indus civilization was thus hydraulic in origin. Great cities like Harappa and Mohenjo-daro owe much to irrigation. The irrigation works required a large non-agricultural population for their construction, maintenance and administration, thus giving rise to urban centres. The great rivers of the Punjab not only made transport easy but also provided water for irrigation. These rivers frequently changed their courses in the absence of man-made embankments—there are numerous deserted channels to prove this—and caused disastrous floods. These frequent changes in river courses also interrupted the irrigation systems of the Harappa civilization. In Aryan literature too there are frequent references to the practices of irrigation.

Before the introduction of modern canals great indigenous systems of irrigation existed in Sind.

The Mirs of Sind used to charge an additional tax on land irrigated by man-made channels. But no proper attention was given to the maintenance of these, with the result that many of them went out of use. Almost all of them took their water from the Indus river, some simply from water spilled over in time of flood. In the arid south-western Punjab (Pakistan) before the introduction of the modern canals, cultivation was possible only in riverine tracts where land was inundated by annual floods and where irrigation from wells and channels was practised. In the 'bars' nomads were dominant. They were mostly engaged in grazing and cultivation was practised only on favoured plots. During the Sikh rule Dewan Sawan Mal, the Governor of Multan, made efforts to settle the area and constructed many inundation canals in the region.

The development of the modern perennial canal irrigation system started in 1859 when the Upper Bari Doab Canal was constructed from the Ravi River with headworks at Madhopur. Another canal, known as Sidhnai Canal, was constructed in the Multan district in 1861 from the same river. A third canal, using water from the Chenab River and known as the Lower Chenab Canal, was completed in 1892. But the area between the Jhelum and Sutlej rivers was still in great need of water. In order to bring this area under irrigation and to utilize the waters of the rivers in the best possible way the Grand Triple project of the Punjab was planned and was completed between 1905 and 1917. By this project the water of the Jhelum is taken into the Chenab and that of the Chenab to the Ravi. In this way none of the three Doabs is left deficient in water supply. At present the Upper Jhelum and Lower Jhelum Canals irrigate the Doab between Jhelum and Chenab, the

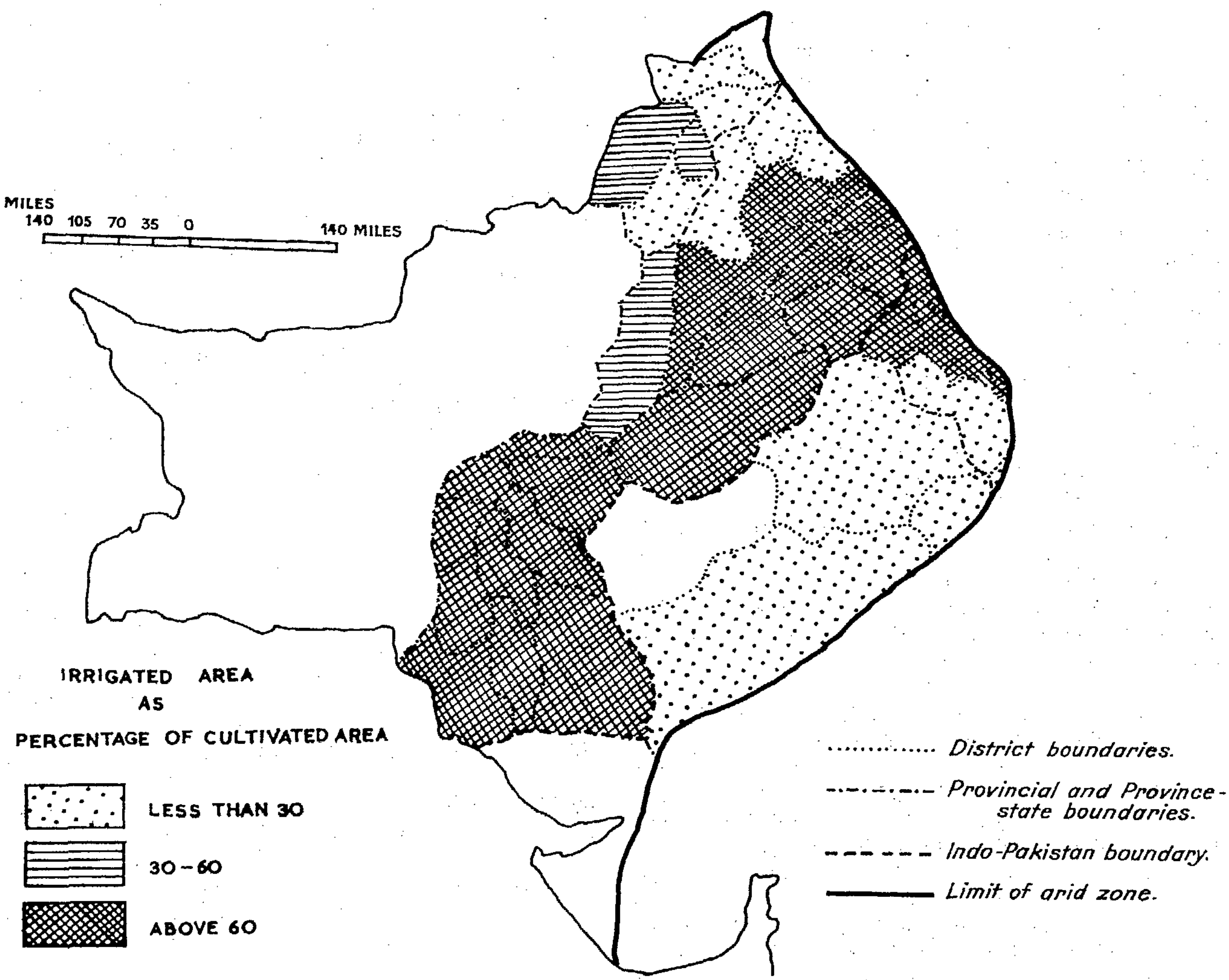



FIG. 7. Arid zone of India and Pakistan. Irrigation 1942-1943. (*Indian Agricultural Statistics*, vol. 2.)

Upper Chenab and Lower Chenab Canals irrigate the area between the Chenab and Ravi while the Upper Bari Doab and Lower Bari Doab Canals irrigate the Doab between the Ravi and Sutlej. Canals taken from the Sutlej River irrigate areas of Punjab (India) and parts of Rajasthan adjoining Punjab and Bahawalpur State.

In Sind perennial irrigation dates from 1932 when the Sukkur (Lloyd) Barrage was constructed on the Indus River. From this barrage seven main canals command a huge area in the Indus Valley of Sind. The main canals and their distributaries total about 36,000 miles in length and this is the largest project of the subcontinent. Later projects, some still under construction, have vastly increased the irrigated area.

Thus a large portion of the arid zone which lies in Sind and the Punjab and which was at one time thought to be an unpromising land has been changed by these canals into one of the best agricultural regions of the subcontinent.

At present the canal-irrigated area in the Punjab, Sind and Bahawalpur[1] is about 11 million, 5 million and 2 million acres respectively. In addition to this, considerable areas in the North-West Frontier Province (Pakistan) and Rajasthan (India) is irrigated by canals. The maximum percentage of area under irrigation is in the Doabs of the Punjab and Sind (Fig. 7). In Sind and southern districts of the Punjab almost the whole of the area under cultivation is irrigated by canals. Though the intensity of irrigation in Dera Gazi Khan, Wazirsthan and Bannu does not compare with that of western Punjab it is still of considerable importance.

The minimum percentage of cultivated area under irrigation is in western Rajasthan, Hissar and Mohindergarh districts of the Punjab and the north-western tract of desert extending over Sind Sagar Doab, the Potwar Plateau of Punjab and the adjoining districts of the North-West Frontier Province. The hilly nature of the land in the Potwar Plateau and in Kohat and Bannu districts has greatly restricted the development of canal irrigation. There are a few wells near the streams because the water table is fairly close to the surface, but in this region less than 30 per cent of the cultivated area is irrigated.

In western Rajasthan the percentage of the irrigated area is also less than 30. In contrast with the Potwar region this area is handicapped more by lack of water and less by surface configuration. The water table is so deep that well irrigation, though not totally absent, is little developed. The water table is commonly about 300 ft. below the surface and nowhere less than 200 ft. No major canal traverses the region as the main rivers lie too far from Rajasthan. Only the northern and north-western fringes of Bikaner together with the Hissar district of Punjab are canal irrigated. Rajasthan Canal and Bhakra-Nangal Canals are the future hopes of these regions.

The maximum percentage of cultivated area under irrigation is found in a long and wide tract running through the arid zone from north-east to south-west (Fig. 7). This region includes the area from Jhelum to Sutlej, Ferozepur and Bhatinda districts of Punjab (India), Bahawalpur State and the whole of Sind. In this large tract the cultivated area under irrigation is nowhere less than 60 per cent. In Sind nearly the whole of the cultivated area is canal irrigated. In Multan, Montgomery, Lyallpur, Lahore and Sheikupura again most of the cultivated area is canal irrigated. In northern districts well irrigation is also practised though its importance as compared to that of canal irrigation is small.

Thus, from the very earliest times the development of parts of this arid zone has been closely tied up with the development of irrigation.

## HISTORY OF AGRICULTURAL LAND USE

The Pleistocene period in which climate fluctuated greatly is characterized by the appearance of man in north-west India. He witnessed and was subjected to those changes of climate. The environment was harsh and his intellect was meagre; hunting and food-gathering remained the basis of his subsistence throughout the Palaeolithic period. He depended on the environment for his food and shelter and it is often argued that he was not far different in his habits from his contemporary animals, but he was able to hunt those animals and followed them over large areas. During the Second Glacial Phase, Palaeolithic man inhabited the Potwar Plateau where his artifacts have been discovered in the river terraces of the Sohan. During this period people lived in small and isolated groups; communication of ideas was extremely slow. The lack of exchange of ideas and the low intelligence of man contributed to the slowness of his progress in general, and in particular in the development of tools.

Man's skill and intelligence being low, his tools were very crude thus making him dependent on nature. Consequently his life was precarious. The man-made stone tools which have been found embedded in the older alluvium are the only evidences of the Stone Age culture. In the Second Interglacial Phase, when climatic conditions were favourable, Palaeolithic man inhabited Potwar in fairly large numbers as is indicated by the presence of many stone tools. It is in the last part of the Second Glacial Phase that first stone tools of Palaeolithic man are found in the river terraces of the north-western Indian subcontinent.

In Sind at Rohri and Sukkar and near Karachi

1. It is convenient to refer to these divisions though they have been abolished as administrative units.

at Draigh Road, remains of a chert industry have been found which have been given a very early date. The stone sites of Sukkar and Rohri might well be representative of an indigenous culture which led to the first urban civilization in the Indus Valley.

During the long Palaeolithic period man gained knowledge by experience. It was a sort of prelude to the period which followed (fourth or fifth millennium B.C.) in which agriculture was introduced [21, p. 25]. It is not certain whether the Palaeolithic Indian communities which made diminutive stone tools were hunters and food-gatherers or practised agriculture. Our knowledge is also meagre about the stage of human progress in the Neolithic period when agriculture and stock breeding were certainly practised but metal was not known [21, p. 36-37].

Hunting and food-gathering activities probably persisted throughout the Pleistocene ice age. It was after the final withdrawal of ice that the climate changed considerably, in consequence whereof the fauna and flora also underwent changes. It is in this period that primitive man may have taken to a sedentary life, where he could live in a small fixed abode which provided security of food and in which he was able, in some cases, to store the surplus food and found time and opportunity to develop his inventive skills. The change over from hunting and food-gathering to human control over food production was the first revolutionary step toward the establishment of ancient civilizations.

We cannot trace this process in India itself, and on the whole it seems improbable that this essential transition from food-gathering to food production was made independently in India as early as it was farther west [21, p. 43]. In India we have no known archaeological evidence to indicate the changing economy from hunting and food-gathering to agriculture and herding as exist elsewhere. One site in Baluchistan—Rana Ghundai—which affords information on the succession of occupation, has been studied by Ross [25, p. 284-316]. The sequence in the Rana-Ghundai mound makes us believe that in the earliest occupation—as evidenced by the lowest stratum of the mound—the people lived a semi-nomadic or pastoral life whilst occupying the same site for a very long time. Following this period there was a sudden introduction of a fully developed culture with settled agricultural life—the Bull culture—which Ross believes did not evolve at the site. This suggests that the development of the art of agriculture in north-western India came from the west—from the Middle East. Pottery of this period indicates that agriculture depended on minor irrigation works similar to those of the present day. In this second stage the newcomers arrived and built houses over the debris of the earlier settlement. They painted their pottery with figures of bulls. The period is characterized by peaceful agricultural pursuits. Piggot [21] would have us believe that this culture was introduced from the west.

According to Carl Sauer's thesis, which has been supported by later students (Wissmann and others), the first agriculture was started by fisher folks in the areas north of the Bay of Bengal from whence ideas of cultivation were passed on towards western India—into the wooded steppe and drier regions. In western India the spread of agriculture was hindered by the prolonged dry period during the course of the year. Primitive man here applied the ideas of cultivation to millet plants and thus the cultivation of millets was started first of all in the wooded steppe of India. From this part of India similar ideas and techniques of cultivation seem to have migrated to the Middle East where they were applied to the cultivation of bigger-seeded grasses such as wheat and barley. Cultivation was carried on without the plough. The small seed required only to be covered slightly with earth while the harvest needed no special tools. The ripe seed heads were broken off or pulled off as is still done in north-western India. The hardier varieties of seed plants were shifted to new areas because of their resistance to a harsher environment. Whether the selection and cross-breeding were intentional or natural, it enabled certain plants to grow in regions which earlier did not suit them. The transitional areas between the monsoonal forests and the wooded steppe of India were significant for the sowing and seeding of small grain plants—millets. It is surmised that at the edges of deserts man or more probably woman discovered that certain heavy grasses yielded seed which could be used as food and also stored for future use after the mere process of drying. With a more sedentary life the people would have the time to think of selecting the seeds. According to Carl Sauer and Vavilov, the planting-hearth cultivation in the seed-hearths also started in areas of diverse relief—a country of hills and valleys—with varied vegetative growth.

Carl Sauer believes barley to be certainly of ancient cultivation in India. It is possible that this superior crop replaced some earlier native plants. The local diversification of barley may indicate its early use in India. Western India is also considered to be the first home of the gourd, eggplant, cucumber, radish, lettuce and hemp [27, p. 79]. Many important vegetables, such as lentils, peas, and grass peas were domesticated west and north of the Indus. According to Vavilov, bread wheat was first grown near the Himalayas in Afghanistan, but Peake would place the first cultivation of wheat in Palestine, from whence the cultivated wheat migrated to India slowly and gradually. Beyond Afghanistan wheat cultivation spread via the Khyber Pass into the Punjab. The plains of the Punjab, then marshy and covered with original jungle, would not have attracted the primitive agricultural people who must have clung to the foot-

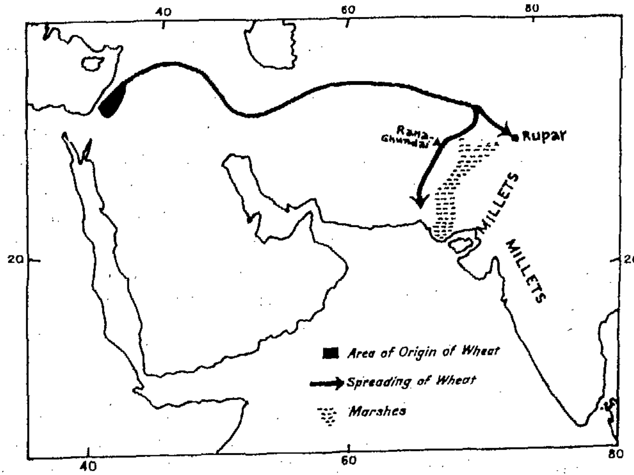



FIG. 8. Dispersal of wheat and millets in ancient times in South-west Asia. (After H. J. E. Peake.)

hills—a topography to which they were accustomed. From these foothills, people turned eastwards along the northern border of the plains or southwards along the Baluchi border of the Indus Plain. The site at Rupar was probably inhabited by these immigrants. Peake is inclined to believe that the early Indus civilization was derived from Turkistan [20, p. 53]. At a slightly earlier date, pottery from Sistan and Baluchistan resembling that from Susa II began to filter in from the west. The grain found in these sites is *Triticum sphaerococcum*, which is still grown in western India and Afghanistan (Fig. 8).

The techniques of cultivation seem to have developed gradually. Land was first only roughly cleared with the help of fire. Only such instruments as the hoe were used or the land was dug with the big toe of the foot. Elsewhere seeds were scattered on the virgin soil.

Two types of agriculture are likely to have existed in the arid zone of India and Pakistan during the Chalcolithic times. In the riverine areas which were inundated or irrigated, sedentary agriculturists with comparatively large settlements dominated. The continuous level surface with rich soils must have been a very attractive environment whereon to develop large village communities with a good deal of surplus grain. On the more difficult environment of the 'bars' with isolated water-points and with no comparable irrigation facilities only small hamlets developed. Cultivation remained confined to small patches around the few wells in favourable plots. Cultivation remained subsidiary to nomadic herding.

In Baluchistan, characterized by its diversity of relief, few and isolated tracts of arable land and restricted irrigation facilities, the agricultural settlements were small and isolated. The existence of virtually self-contained small peasant States in Baluchistan is to a large extent a reflection of the physical environment. There was little exchange of ideas between different valleys since there were few routes from one valley to another and this resulted in a heterogeneity of development. Quite in contrast was the development of urban and large village communities of the Indus Valley. 'Great cities with teeming population like Mohinjo-Daro and Harappa could never have come into being save in a country which was capable of producing food on a large scale and where the presence of a great river made transport, irrigation and trade easy.' [17, p. 271.] In the excavations of Mohinjo-Daro and Harappa carbonized wheat and some quantities of barley have been unearthed, showing their cultivation during the Chalcolithic period. The varieties of wheat grown in the Punjab resemble those found at Mohinjo-Daro. The wheat found from Mohinjo-Daro has been identified as *Triticum compactum* or *T. sphaerococcum* while the barley is identified as *Hordeum vulgare*. Date stones have also been found. Apart from the two important bread grains, wheat and barley, other items of food were beef, mutton, pork, poultry and milk. The cotton found there resembles the coarser varieties of present Indian cotton and was produced from a plant closely related to *Gossypium arboreum*. Whether or not the plough was being used in the Indus Valley during those times remains a controversial point because of lack of direct evidence. Yet it may be argued that such a large population with its big urban centres could scarcely have depended upon hoe agriculture; also India at that time had commercial contacts with Babylonia where ploughs were being used and therefore it may be inferred that the plough was being used in the Indus Valley too. The huge granary at Harappa indicates the fact that revenue was paid in kind and that the Indus civilization was based upon a well-developed agricultural society. The destruction of Harappa was probably due to adverse effects of changes in the course of the Ravi River rather than to a deterioration in climate as is often supposed.

The Aryans during the Rig Veda period were primarily pastoral people and inhabited the north-western Punjab. The latter fact is indicated by the reference in *Rig Veda* to all the five rivers of Punjab but rarely to the Jumna. The tiger is nowhere mentioned, nor is rice—showing the absence of humid conditions. According to another view agriculture among the primitive Aryans was as important as pastoralism and that tillage had preceded nomadism. The ploughs —heavy in many cases—were drawn by bullocks. Seed was sown in furrows and harvesting was done with a sickle.

To summarize, the area under investigation was the scene of domestication of seed plants from the earliest times, with numerous intra-regional variations in accordance with the environmental conditions.

In the Indus Valley the surplus production of many crops became the basis of an urban civilization.

## PRESENT AGRICULTURAL LAND USE

In an arid environment cultivation depends upon the availability of water. Areas of extensive irrigation are areas of extensive cultivation. Where irrigation is lacking, cultivated acreage is small and most of the land remains unreclaimed. In the arid zone of India and Pakistan the most important source of irrigation water is the river system and thus the cultivated land is almost restricted to those areas through which the rivers flow and where the water of the rivers is accessible through canals.

The maximum percentage of the total area under cultivation is in the north-eastern region of the desert (Fig. 9).[1] From this area the percentage decreases on all sides but more rapidly to the north-west. The lowest percentage is found in the Sind Sagar Doab and in much of Sind. In Sind Sagar and the Potwar Plateau both the uneven surface and the arid climate restrict the cultivated acreage. In the Potwar small hills and shallow depressions are prevalent. Vegetation is thin; the soils are stony and bare. Dry stream beds intersecting the plateau are covered with sand. This badland topography in the Potwar area is the result of soil erosion due to overgrazing and deforestation. In this region less than 50 per cent of the total area is cultivated. Further west and to the south, from Attock and Kohat to Dera Gazi Khan, less than 25 per cent of the total area is culti-

1. The discussion on the cultivated area and the crop-acreages in this section is based on the data for 1942-1943. This is the most recent year for which an outline map of the entire arid zone showing district boundaries is available. The data for more recent years (after 1947) for the areas falling in Pakistan and those in India are not comparable as they do not relate to the same year. In addition, base maps showing district boundaries for these later years are not available, thus making it impossible to represent the data cartographically.

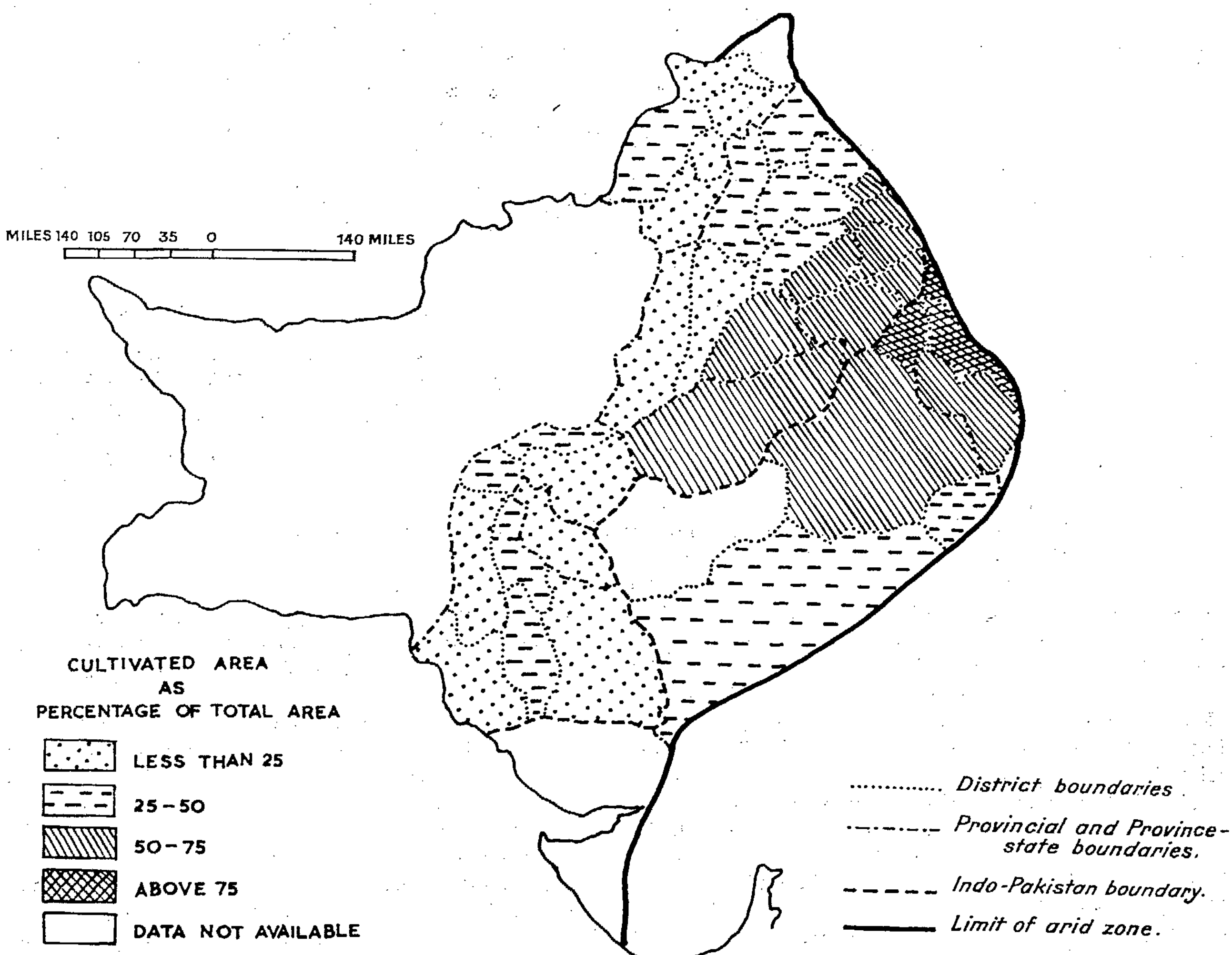



FIG. 9. Arid zone of India and Pakistan. Area under cultivation 1942-1943. (*Indian Agricultural Statistics*, vol. 2.)

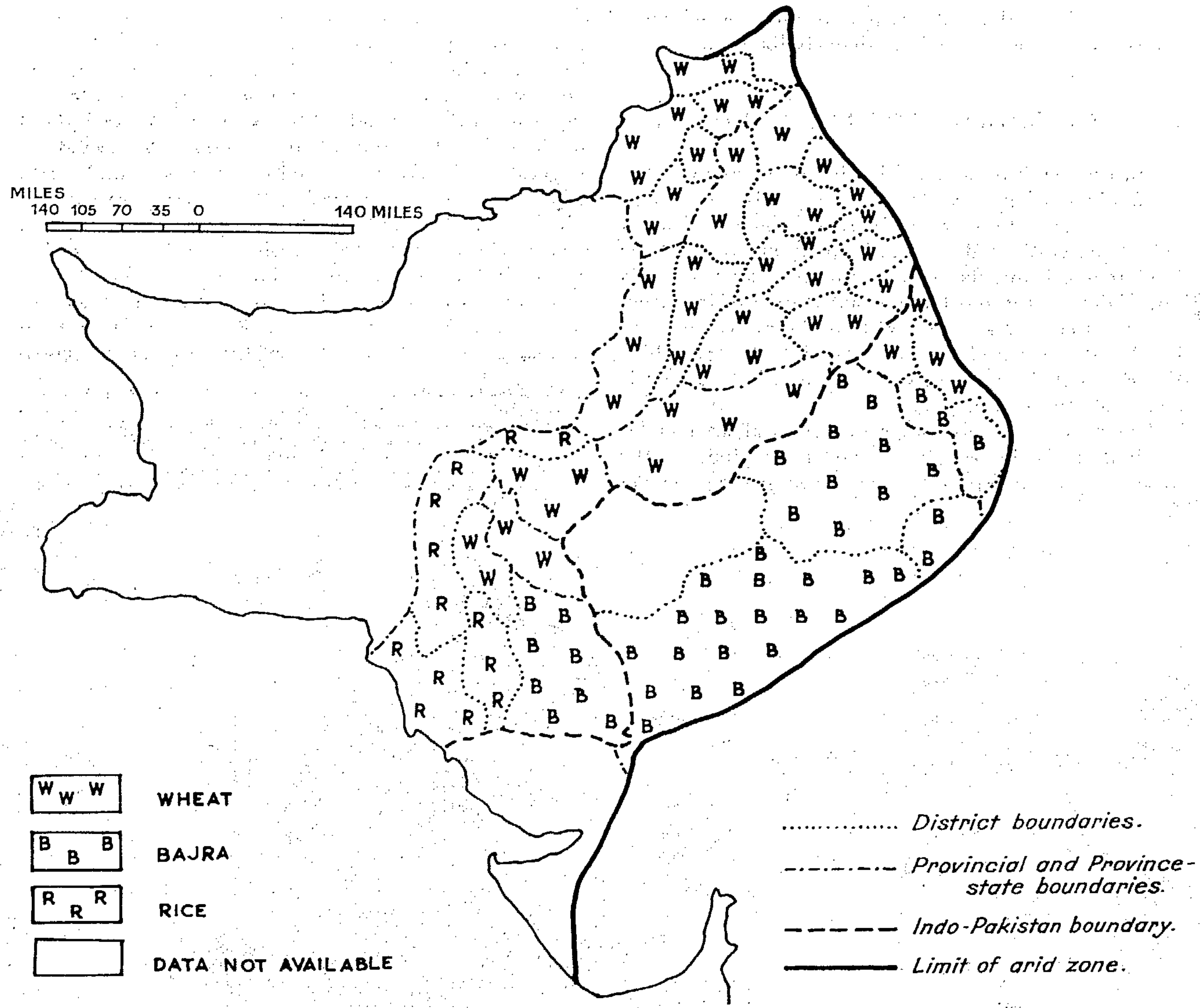



FIG. 10. Arid zone of India and Pakistan. First ranking crops 1942-1943. (*Indian Agricultural Statistics*, vol. 2.)

vated. The main hindrance in the north is the broken nature of the land while in the south scarcity of water is the major handicap. The fertile alluvial plains of Peshawar and Mardan where irrigation is also ample have much more land under cultivation but in the rest of the hilly tract cultivation is restricted.

Sind is the second major region where the percentage of the area cultivated still remains small. In Dadu and Karachi in the west and from Sukkar to Thar Parkar in the east it is less than 25 per cent. Wherever land is irrigated it is cultivated but the rest is almost a sandy desert. The amount of rainfall is so meagre (see Fig. 4) that without irrigation reclamation of the land is impossible. In a long and narrow tract from the Upper Sind Frontier to the southern limit of Hyderabad the cultivated percentage is higher because of the availability of canal water.

In Jodhpur and Jaipur from 25 to 50 per cent of the total area is under the plough. Irrigation facilities are few, and aridity puts a definite limit on the cultivated area. As most of the cultivation is associated with monsoon rainfall a big portion of the land remains under current fallow.

The middle north-eastern side of the arid zone, from Gujrat to Bikaner and from north-western Bahawalpur to the eastern limit of Ferozepur, is the area where the maximum percentage of the total area is cultivated. More than half of the total area is under the plough and in Ferozepur it is more than 75 per cent. This region receives comparatively more rainfall. Moreover the region is plain and the soils are definitely better than those of the rest of the arid zone. But the most important factor is the development of canal irrigation; this alone is responsible for bringing such a large proportion of the land under cultivation in these districts.

Because of the small amount of rainfall and its high degree of variability, the intense evaporation and the limited amount of irrigation developed, the area under double cropping is very small. However the proportion varies from area to area. Only in the south-eastern Punjab (Pakistan) does the proportion of the net sown area which is cropped more than once exceed one-quarter of the whole. The other areas where about one-third of the net sown area is cropped more than once are the small irrigated alluvial plains in the districts of Peshawar, Wazirstan and Mardan.

In the rest of the Punjab and North-West Frontier Province less than 15 per cent of the net area sown is double cropped. In Sind it is less than 10 per cent. As the soils are poor and the irrigation is not extensive most of the area cropped in one season is left as a current fallow in the next so that it may regain its fertility. In Jodhpur State the area under current fallow and the area cultivated is almost equal. The area cropped more than once hardly exceeds 25 per cent of the net area sown in the whole of Rajasthan. After the harvesting of the crop, the stubble left

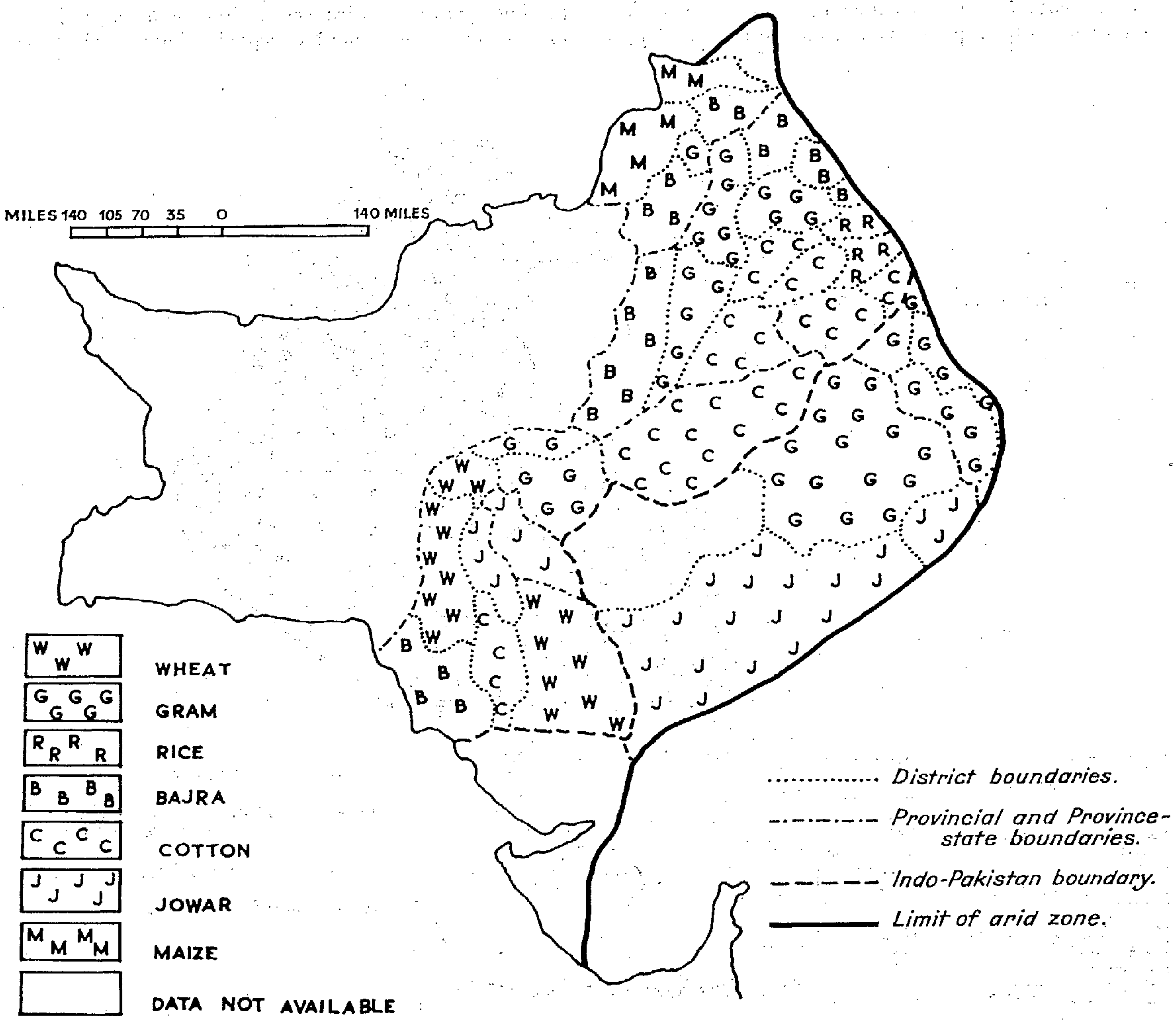



FIG. 11. Arid zone of India and Pakistan. Second ranking crops 1942-1943. (*Indian Agricultural Statistics*, vol. 2.)

in the fields provides grazing facilities for millions of cattle.

MAJOR CROPS

The crop pattern of the arid zone of India and Pakistan is a reflection of the availability of water for irrigation. Crops change from area to area in accordance with the amount of water available. The crops with greater water requirements are cultivated in areas where irrigation facilities are provided; hardier and drought-resistant crops become dominant in areas of meagre irrigation. Thus wheat, cotton, rice and gram are mostly confined to irrigated areas whereas bajra, jowar, barley and 'til' (an oil seed) are the rule in areas of meagre water supply. The cultivation of crops in the area under inquiry, is thus properly adjusted to environmental conditions.

Four distinct crop-combination regions can be discerned in the arid zone of India and Pakistan (Figs. 10-12): Western Rajasthan and adjoining districts, Thar Parkar (Sind) and Hissar (Punjab, India); the region between the Jhelum and the Sutlej; North-West Frontier Province and the adjoining districts of the Punjab; Sind.

*Western Rajasthan and adjoining districts of Thar Parkar (Sind) and Hissar (Punjab, India)*

In this area the winter rainfall is very small compared to summer rainfall, irrigation facilities are meagre, most of the rain comes during the summer. Consequently the Kharif harvest far exceeds the Rabi (spring) harvest. Bajra ranks first in acreage, jowar and gram come second except in Thar Parkar. Til

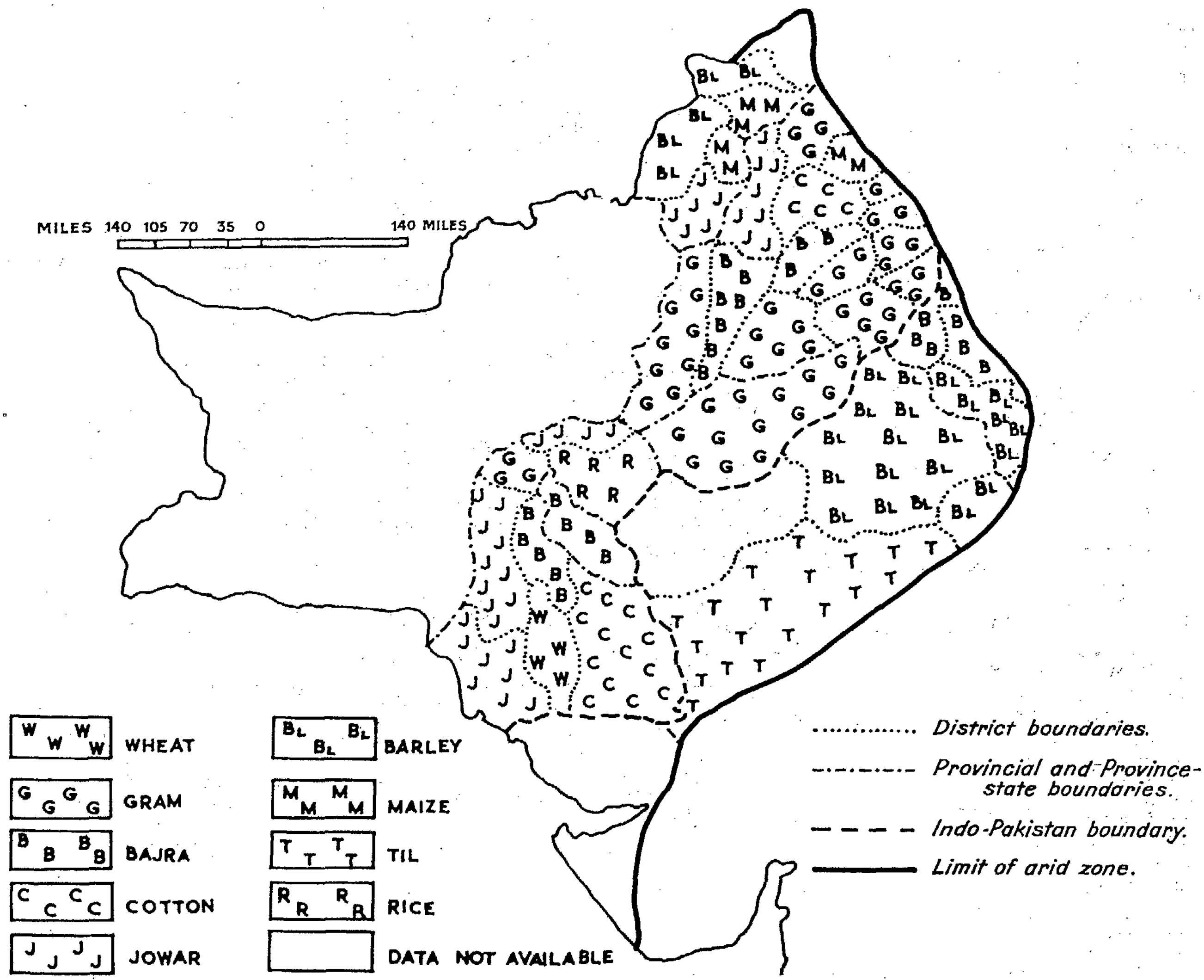



FIG. 12. Arid zone of India and Pakistan. Third ranking crops 1942-1943. (*Indian Agricultural Statistics*, vol. 2.)

and barley are in third position except in Thar Parkar where cotton occupies the third place because of the limited irrigation. The dominant position of bajra in this region is due to the general absence of irrigation, the sandy soils and the precarious rainfall. Nowhere else in the arid zone of India does bajra attain the first rank among crops. Bajra is sown with the advent of the monsoon and is harvested a few weeks after the retreat of the monsoon in autumn.

Jowar is the second ranking crop in Jodhpur and Jaipur while gram occupies that position in Bikaner and Hissar. The acreage of jowar runs side by side with bajra as the physical requirements of both are almost the same. The northern portion of this region receives some rainfall in winter which enables the cultivation of gram. The gram of Bikaner shows that it receives preference over wheat because the inadequate winter rainfall does not satisfy the needs of wheat. For the same reason barley occupies the third position in this area while in Jodhpur til is the third crop. The other important crops of the region, though covering a small acreage, are wheat and pulses. Thus, in this region the crops grown are such as require less water and can do well in sandy soils.

### *The region between the Jhelum and Sutlej*

This is one of the most productive regions of the subcontinent. Here the soils are mainly sandy loams. Monsoon rainfall, though small in amount, is of great help; winter rainfall even smaller in amount is of considerable effectiveness. Above all this the area has excellent irrigation facilities. Rabi and Kharif harvests are of equal importance. Wheat occupies the first place in crops grown in the region (Fig. 10). The crop is sown following the retreat of the monsoon and is harvested in the late spring. This is the most important crop of the irrigated areas and fits well into their agricultural system. Canal irrigation is necessary for sowing but in some years, when the monsoon rainfall in late September is more than the usual, this crop may be sown by just conserving that moisture; such years are, however, infrequent. Due to fertile soils and excellent irrigational facilities yields are high.

Cotton holds the second position (in acreage) among the crops of the region, which is the most important producer of American varieties of cotton in the subcontinent of India and Pakistan. Soils are excellently suited, water requirements are met by canal irrigation and the hot and dry climate is a further asset. Cotton is now a major source of income in the canal colonies of West Pakistan. Gram is the third most important crop of the region (Fig. 12). Next to wheat this is the major Rabi crop. The advantage of this crop is twofold: in addition to supplying seeds used like grain for human and cattle consumption this crop helps in maintaining the fertility of the soil. Generally it is sown in rotation with cotton and wheat. Gram does well even in inferior soils and without irrigation. Rice, barley, sugarcane, maize and pulses are the other important crops which contribute, though to a lesser degree, to the economy of this region.

### *North-West Frontier Province and adjoining parts*

In this region winter rainfall is relatively greater than in the regions discussed above. However, irrigation facilities and soil conditions are poor. Wheat remains the foremost crop. In the extreme north and north-west maize occupies the second place. In submontane districts, where summer rainfall is considerable, most of this crop is grown without irrigation. But in Peshawar and Wazirstan and the adjoining districts it is grown with the help of irrigation. In Muzaffargarh and Mianwali gram is the second crop and in a long tract from Dehra Gazi Khan to Jhelum through Dera Ismail Khan, Bannu, Kohat and Attock, bajra ranks second to wheat. The amount of rainfall here is small; irrigation facilities are restricted; the soils are sandy in the south and stony in the north. Under these conditions bajra and gram are more successful crops than wheat. In the Potwar and in Bannu and Kohat districts maize occupies the third place. In the Punjab areas maize is grown without irrigation while in the other two districts it is an irrigated crop and is grown in the narrow alluvial plains with the help of irrigation.

### *Sind*

Canal irrigation has played a very vital role in the agriculture of Sind. Here the summer monsoon rainfall is too limited for Kharif crops. The cultivation of Rabi crops is also impossible with winter rainfall alone. Almost all of the cultivated area is under irrigation. In western and southern Sind rice is the major crop and is closely followed by wheat in the north and bajra in the south. In Sukkar and Nwabshah wheat occupies first place (Fig. 10) and rice ranks at third place. The conditions in Thar Parkar are like those at Jodhpur so that bajra comes at the top but, instead of jowar, wheat is the second crop followed by cotton. In a few other parts of Sind cotton is also grown but its relative importance is not as great as in the Punjab.

## DOMESTICATION OF ANIMALS

The hearths of many of the domesticated herd-animals and of seed agriculture are in the same general area of south-west Asia extending to the Indus Valley. It is believed that in this area the domestication of herd-animals followed sedentary agriculture and not hunting.

It is from the study of excavations at Rana Ghundai, Harappa and Mohinjo Daro that we can reconstruct the importance of herd-animals in the Indus Valley civilization. At Rana Ghundai for example, were excavated the remains of domestic goat, ass, sheep and horse. At Harappa the remains of zebu, buffalo, sheep, elephant and camel have been unearthed. The remains of the humped Indian bull indicate that during the Chalcolithic period the Indus Valley had a fine breed of animal stock resembling that of Rajasthan, Sind and northern Gujarat.

The goat was probably the earliest domesticated animal. The origin of the goat may be placed in the cis-Indus country on the high mountains adjoining the ancient agricultural valleys. Sheep also probably had their original home in the arid zone of India. The *Ovis vigni* now living in the area from the Salt Range of the Punjab to Baluchistan is the descendant of the ancient sheep. The representation of cattle on terracotta figures at Mohinjo Daro and Harappa also points to the conclusion that domestication of cattle had taken place long before the Indus Valley civilization had developed. It is doubtful whether the Indus Valley civilization could have attained such grandeur without the domestication of herd-animals, particularly cattle for drought purposes. As with the goat, so with the buffalo and humped ox, they were found in wild form on the hills immediately adjoining the agricultural valleys and seem to have been domesticated from there by the agricultural people. The camel which today is a useful and widespread animal in the arid zone of India had definitely been domesticated long before and used by Harappa people [23].

While there is general agreement that domestication of herd animals came after the establishment of sedentary agriculture, there is still a controversy as to why at all the ancient agricultural people developed herding. It is probable that the growth of population in the Indus Valley may have given the incentive to the people to engage in activities other than agriculture. Close to the river valleys the slightly higher bars were available—with meagre possibilities for sedentary agriculture, owing to the lack of irrigational facilities, but with vast areas for grazing, which consequently became a dominant occupation. Even today herding remains of importance in the 'bars' despite the introduction of recent irrigational facilities and the consequent development of agriculture.

In Baluchistan where the agricultural valleys were few and isolated, herding may have originally developed as a supplement to crop farming. But once the herding of sheep and goats did start, it resulted in the overgrazing of the scanty vegetation cover exposing the soil to the occasional but heavy downpours characteristic of the arid areas. This must have resulted in large-scale soil erosion in the valleys. No longer able to graze the herds close to the valleys, persistent search for summer pastures resulted in what today is a well-developed transhumance. In fact no hard and fast line can be drawn between agriculturist and pastoralist in Baluchistan. During winter the people move into Sind with their families and flocks to escape the winter cold while in summer there is a move towards the higher mountainous parts in search of pastures and into valleys for practising agriculture. The present importance of pastoral nomadism may be judged easily from the fact that in Baluchistan over 80 per cent of the stock consists of goats and fat-tailed sheep.

## PRESENT DISTRIBUTION OF HERD ANIMALS

Two regions are most important for cattle, where the density is more than 30 per hundred acres. One is the Jodhpur State area and the other comprises Lahore, Lyallpur, Montgomery, Shekupura and Gujranwala. In the Jodhpur area the cattle are of superior quality. Most of them are grazed on current fallows where the grasses are rich in salt content and there is no leaching of the soil in this area. Both milch and draught cattle are important—cows and bullocks are much more important than buffaloes. This area supplies not only bullocks for draught purposes in the local areas but also much of the superior young stock which is sent to the other parts of the country.

In the Punjab region most of the cattle are stall-fed and fodder crops are grown on an extensive scale. In this region cattle and buffaloes are of equal importance; both bullocks and male buffaloes are used for drawing the ploughs.

In the rest of the region the density of cattle is not more than 20 per hundred acres. The main cause of this decrease in density in comparison with that in the Punjab is that here the cultivated area is already small and it cannot be given over to fodder crops in preference to food crops. On the other hand the climate and the soils in most parts are such that grass does not flourish on which cattle may be reared on any extensive scale.

In the arid zone sheep grazing is mainly for wool for which Rajasthan is the most important area. In Bikaner and Jodhpur there are more than 20 sheep per hundred acres. Most of the sheep are kept by the non-cultivators and are reared on waste land and occasionally on current fallow. There are 10-20 sheep per hundred acres in the area from Bahawalpur to Shahpur and due east. In the whole of the western tract from lower Sind to the North-West Frontier Province the number of sheep per hundred acres is less than 10. The grasses are very poor and a larger area is required to support even a small number of sheep. Moreover, as the sheep are owned by nomads and people who are landless, all the stock depends upon grazing the waste land. The quality of the grasses in these areas is very poor and therefore the resulting flock of sheep is of poor quality and so is their wool.

Goats are found everywhere in the arid zone and are used both for their meat and milk; however, they are not so important as cattle or sheep. Rajasthan has the largest number of goats. Like the sheep, the goats are also kept by the non-agriculturists. The goat is the only source of milk in this area. In addition, the nomads sell the young stock of goats as the people prefer goat's meat to mutton. Camels are found throughout the desert, mainly for draught purposes.

The arid zone of India thus seems to be a very significant area for the original domestication of herd animals. These animals have continued to be part and parcel of the arid zone agriculture from ancient times to the present day.

## PROBLEMS OF SOIL EROSION AND SOIL CONSERVATION

In the arid zone of India and Pakistan, as in many other similar areas of the world, the wind works as a powerful agent for erosion. Its action in the subcontinent is twofold. At a velocity of over twenty miles an hour during May and a somewhat similar velocity during the whole of the monsoon season the wind is active both in removing and transporting relatively fertile arable soils and in depositing coarser sandier soils over arable lands. The problem is thus clearly twofold also: to save the topsoil of arable land from erosion, and to prevent the deposition of an agriculturally useless sandy cover. In each case the problem of wind erosion is of great concern. The seriousness of wind action is increased by the fact that a large part of the arid zone is comparatively flat land where the wind carries on its dismal campaign with few obstacles. Most of the irregularities of this vast area are the work of the wind itself. However man, by disturbing the ecological balance in favour of his immediate economic motives, cannot be absolved from the responsibility of collaborating with the wind in destroying his own fertile tracts. Trampling and over-grazing of the sparse vegetative cover by a comparatively larger number of animals—particularly sheep and goats—has resulted in making the already barely coherent soil susceptible to wind action. Erosion is not *per se* a bad phenomenon; it is when we remove the natural cover of soil without providing a substantial equivalent that the problem arises. This is what has happened in our arid zone. While it is true that the disintegration of the rocks proceeds at a fairly rapid rate, we do not get soil, but simply disintegrated rock material, from which soil can only be formed later. The low, erratic rainfall, high mineral and low humus content of the upper surface are inimical to the development of a good soil cover. And even this somewhat poor soil is constantly in danger of being overwhelmed by wind action. The dominant action of wind should not be overstressed, however, for water remains of importance as an agent of erosion in the hilly and uplifted areas of the arid region particularly in the Potwar and Baluchistan. In the Potwar there is an extensive development of badland topography. In the Jhelum district alone over 65,000 acres have been lost by erosion during the last 30 years.

The domestication of herd animals and the development of pastoral-nomadism started in the arid zone of the subcontinent during ancient times. The latter practice continues to gain more and more importance. In most herding tribes the possession of a large number of animals has come to be accepted as a criterion of wealth. This naturally led, even in the past, to competition, which in turn meant a larger number of animals being recklessly grazed on the land, seriously disturbing the delicate balance between soil and wind. Large-scale soil-drifting has therefore resulted. In the hilly areas overgrazing has resulted in gullying and soil wash. In the arid zone the number of herd animals demands that a large area be devoted to fodder crops, but it is precisely here that good land, even for food crops, is limited. Therefore the success of food crops is delicately balanced upon the knife's edge. Selective grazing by animals has resulted in an overstrain on the favoured or more nutritious species of plants which fail to survive or to establish themselves again. The sharp edges of the hoofs of the omnivorous goat and sheep and their ability to reach even very steep slopes for grazing has created the problem of erosion where it is most difficult to combat. One good year may tempt the herdsman to keep a large flock despite the many bad years—if only in the hope of further good years which are only too few in these areas of high variability of rainfall. There is no doubt that overgrazing has eliminated itself in many areas but not before long-term damage had occurred to the soil.

### SOIL CONSERVATION

Man, in an attempt to scratch a living in the arid and semi-arid areas of India has, through trial and error, evolved such techniques of farming as have maintained the fertility of the soil and have given him fairly satisfactory yields—satisfactory only in view of the harshness of the environmental conditions. Some of these techniques can be further improved but in the case of others little improvement is possible.

Dry farming is a system of conserving soil moisture, of preventing soil erosion and of crop management in regions of low and uncertain rainfall. Within the arid zone under inquiry dry-farming practices vary in accordance with the amount and temporal distribution of precipitation. In western Rajasthan and south-eastern Punjab (India), the farmer through his long experience of centuries has developed certain techniques which are excellently suited to conserve soil moisture and fertility for dry farming. The practice of preparatory tillage is widely carried out. The farmer ploughs the fields before the advent of the monsoons and thus opens the hardened crust of the soil to absorb a maximum amount of rainwater; the indigenous wooden plough is probably the best suited for preparatory tillage. To conserve the soil moisture absorbed from monsoon rains, the farmer in south-eastern Punjab repeatedly ploughs fields to creat soil mulch which checks evaporation through capillary action. Almost all the crops are sown mixed—particularly kharif. Legumes are sown mixed with bajra or jowar. This is probably the best system of utilization of soil moisture and it maintains soil fertility. The roots of the legumes have nitrogen-fixing bacteria and also they are long and get the moisture from the lower layers. On the other hand bajra and jowar have short roots which make use of the moisture in the uppermost layer of the soil. Thus there is little competition for moisture among the mixed crops. Some leguminous crops spread over the ground (mong, moth) and check soil erosion. In areas along the foothills of the Aravallis—particularly in Gurgaon and Ajmer—there is a unique system of conserving monsoon rainwater, especially for rabi crops. Dams are constructed at the foot of hills to impound the water of local torrents. These dams have multifarious advantages : they provide water for cultivation, check soil erosion and raise the spring level of adjoining areas thereby making well irrigation possible.

In addition to these existing practices, contour-bunding of fields, contour cultivation, superior varieties of crops and manuring should be introduced. There is a need for a detailed soil survey to assist in the scientific assessment of local requirements for soil conservation—a close relation exists between the nature of the soil and the techniques for its conservation. In addition, techniques of soil conservation should be devised taking into consideration the economic conditions of the peasants. Costlier techniques, however useful they may be, would not be employed by the peasant if they are not within his means.

### *Contour bunding*

Although the plains of the arid zone under inquiry are level on the whole, there are local irregularities of the surface. The local uneven configuration of the fields does not allow of uniform absorption of rainwater and moreover it causes immediate run-off of water and soil erosion. Contour bunding and levelling of fields are essential remedial measures. Fortunately the thickness of the soil and subsoil is considerable so that quantities of water can be stored safely for future use of crops. The dimensions of the bunds depend upon the intensity and amount of rainfall, the nature of the soil and the slope of the land and therefore should be devised according to local requirements. To maintain the fertility of soil, proper crop-rotation and fallowing are necessary. It has been observed that it is possible to carry over a large part of the subsoil moisture conserved in fallow fields from one year to another. In the years of scanty rainfall the conserved subsoil moisture of the fallow field is of considerable importance. But it should be stressed that this practice is suited only in those soils which have storage capacity.

The sowing should be done with drills in properly spaced rows. Organic and green manuring may also prove advantageous.

Until now no scientific evaluation of the soil conservation problem has been made in this vast area. Agricultural research stations are needed to investigate the problems of soil conservation.

## WATERLOGGING

Canal irrigation, although vitally important in arid areas, is not without its adverse effects. It has led to the serious problem of waterlogging. The barren, arid areas of India and Pakistan which were made productive by canal irrigation, are now being damaged by waterlogging and also by the formation of alkaline and saline soils. In pre-partition Punjab, in the year 1942-1943, more than 700,000 acres of land were rendered useless in this way (see Fig. 13).

In the Punjab the problem of waterlogging was first realized as serious in 1915 but it was not until 1926 that any scientific probe into the problem was made. Since then measures have been applied to prevent fertile land from becoming waterlogged. Reclamation of waterlogged areas has also been carried out on a large scale.

Prior to the introduction of canal irrigation, seepage of water in large quantities was mainly restricted to the areas along the rivers. In the Doabs the water table was very deep. The construction of canals in the *dhaia*[1] areas of the Doabs increased the percolation of water and thus raised the water table. Due to the rise of the water table, the areas along the canals became waterlogged first. It has been noticed that in arid areas a very large proportion

1. *Dhaia* (Punjabi)—an upland area away from the floodplain of the rivers.

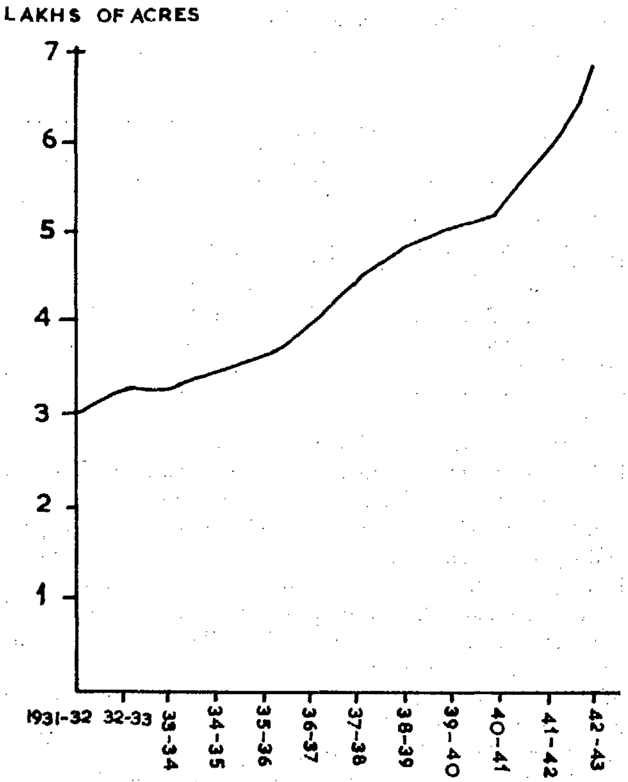



FIG. 13. Total area damaged by salt accumulation (thur) in pre-partition Punjab.

of the increase in the volume of groundwater can be attributed to the percolation of canal and river water. The groundwater will rise up to a point where equilibrium is established between surface percolation and disposal of groundwater. Here it must be stressed that the sub-alluvial ridges in the Indus Valley act as barriers to the flow of underground water, consequently the water table has a tendency to rise. Gravity surveys in the Punjab have indicated the shallowness of the alluvium in the plains. Under these circumstances the rise of the water table is bound to be rapid in canal irrigated areas.

In the submontane districts of the Punjab, where subhumid conditions prevail, excessive rainfall in recent years has also caused waterlogging. Moreover the construction of roads, railways and canals has obstructed the natural flow of the watercourses and this has aggravated the situation. But in the arid areas of India and Pakistan, rainfall, even in abnormal years, is not sufficient to cause waterlogging. The insignificant slope, the shallowness of the alluvium, the existence of underground impervious ridges and a dense network of rivers and canals—which are the source of percolating water—are significant causal factors in the waterlogging of arid areas in India and Pakistan.

Prior to the introduction of canal irrigation the soil profiles in the Punjab showed complete salinization of the soil. There was an upward movement of the salts in the soil in the dry season and a downward movement in the wet season. This eliminated the accumulation of salts in any well-marked horizon. Introduction of canal irrigation resulted in the formation of a zone of accumulated salts in the soil. In the areas where subsoil water rises to the capillary zone, salts dissolved in the subsoil water are brought to the surface and due to evaporation a fine crust of sodium salts is formed at the soil surface. Soils thus affected have gone out of cultivation. In the areas where groundwater has risen to within 6 ft. of the surface the problem of waterlogging is very acute, and these are the areas where rapid deterioration of cultivated land is taking place.

Waterlogged areas have shown a constant rise in the Punjab since the introduction of canal irrigation. A graph prepared for the years 1931-1943 clearly depicts the trend of increase in areas damaged by waterlogging (Fig. 13). As more water is added through percolation to the groundwater, the water table rises and in those peripheral areas where the water table is near the critical limit the menace of waterlogging spreads. Thus valuable cultivated land is deteriorating at an increasingly high rate.

The general flow of groundwater in the Punjab is from north-east to south-west along the river valleys. The impervious sub-alluvial ridge which runs from Delhi to Shahpur checks the flow of groundwater and thus accentuates the problem of waterlogging. The water table is quite close to the ground surface in the districts north-east of the sub-alluvial ridge and these are the districts most badly affected by waterlogging. To the south-west of the sub-alluvial ridge the water table is deep. Consequently to the north-east of the Delhi-Shahpur ridge there is a zone of surplus groundwater and to the south-west of it is a scarcity zone.

Similarly, in Sind, in the western Indus Valley the problem of waterlogging is probably accentuated by a sub-alluvial ridge. The western Indus Valley, which is underlain by the Kohistan-Sukkur-Suleman underground warp, is the only acutely waterlogged part of Sind.

Analysis of the data on the waterlogged districts of the Punjab clearly indicates that in the districts of Shekhupura, Gujranwala and Shahpur the problem is acute. There were nearly 500,000 acres of land under thur and sem[1] in 1943. Soon after the introduction of canal irrigation in these districts water appeared at the surface along the canals and low-lying areas were turned into swamps. The obvious explanation for such acute and rapid waterlogging, in these districts, is that the alluvium

1. The alkaline and saline soils are called *thur* and the waterlogged areas are called *sem* in the Punjab.

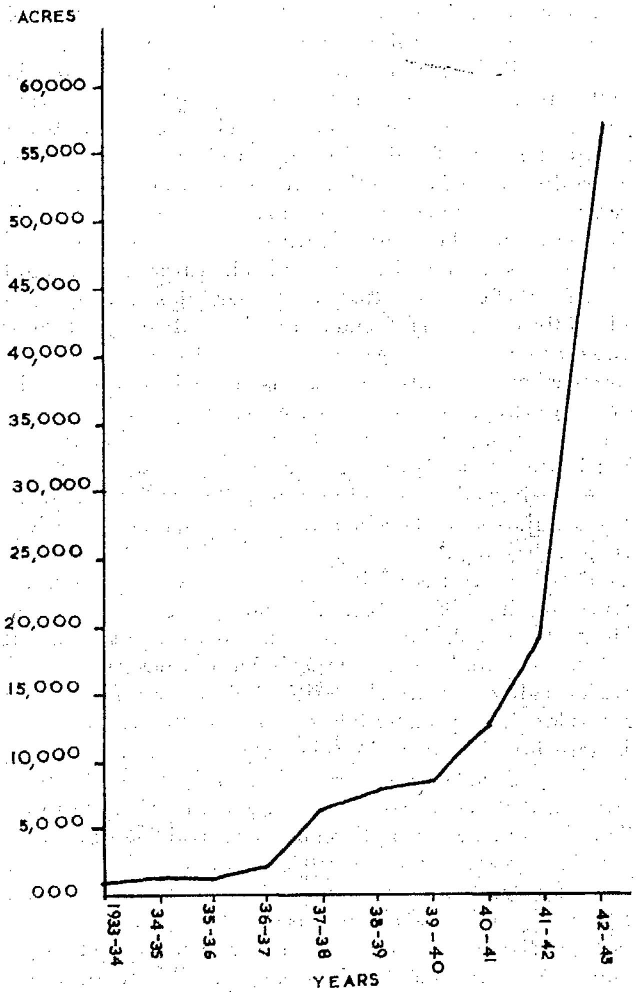



FIG. 14. The rate of increase of salt accumulation (thur) in Montgomery.

is shallow and these districts lie north-east of the Delhi-Shahpur sub-alluvial ridge. The districts of Shekhupura, Shahpur and Gujranwala showed an alarming rise in the area under thur for the years 1931-1943, the absolute increases for these years being 132,000, 20,000 and 40,000 acres respectively.

In the districts of Montgomery, Lyallpur and Multan (West Pakistan), Ferozepur and Bhatinda (Punjab, India) the problem of waterlogging is not quite so acute, although nearly 100,000 acres were under thur and sem in 1943. These districts lie to the south-west of the Delhi-Shahpur sub-alluvial ridge. Nevertheless in the years 1931-1943, the waterlogged areas increased by 35,000 acres in Lyallpur and by 58,000 acres in Montgomery (Fig. 14).

In passing, it needs be made clear that the problem of waterlogging is not entirely due to the presence of sub-alluvial ridges but they seem to have accentuated the problem considerably.

TABLE 2. Total area damaged by thur and sem in some of the main canal irrigation tracts, 1942-1943. (From: Proceedings of thirty-second meeting of the Waterlogging Board, Punjab, Lahore, 1944.)

| | Acreage under thur | Acreage under sem |
|---|---|---|
| Lower Jhelum Canal | 33 948 | 5 214 |
| Upper Jhelum Canal | 9 916 | 4 293 |
| Lower Bari Doab Canal (except Lahore) | 43 567 | — |
| Lower Chenab Canal | 228 039 | 5 100 |
| Upper Chenab Canal | 208 339 | 2 840 |
| Haveli Canals | 24 263 | — |

Waterlogged and saline acreage of some major canal irrigated tracts of the region are shown in Table 2.

Several remedial measures have been adopted to combat waterlogging and to reclaim waterlogged and saline infected areas. Where waterlogging is severe—as in Gujranwala and Shekhupura districts—drains have been constructed. In certain cases tube wells and percolation wells have been installed to pump out the subsoil water. In waterlogged areas the cultivation of rice has also been introduced since it acts as an agent for decomposing the sodium clay and checks the formation of thur soil. Gypsum has also been applied to thur affected areas; it introduces sufficient calcium ions in the soils to prevent the base exchange reaction between sodium salts and calcium clay. Some have suggested that the sub-alluvial ridge be cut at suitable sites to allow the passage of underground water. This would eventually lower the water table in the districts lying north-east of the ridge. There is need of a gravity survey to determine the site for puncturing or cutting the ridge. What looks simple and feasible at first sight would not be without many complicated and intricate problems. The whole of the system of the flow and speed of the underground water would undergo a great change if the work of cutting the ridge is made possible. The change in the rate of the flow of underground water might lead to subsidence of certain areas on a large scale. This might damage some of the urban and rural settlements.

There is a need of intensive study of the problem, to devise suitable methods for balanced, judicious and controlled application of canal water, and for protecting the valuable land from the ravages of waterlogging. In 1952 C. R. Maierhofer, of the United States Bureau of Reclamation, visited West Pakistan and reported to his Commissioner on 3 October 1952. He found the evidence conflicting and recommended the selection of one doab for intensive study. The land use and reconnaissance survey by means of aerial photographs carried out for the Pakistan Government in 1954-55 showed clearly the extent of the damaged lands.

## CONCLUSIONS AND SUGGESTIONS

The arid zone of India and Pakistan is a very fascinating area for scientific investigation regarding what it has been in the remote past and what it is becoming in the present period. Great changes of climate and culture have taken place in the arid regions, and the dry zone of the Indian subcontinent is no exception.

Recently it has been contended by many geologists that the last phase of the change from humid to the dry climate in the north-western section of the Indian subcontinent took place with the final retreat of the ice to the north. The advance of the ice is rightly supposed to have spread moist conditions to all the adjoining areas and that with the retreat of the ice moist conditions disappeared and aridity stepped in instead. It is interesting to note that according to many authors the northern limit of the present dry region coincides with the southernmost limit of glaciation thus indicating a relation between the two.

The changes during prehistoric and historic times have been equally vital and noteworthy. The river terraces in Potwar in this dry zone first became the home of man in this part of the world. Man changed over from food-gathering to food-production during the early prehistoric times and gradually made further advances and improvements in the agricultural land use and in the techniques of farming. It must be noted that agriculture was entirely confined to the river valleys, whilst the upland plains (or the 'bars') were the scene of a nomadic herding economy during this period. It is the advance of irrigation agriculture along the valleys which led to surplus production which in turn became the basis of an urban civilization. The ruins of cities, the remains of irrigation and the drainage works, and the pattern of houses, as revealed by recent excavations, all point to the development of an advanced civilization in this region. The society was matriarchal. The destruction of such an advanced urban yet agricultural civilization represents one of the most serious turning points in the history of this region. The forces which laid the civilization in ruins are far from clear and are the subject of much controversy. Some believe that the axe of destruction was brought by climatic changes, whereas others attribute the disaster to changes in the courses of rivers which were the life-blood of the people. Still others think that the ruination of the entire civilization was brought about by the invaders from central Asia and the west. The invading tribes introduced new values of life, changed social and cultural traditions and changed the very sources of livelihood. Thus the Aryans, after their arrival in this region, gave stimulus to pastoralism and introduced a patriarchal society.

During the British rule the development of canal irrigation brought a very significant turning point in the life of a large part of the area. The very 'bars' which were the scene of nomadic herding and supported only a sparse population became the granary of the subcontinent and the home of prosperous farmers. So vital is water to the farmer that in the driest parts irrigated land along the river is the only cultivated land and there is a sharp knife-edge boundary between the irrigated and the unirrigated and thus uncultivated barren land.

Apart from water, another serious problem facing large parts of this region is that of wind erosion. Because of the consistency and the strong nature of the south-west monsoon winds, a large amount of fine soil from the cultivated fields is being removed every year causing a scarcely perceptible but nevertheless enormous loss. Also every year these winds are drifting tremendous amounts of coarse sand which is deposited over fertile fields rendering them useless. This problem has become alarming in recent decades.

In the light of the difficulties and problems experienced by man at different points in time in this region a few suggestions are warranted. The most important of all is the extension of irrigation. Not only does the extension of irrigation help in bringing new areas under the plough but, by supporting plants and crops, the soil is saved from the menace of wind erosion. Plans are already under way to reclaim many parts of Rajasthan by introducing irrigation into them. What a great miracle can be worked by irrigation is to be seen in the Ferozepur, Hissar and Bikaner districts in India and the 'bars' in west Pakistan.

Wind erosion should be checked by setting up windbreaks, planting and maintaining more trees and shrubs, contour ploughing and contour bunding.

To make better use of the marginal areas of the dry zone, experimental farms should be set up where new and better techniques of dry farming may be evolved and demonstrated to the farmers of the local areas. In the spread of such scientific knowledge the agricultural extension service department can lend great help. On such farms research may be carried out not only on evolving new techniques but also on new crops for which the conditions may be suitable in such areas. This seems to be a very fertile area of research.

Apart from the research on the agronomic problems at the experimental farms, there is a dire need for the universities to start research into the socio-economic problems of these dry areas. Each university may specialize in a particular area and co-ordinate with other universities where work on other aspects is done. Co-ordination between the various fields of study is very essential to get an integrated picture of the problems and remedies. Scholars should be encouraged to do extensive field work and to collect first-hand information which otherwise is so much lacking.

If close attention is given to this vast area suffering from dry conditions, and efforts are made to overcome the barriers, there are certainly possibilities of a much better utilization of the land.

ACKNOWLEDGEMENTS

The author acknowledges with appreciation the help rendered by Dr. Gurdev Singh Gosal, M.A., Ph.D. (Wisconsin), Shri Jai Pal Singh and Shri Harpal Singh, Reader and Research Scholars respectively in the Department of Geography, Punjab University, Government College, Ludhiana and Shri Surrinder Mohan Bharadwaj of Government College, Malerkotla, Punjab, by offering valuable suggestions and reading the manuscript. The author also acknowledges with grateful appreciation the encouragement given to him by the Director of Public Instruction, Punjab, by permitting him to undertake this work. Last but not the least the author would like to thank Shri J. R. Taneja, Assistant Librarian, Seminar Library, and Shri O. P. Sarna, Cartographer of the Department of Geography, Punjab University for sparing time to type the manuscript and giving suggestions for drawing the illustrations respectively.

# BIBLIOGRAPHY

1. AMMAL, E. K. Janaki. Introduction to the subsistance economy of India. In: W. I. Thomas (ed.) *Man's role in changing the face of the earth.* Chicago, University of Chicago Press, 1956. p. 324-335.
2. AUDEN, J. B. Introductory report on the ground water resources of western Rajasthan. *Engineering Geology and Ground Water Section, Geological Survey of India.* Series B, no. 1, 1950.
3. BADEN-POWELL, B. H. *Land systems of British India.* Oxford, University Press. 3 vols.
4. BASU, S. Modern ideas on Indian monsoon. *Bulletin of the Association of Indian Geographers*, no. 1, 1956. p. 2-8.
5. BHATIA, S. S. Arid zone of India and Pakistan : A study in its water balance and delimitation. *Indian Journal of Meteorology and Geophysics*, vol. 8, no. 2, 1957. p. 355.
6. DASS, Santosh Kumar. *The economic history of ancient India.* Howrah, 1925.
7. DE TERRA, H.; PATERSON, T. T. *Studies on the Ice Age in India and associated human culture.* Washington, Carnegie Institute, 1939.
8. FOSTER, E. E. *Rainfall and run-off.* New York, Macmillan, 1948.
9. GHOSAL, U. N. *The agrarian system in ancient India.* Calcutta, University of Calcutta Press, 1930.
10. GHOSH, P. K. Western Rajputana—its tectonics and minerals including evaporite. *Proceedings of the Symposium on the Rajputana Desert.* New Delhi, National Institute of Sciences of India, 1952. Vol. 1, p. 131-136.
11. KHAN, M. N. Climate of Sind. *Pakistan Geographical Review*, vol. 9, no. 1, 1954. p. 1-10.
12. KRISHNAMURTY, K. V. Creep of the desert. *Proceedings of the Symposium on the Rajputana Desert.* New Delhi, National Institute of Sciences of India, 1952. Vol. 1. p. 131.
13. KRISHNAN, M. S. *Geology of India and Burma.* Madras, The Madras Law Journal Office, 1949.
14. ——. Geological history of Rajasthan and its relation to present day conditions. *Proceedings of the Symposium on the Rajputana Desert.* New Delhi, National Institute of Sciences of India, 1952. Vol. 1. p. 19-31.
15. LEIGHLEY, J. B. Dry climates : their nature and distribution. *Desert Research. Proceedings International Symposium held in Jerusalem, May 1952.* Jerusalem, Research Council of Israel, 1953. p. 3-18. (*Special publication* no. 2.)
16. MAJUMBAR, D. N. *The matrix of Indian culture.* Lucknow, Universal Publishers, 1947.
17. MARSHALL, Sir John (ed.). *Mohenjo-Daro and the Indus civilization.* London, Arthur Probsthain, 1931. 3 vols.
18. MEDLICOTT, H. B. *Sketch of the geology of the Punjab.* Calcutta, The Calcutta Central Press, 1888.
19. PASCOE, H. *Manual of the geology of India and Burma.* Calcutta, Government of India Press, 1950. Vol. 1.
20. PEAKE, H. J. E. The first cultivation of wheat. *Man*, 36, vol. 39, 1939.
21. PIGGOT, S. *Prehistoric India.* Harmondsworth, Penguin Books Ltd., 1950.
22. PRAMANIK, S. K.; HARI HARAN. The climate of Rajasthan. *Proceedings of the Symposium on the Rajputana Desert.* New Delhi, National Institute of Sciences of India, 1952. Vol. 1. p. 19-31.
23. PRASHAD, B. *Animal remains from Harappa.* New Delhi, Government of India Press, 1936.
24. RAPSON, E. J. (ed.). *The Cambridge history of India. I: Ancient India.* New Delhi, S. Chand. (First Indian reprint 1955.)
25. ROSS, E. J. A Chalcolithic site in northern Baluchistan. *Journal of Near Eastern Studies*, vol. 5, 1946. p. 284-316.
26. RUSSEL, R. J. Climatic changes through the ages. In : *Climate and man.* Washington, D.C., United States Department of Agriculture, 1941. p. 67-97. *(Yearbook of Agriculture.)*
27. SAUER, Carl O. *Agricultural origins and dispersals.* New York, The American Geographical Society, 1952.
28. SPATE, O. H. K. *India and Pakistan: A general and regional geography.* 2nd edition, London, Methuen, 1957.
29. THORNTHWAITE, C. W. An approach towards a rational classification of climate. *Geogr. Rev.*, vol. 38, no. 1, 1948. p. 55-94.
30. WADIA, D. N. *Geology of India.* 3rd. edition, London, Macmillan, 1953.
31. WHEELER, Sir Mortimer. *The Indus civilization.* Cambridge, University Press, 1953. 98 p. *(The Cambridge history of India, supplementary volumes.)*
32. WISSMANN, H. VON, *et al.* On the role of nature and man in changing the face of the dry belt of Asia. In : W. I. Thomas (ed.) *Man's role in changing the face of the earth.* Chicago, University Press, 1956. p. 278-303.
33. WITTFOGEL, Karl A. The hydraulic civilizations. In : W. I. Thomas (ed.) *Man's role in changing the face of the earth.* Chicago, University Press, 1956. p. 152-164.
34. ZEUNER, F. E. *Stone Age and Pleistocene chronology in Gujurat.* Poona, 1950.

# LAND USE DEVELOPMENT IN THE ARID REGIONS OF THE RUSSIAN PLAIN, THE CAUCASUS AND CENTRAL ASIA

*by*

V. A. Kovda

*Corresponding Member of the USSR Academy of Sciences,*
*Professor of Moscow University*

## PECULIARITIES OF THE NATURE OF THE ARID ZONE OF EURASIA

Europe and Asia constitute the largest continent on our planet, with an area of 51.6 million square kilometres. Eurasia and Africa together form, as it were, a single giant land mass in the Eastern Hemisphere, with comparatively small inland seas—the Mediterranean, Black Sea, Caspian Sea and Aral Sea. The continental character and dryness of the climate on the mainland is more marked the greater the area and the farther away from the shores of seas, where the influence of the ocean is least apparent. Europe, Asia and Africa constitute about 60 per cent of the whole of the dry land on the earth's surface. The central parts of Africa and Asia are hundreds and thousands of miles away from the shores of the Arctic, the Atlantic, the Pacific and the Indian Oceans.

The moisture circulating in the air over Africa and Eurasia, coming from the ocean, falls in the form of abundant atmospheric precipitations in the temperate maritime zones. Inland, the atmospheric precipitations progressively decrease. The damp forests along the ocean borders give place to forest steppes and steppe lands. In those parts of Eurasia farthest away from the ocean, along the horizontal axis of the continent (latitudes 50°-20°) lie the arid zone plains, with a total annual rainfall of between nil and 400 mm. South-westwards from Eurasia, this zone continues across Arabia and the whole of North Africa. The ultra-arid deserts of Central Asia, the semi-deserts and steppes of north-west China, Mongolia, Kazakhstan, Uzbekistan, Turkmenistan and Azerbaijan, the Volga region and the Black Sea area constitute the main and the greater part of this belt. To the south and west, the Afro-Asian desert and steppe belt extends into northern India, Pakistan and Arabia, taking in the shores of the Mediterranean Sea (both European and African).

The climate of the arid zone of Eurasia is characterized by sparse rainfall throughout the year, very hot summers and warm dry autumns; but, unlike the arid zones of Africa and the Mediterranean area, the Eurasian arid zone has cold winters when minimum temperatures fall as low as 25°-30° below zero, the soil freezes to various depths, and there is snow which sometimes remains lying on the ground. All these cold, winter characteristics of the arid zone of Eurasia are most marked in Central Asia, the Volga area and Siberia, and less marked in the Turanian depression, the Caucasus and the southern Ukraine, where the winters are very mild and there is sometimes no frost at all.

The general contours and dimensions of the Eurasian continent and its mountain chains were established as early as the Tertiary era. It is probable that the arid climate of Central Asia, the Aral-Caspian depression and the Black Sea area was also established at that period, and changed little in its general character throughout the Tertiary and Quaternary eras; although the structure of the mountains, the epeirogenic rises and falls, the ice-cover on the mountains and the flooding and migrations of the rivers may have altered the area and caused minor changes in the nature of the Eurasian deserts and steppes. But there is every indication that the arid belt of Eurasia existed, and was characterized by marked accumulation in the soils of easily soluble salts—gypsum and calcium carbonate—as early as the Tertiary era. Thus the development of the arid climate dates back tens of millions of years. The great geological age of the desert and arid climate in Eurasia explains the prevalence in this area of pure salt deposits of Tertiary age; the general salinity and gypsiferous character of the Tertiary, Quaternary and contemporary geological deposits; the mineralization of the underground waters in this region; the salinity of both old and new lakes; and the high salt content of fossile and contemporary soils.

The aridity of the central areas of Eurasia was always accentuated not only by the size of the continent, but also by the existence of a network of extremely high multi-peaked mountain chains, whose slopes intercepted the moisture blown in by air currents from the oceans. The Pyrenees, the Alps, the Balkan Ranges, the Carpathians, the Black Forest Mountains, the Caucasian Mountains, the Urals, the Himalayan Ranges, the Tien-Shan Mountains, the Kunlun Ranges, the Stanovoi Peaks and the Yablonoi Mountains act as a kind of barrier preventing the moisture from the oceans from penetrating into the central regions of Eurasia.

The ice which in the Quaternary era covered the northern part of Eurasia three or four times (the north-western region in particular) also formed glaciers on the summits of the mountain ranges. At the same time it is generally accepted that the climate of the central parts of the Eurasian continent, though perhaps becoming colder, remained arid. It is possible that the aridity of the climate was even accentuated in view of the fact that large masses of water became solidified, so being excluded from the moisture cycle.

The melting of the mountain glaciers in the interglacial periods was accompanied by a rise in the flow of river waters, intensification of mountain erosion, and increased accumulation of alluvial deposits in the middle and lower reaches of rivers and, in particular, in river deltas. The number of terraces (three or four) along the banks of rivers such as the Volga, Ural, Don, Dnieper, Sir Darya, Amu Darya, Kura, Kuban, etc., indicates that there were three or four periods of alluvial flooding of the depression, but it is hard to say whether these periods were the hot and dry (xerothermic) periods or the interglacial 'pluvial' periods—more probably the former. Nowadays also, unusually hot summers in the deserts of Central Asia normally cause the melting of larger quantities of ice in the mountains, with a consequent rise in the flow of ice-fed rivers.

The theory that the three or four periods of diluvial, alluvial and 'proluvial'[1] accumulation corresponded with a time of dry, hot climate in the steppes and deserts of Eurasia is supported by the fact that all these sediments everywhere are calcareous, gypsiferous or contain easily soluble salts, while the groundwaters of the sediments are mineralized.

The formation of the vast diluvial-alluvial plains of Eurasia, begun in the Tertiary era, continued intensively during the interglacial periods of the Quaternary period, and is still not complete.

A large proportion of the area of the Eurasian arid zone consists of vast alluvial plains, formed by the

1. The term 'proluvial' is used in the USSR for delta sediments formed by temporary rivers.

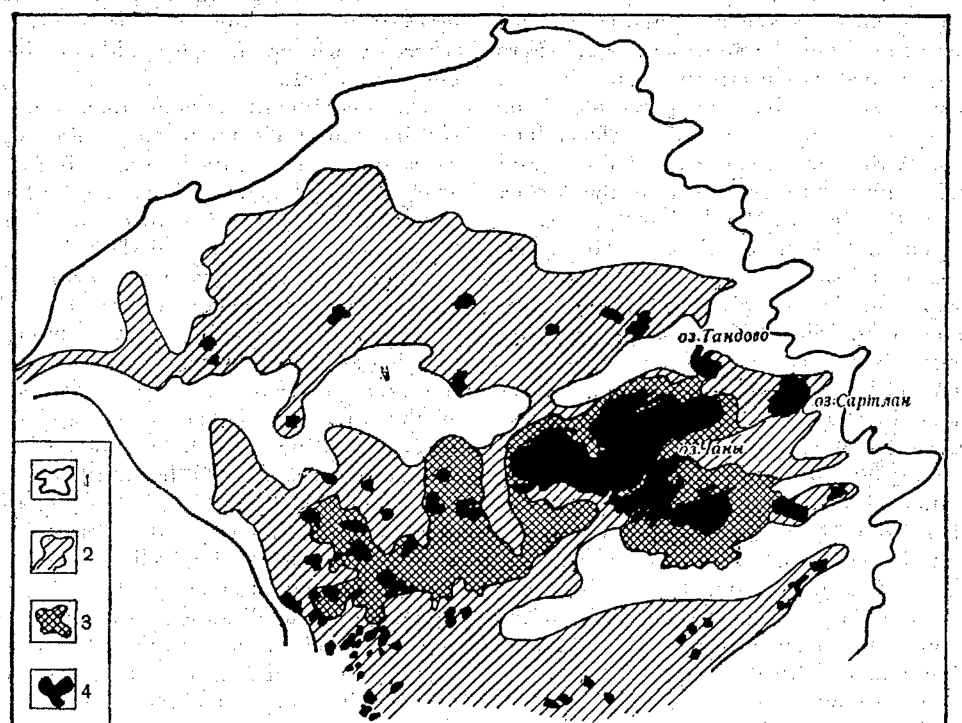



FIG. 1. Paleographic map of the Chany basin. (1) Limits of the basin towards the end of the middle Quaternary period. (2) Limits of the basin in the middle of the late Quaternary period. (3) Lake Chany and Lakes Sum and Abyshkan shown on maps drawn up in 1894 (Yadintsev). (4) Present basin of Lake Chany and Lakes Cheblaky and Sum.

deposits of the great ancient rivers. Thus, a very large part of the purely alluvial and deltaic-alluvial plains was formed by the deposits brought down by the Danube, Dniester, Dnieper, Don, Donetz and Kuban—in the Black Sea area; by the Volga, Ural, Kura, Terek and Emba—in the Caspian area; by the Ob and the Irtysh—in western Siberia; by the Amu Darya, Sir Darya, Murghab and Zeravsan—in the Aral-Caspian depression; by the Turufan, Tarim, Ili and Chu—in western China, and by the Hwang Ho and Hwai Ho in eastern China.

As we know, a large part of the Eurasian arid zone is endoreic, being cut off from the oceans. In periods when the level of the river water rises, due to the melting of unusually large volumes of the continental or mountain glaciers, there is an increase in the area of the inland lakes and seas, such as for instance the Chany lakes in western Siberia, and the Aral and Caspian 'seas' in the Turanian depression. The transgressions of the Caspian have been particularly marked. Thus, in very early times the Caspian (then called the Khvalyn Sea) rose to 75 m. above sea level (now —27 m.).

In the drier periods, the area of the lakes and 'seas' shrank substantially, and they sometimes changed their shape or even disappeared altogether (Figs. 1-3).

The considerable size of the area, on the Eurasian plains, covered by lake, alluvial and deltaic deposits is the result of this accumulative action of the rivers. Together with the 'migrations' of the lakes and seas, there were also changes in the position of the river deltas, which moved frequently, so shifting the points of accumulation of their mechanical and chemical deposits.

The discharge of the waters of many of the giant rivers of Eurasia was wholly confined within the continent, a fact which played a decisive role in the formation of saliferous rocks and saline deposits. Such for instance was the case with the Volga, Ural, Emba, Kura, Terek, Sir Darya, Amu Darya, Ili and Tarim. Others of the main rivers of Eurasia, such as the Irtysh, Ob, Yenisey, Hwang Ho and Hwai Ho in Asia, and the Don, Kuban, Dnieper and Danube in Europe, had an outlet to the ocean, but it was hampered by the frequent rise and fall of the level of the seas, which also led to the formation along the lower reaches of extensive lake-deltaic plains. Research by Soviet geologists and soil scientists shows that, owing to the rises and falls in the level of the Caspian, the Volga Delta shifted from Kamyshin (north of Stalingrad) to Baku before moving to its present position at Astrakhan (Fig. 2).

Since the end of the Tertiary period, the delta of the Amu Darya has shifted a thousand kilometres, and its mouth has moved from Krasnovodsk on the Caspian to the Aral Sea (see Fig. 3). Generally speaking, the Caspian may be said to have been created by the Volga, and the Aral by the Amu Darya.

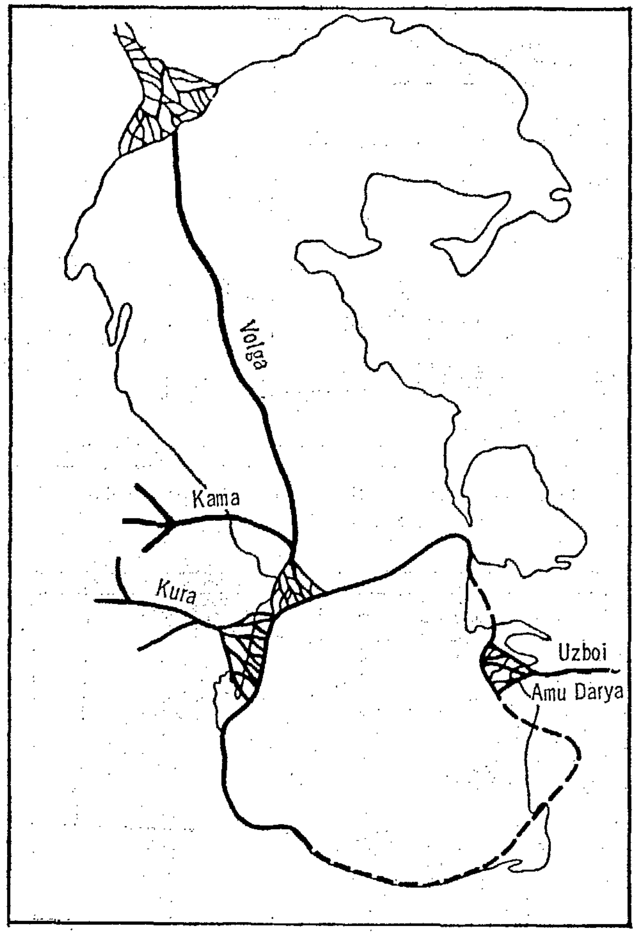



FIG. 2. Map of the Caspian Sea in the last part of the Tertiary period (after V. P. Baturin, 1947).

The presence of glaciers damming the flow of the Siberian rivers Ob, Irtysh, Yenisey, etc., led to the formation in Siberia of a large lake area. During that period, the waters of the northern rivers flowed first into the depression of the Aral Sea, thence into the Caspian, and from the Caspian along the bed of the Manych, into the Black Sea. Thus towards the end of the middle Quaternary period there existed, between the Irtysh and Ob in western Siberia, a large lake region, which became transformed later into the network of shallow, disconnected lakes now known as Chany. This explains the presence, in western Siberia, of widespread clayey lake deposits, peat-bogs, saline soils and salt lakes (Fig. 1). The deltas of the Don, Kuban, Dnieper and Danube have also shifted considerably.

The extensive stretches of Late Tertiary and Quaternary sands in the arid zone of Asia and Europe were formed as a result of the deposits brought down by the Amu Darya, Sir Darya, Volga, Ural, Terek, Don and Dnieper. The loess-type deposits of Central

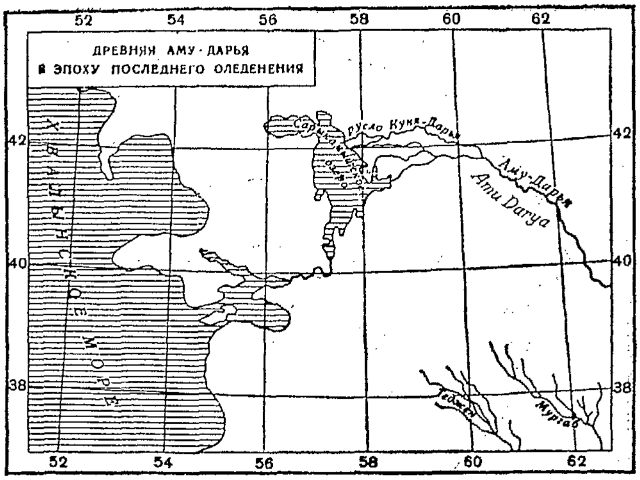



Fig. 3*a*. Pre-Amu Darya River in the Recent Glacial Period. (USSR Academy of Sciences.)

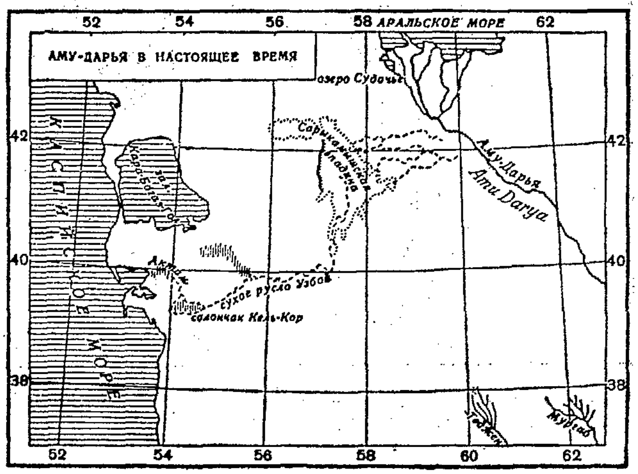



Fig. 3*b*. Amu Darya River in the present time. (USSR Academy of Sciences.)

Asia, the Causasus and the Russian Plain consist of resorbed ancient alluvial and diluvial deposits brought down by these rivers' predecessors and their tributaries, as well as by innumerable small rivers and short-lived streams.

The heavy loams and clays of western Siberia, Turania and Sinkiang were deposited in the lakes and deltas during the periods of transgressions and of high water level.

The Volga and the Amu Darya played an especially important part in the accumulative process. At the present day the large rivers of the Aral-Caspian basin together bring down about 412 million metric tons of solid deposits into the lower reaches annually, which amounts, over a 10-year period, to a volume of about 3 km.$^3$ During the fifteen to twenty thousand years of the Quaternary period, the volume and quantity of material brought down by these rivers reached an astronomical figure—between 4,500 and 6,000 km.$^3$—which accounts sufficiently clearly for the large number of alluvial-type rocks on the plains of the Eurasian arid zone. It is important to note, in this connexion, that the most essential factors in the formation of the alluvial plains of the Aral-Caspian region are the Volga and the Amu Darya, which together bring down 60 per cent of the alluvium and 80 per cent of the soluble salts (Table 1).

Alluvial and lake deposits are likewise prevalent on the mountainous, endoreic plains of Central Asia, where they are responsible for the typical aspect of the arid zone of Central Asia.

However, the landscape of the Central Asian uplands differs substantially from that of the arid zones of the Turanian (Aral-Caspian) depression. The altitude of the latter is mostly between 50 m. and 200 m. above sea level, though in some places it is actually below sea level (Caspian and Transcaspian plains).

The mountain plateaux of Mongolia and western China on the other hand lie at an altitude of from 500 m. to 1,000 m. above sea level, and constitute a series of local endoreic depressions isolated by high mountain chains. The central parts of these mountain depressions are covered with saliferous lake alluvial deposits, fringed by successive lines of foothills of coarse sediments deposited by the waters of short-lived streams and rivers which have since disappeared. The existence in the past of islands of ice-covered mountains in this region was followed by the formation of deposits from these rivers.

Table 1. Figures for salts and solid deposits in the Aral-Caspian depression

| | Liquid discharge | | Solid discharge | | Chemical discharge | | | Harmful salts | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Km.$^3$ | Per cent | Millions of metric tons | Per cent | Millions of metric tons | Per cent | Per cent of solid discharge | Millions of metric tons | Per cent | Per cent of solid discharge |
| Annual discharge | 355 | 100 | 326 | 100 | 86 | 100 | 26 | 21 | 100 | 6 |
| Volga | 256 | 72 | 32 | 10 | 50 | 58 | 156 | 9 | 43 | 28 |
| Amu Darya | 42 | 12 | 168 | 51 | 18 | 21 | 11 | 5 | 24 | 3 |

The arid zone of Eurasia has a complicated mountain structure, the formation of which dates back to the pre-Tertiary times; though some of the mountain ranges, such as the Urals and the Mugodjari, are even older. For the most part, the mountain chains of Eurasia were renewed at the time of the Alpine orogenesis, and in most cases continued to rise steadily throughout the Tertiary and Quaternary eras. The arid zone of Eurasia, and more particularly the Central Asian uplands (Mongolia, Tibet, Pamirs) are characterized, on the whole, by mountains and epeirogenous elevations. The whole of the Turanian depression (Aral-Caspian depression), western Siberia and parts of the shores of the Yellow, Azov and Black seas are subject to simultaneous sinking of the earth's crust operating in different directions. The existence of numerous chains of high mountains which have a permanent or periodical cover of ice and snow and the slopes of which condense the vapour contained in the air has been responsible for the creation, in Eurasia, of the specific geographical conditions which, in turn, have led to the formation of an extensive arid zone traversed by abundant rivers (Ob, Irtysh, Hwang Ho, Amur, Tarim, Amu Darya, Sir Darya, Zeravshan, Volga, Kama, Kuban, Kura, Don, Dnieper, Danube), with catchment basins, in most cases either high up in the mountains or in the northern forest belt.

The mountains of Eurasia are characterized by marked vertical zoning and a sharp bioclimatical asymmetry between the outer and inner slopes. The inner slopes are always much drier; the deserts and steppes on these slopes extend up to an altitude of between 1,000 m. and 1,500 m. before giving place to dry meadows, whereas on the outer slopes which receive most of the atmospheric precipitations, the dry steppe and desert belt gives place, at a much lower altitude, first to forest steppe and steppe, and then to alpine meadows.

The mountain steppes, forests and alpine meadows, on account of their cool climate, abundant water and pleasant pasture land, have always attracted the cattle-breeders living in the arid zone of Eurasia.

The waterless character of the plains of the Central Asian arid zone compelled primitive man to settle near rivers and river mouths, where the struggle for existence was much less grim than on the arid steppes or, more particularly, in the desert.

The valleys and deltas of both the small and more particularly the large rivers of the Eurasian arid zone always constituted the most favourable spots for primitive man to settle. The shellfish and fish in the rivers, lakes and deltas, the animals, the culinary roots and the fruits of the abundant plants growing on the deltas and floodplains and terraces provided primitive man with a reliable source of food. The forests lining water-courses on the deltas and valleys, and the reeds growing on the floodplains supplied fuel and building materials, and were, moreover, teeming with animal life. Cave settlements grew up on the sides of the steep river banks. Pile dwellings were built amongst the trees along the river valleys. It was in the fresh, damp, fertile alluvium in the floodlands and river deltas that the first primitive beginnings of agriculture appeared (*kair* and hoe farming).

The level of the plains of the Eurasian arid zone rose in the second half of the Quaternary period, either in absolute terms or in relation to the sea level; at the same time, the hydrographical network was gradually incised, terraces were formed, and the depth of the groundwaters increased. Due to the arid climate, the sinking of the groundwaters and the cessation of high-water flooding resulted in the desiccation of the great alluvial plains and the formation of steppe and desert zones (xerophytization). The settlements of primitive man, under the pressure of these geographical changes, tended increasingly to be concentrated along the waterways—on the river banks, floodlands and lower terraces, in the river deltas and river mouths along the shore where fresh water flows into the sea. This accounts, in our view, for the fact that the earliest centres of human civilization in the arid zone were situated in the valleys and deltas of the Nile, the Tigris and the Euphrates, the Murghab and the Zeravshan, the Kura and the Arax, the Amu Darya and the Sir Darya, the Hwang Ho, the Hwai Ho and the Yangtse.

After the xerophytization of the alluvial plains, the ancient sand areas became relatively more favourable to human life at the early stages of the development of society. Owing to their greater permeability to water and low moisture capacity, the sands in the arid zone, when atmospheric precipitations are equal, provide more favourable ecological conditions than loams and clays. Sands are seldom saline, they accumulate and preserve rainfall and groundwater more efficiently; and they have a lower wilting ratio. Thanks to this fact, the ancient alluvial sand areas in the arid zone always have more abundant vegetation than deserts of saline, alluvial clay plains. Sand acacias, poplars and haloxylons, together with other species of bushes, constitute a special type of desert 'forest' which is to be found to this day in the ancient alluvial sand areas of Asia. Together with the herbaceous plants growing on the sands, there are also bushes which have provided cattle fodder since earliest times. As a result of centuries of destruction of the primitive vegetation by stockbreeders and nomads (using it as fuel, building material and cattle fodder) the sands began to shift. Subsequently these shifting sands with their dunes and sandhills encroaching on human settlements, became a typical feature of the arid zone.

The arid zone of Eurasia has most varied soils which are characterized by great natural potential fertility especially when there is sufficient natural moisture (atmospheric precipitations, non-saline groundwater, river floodwater or melted snow) or artificial moisture (irrigation, accumulation of snow).

The great natural fertility of the arid zone soils is due to the lack of geochemical run-off (leaching out) of the elements of plant nutrition such as is typical of the humid tropics and the damp forest areas of the temperate belt. On the contrary, the soils of the arid zone usually lie in an area of geochemical accumulation of mineral substances, salts and, in particular, the vital elements of plant nutrition. Hence the soils of the arid zone tend to be rich in salts of calcium, potassium, magnesium, sodium, phosphorus, nitrogen and sulphur. They contain in most cases many compounds of micro-elements extremely important for the life of plants such as manganese, molybdenum, copper, nickel, zinc and iodine. In the driest parts of the arid zone, in western China, and in the Caspian, Turanian and West Siberian depressions, however, especially in the vicinity of groundwaters, the soil is full of salts detrimental to plants, such as carbonates, chlorides, sulphates (in some cases nitrates), and salts of sodium and magnesium. The soils of the mountain depressions of Central Asia and of the depressions in the deserts of Kazakhstan, Uzbekistan and Turkmenistan are particularly highly saline—there are extensive areas where the top layer of the soil has a salt content as high as 10-20 per cent. Here too, there are many salt lakes and areas of salt mud, also accumulations of lake salt deposits forming strata 0.5-1 m. thick. When the salt content exceeds 0.5 per cent, the fertility of soils decreases considerably; and when the salt content rises above 1-2 per cent, the soil usually becomes barren, and requires desalination. The salinity of arid zone soils has always been an obstacle to irrigated farming, and the people of these areas acquired valuable experience in dealing with this problem.

In the steppes of Hungary, Rumania, the Soviet Union, (southern Ukraine, Great Russian Plain, Caucasus, the Volga Region, Siberia), the prairie lands of Manchuria and the forest plains of western China and Mongolia, there are extensive areas of fertile black soil and chestnut soil where dry farming has been carried on since the early Bronze Age. Saline soils (usually sodic) are found here in small patches in depressions or river valleys, in the vicinity of alkaline groundwaters.

On the chestnut soils of the arid steppes of the southern Ukraine, Crimea, the Lower Volga, Central Kazakhstan and southern Siberia, dry farming was pursued, together with cattle pasturing. In these parts, farming was developed most intensively after the October Revolution, when the introduction of the socialist system of land ownership and new agricultural techniques made it possible, during the fifties, to take over more than 30 million hectares (ha.) of virgin land for grain growing. Amidst the prevailing chestnut soil in this area there are a few patches of saline soil, mostly located on the river terraces and depressions.

The arid steppes and deserts of the Central Asian uplands and the Aral-Caspian depression are covered with light-coloured soil containing little humus, and frequently characterized by residual salinity, known in scientific literature as 'sierozem', 'grey soil' or 'brown desert soil'. In these areas we frequently come across solonchaks and crustal, alkaline barren soil known as *takyr*.[1] Farming is possible on this grey and brown desert soil only with artificial irrigation, the first use of which dates back to between the third and fifth millennium B.C. It will be possible in future to irrigate up to 100 million ha. in this area, but irrigation is so costly and complicated that before the October Revolution the actual area of irrigated land in Asiatic Russia was not more than 4 million ha.; while the area of land irrigated in western China before the establishment of the People's Government was under 20 million ha.

## NON-IRRIGATED FARMING IN THE ARID ZONE STEPPES OF EURASIA

Soviet archaeologists and historians, e.g. Grekov [17],[2] Kiselev [24], Passek [36], Rybakov [40], have established that, in early Neolithic times (in the third and second millennia B.C.) there existed in the fields and steppes of southern Siberia, the southern parts of the Dnieper and Dniester basins, the area between the Volga and Kama Rivers, and the Kuban plains, a primitive form of farming. There is every indication that this farming was done under a matriarchal community system by tribes living a more or less sedentary life and inhabiting permanent communal dwellings.

Judging by the excavations of sites of ancient towns and villages of the Palaeolithic period in the middle Dnieper basin, the main farming implements used for working the black soil meadow land were spades and hoes fashioned by hand out of stone, bone, horn and wood. This farming was combined with hunting and fishing, but domesticated animals were not yet used in farming.

The area cultivated was not large and most of the farming was done in gardens. The fact that these plots were close to settlements guaranteed a high and lasting degree of fertility, maintained by the use of local manure (dung, human excrement, refuse, ashes). Judging by the relics excavated in the 'Tripolye

1. *Takyrs*: heavy unstructured clayey soils. In summer time their surface forms a solid crust underneath which the soil frequently retains an increased quantity of salts soluble in water. In winter when these takyrs get wet, they turn into a marshy bog. As regards physical relief, takyrs can perfectly well be irrigated, but they need structural improvement.
2. The figures in brackets refer to the bibliography at the end of the chapter.

culture' settlements [1] on the Dnieper, the main food of these people was the meat of domesticated animals (sheep and horses), the meat of wild animals living on the steppes, shellfish from the rivers (edentates), fish and acorns.

The Tripolye-type of ancient farming discovered at the end of the nineteenth century by the Russian archaeologist, B. V. Khvoiko, and investigated by Mrs. T. S. Passek [36], the Soviet scientist, covered a large area stretching from the Lower Danube to the middle reaches of the Dnieper and existed for over a thousand years, from Neolithic times to the early Bronze Age. Judging by the seeds found in the burial grounds, wheat, barley, millet and rye were already cultivated at that time. In the western parts of the Black Sea area, farming began even earlier (in the middle of the third millennium B.C.); farther to the east, in the Don and Volga steppes, it began somewhat later (in the second millennium) and was apparently confined to the cultivation of more drought-resistant crops such as millet.

A study of the abundant statistical data on the bones of animals discovered in the excavation of tombs and settlements belonging to the steppe civilization of Neolithic times shows that stockbreeding began gradually during the hoe-farming period. Small animals (sheep, goats) were the first to be domesticated, then large, horned animals and finally, horses. Thanks to the discovery of the use of metal (first bronze and then iron) and the use of strong draught animals such as horses and oxen, man was able to embark upon plough farming and develop nomad stockbreeding (Liberov [32]).

Stockbreeding predominated in the dry eastern parts of the Russian Plain, whereas in the north-western Black Sea areas, cultivation was obviously more important.

The extension of the areas used for vegetable gardening in the black earth field steppes of the Dnieper area was seriously hampered in Neolithic times by primitive farming methods, the abundance and thickness of the steppe grass and the unusual depth and toughness of the steppe sod, sometimes as much as 20-40 cm. thick and impenetrable with wooden hoes. The invention of bronze and iron tools in the middle of the first millennium B.C. in the northern Black Sea area, and the introduction of the use of draught animals, facilitated the ploughing-up of the virgin black earth steppes and meadows, and led to the transition from primitive market gardening in small plots to field-crop farming on a relatively extensive scale. This transition occurred in the steppes of eastern Europe in the same way as elsewhere, accompanied by the disintegration of the matriarchal community and the formation of a patriarchal community due to the fact that men wielded the metal instruments and tended the cattle (F. Engels).

The burning of the steppe grass and sod and turf apparently constituted an essential, though naturally not very desirable, part of this peculiar system of 'burnt earth' farming.

The steppes of eastern Europe, the Black Sea area, the Volga area and southern Siberia were inhabited by many different tribes known by the general term of 'Scythians', the direct predecessors of the later Antes, Alani and, subsequently, Slavs.

In the seventh to second centuries B.C., the use of iron became general amongst the Scythians. Their farming implements were made of iron or of wood reinforced by iron—a simple plough without mouldboard, or *ralo* (which existed in Ancient Greece also), axes, knives and the scythes. These implements, together with the use of strong draught animals, facilitated the cultivation of the virgin black soil. The old Scythian plough is represented on coins of that period; and remnants and pictures of yokes have been found in excavations. It is clear from historical and archaeological sources that the Scythians in the southern Russian steppes towards the end of the first millennium B.C. went in for extensive stockbreeding and farming, and used the long-term fallow system. They cultivated hard spring wheat and in particular millet—one of the drought-resisting plants particularly suitable for growing in virgin land only recently cultivated.

Herodotus and Pliny, describing the life of the Scythians and Sarmatians, reported that their chief foods were wheat, meat and milk. Very few traces have been found in excavations of ancient Scythian towns and villages of either rye or oats, which are northern climate crops.

The fact that Scythian farming dates back to a very early period and existed in these areas in the Neolithic and Bronze Ages is indicated, in the view of Soviet scientists, by the Scythian legend related by Herodotus. The legend says that in ancient times the Scythians received from the heavens a golden plough and yoke, a pole-axe and drinking cups. The 'Paralaty' (ploughmen), a certain tribe of Scythian farmers, were supposed to be the direct descendants of the people on whom these gifts of the gods had been bestowed. The standard of plough farming amongst the Paralaty, who lived along the Bug and Dniester Rivers, was higher than that of the Scythians in the eastern steppes. The main crops cultivated by the Scythians were hard wheat and millet, though they also grew barley, hemp and flax, onions and garlic; and engaged in horticulture, vine-growing and bee-keeping (Herodotus, Theophrastus, Emnan).

Together with field-crop cultivation, stockbreeding was also developed in the Scythian steppes. Judging by the bones found in excavations, wild animals provided only 30-40 per cent of the Scythians' meat; the largest proportion of bones are those of horned

1. So named after the village of Tripolye, near Kiev, where the first such settlement was excavated in 1896.

cattle; horses and sheep occupy second and third place respectively. In the area between the Dnieper and Don and in particular the area between the Don and the Volga, the bones of horses and sheep predominate. In the western steppes, at the end of the first millennium, the Scythians were engaged mainly on field-crop cultivation and the breeding of pasture herds; whereas in the drier, less fertile steppes towards the east nomadic stockbreeding was more common, instead of hoe farming.

The agriculture of the Scythians in the Black Sea area was so productive that grain was exported to Ancient Greece, thanks to the use of the long-term fallow system, and to the natural fertility of the black earth soil.

The Scythian farming system was inherited, in the first millennium B.C., by various tribes of eastern Slavs, and in particular by Kiev Rūs (Grekov [17]). Roman authors of the first to the sixth centuries A.D.—Pliny the Elder, Tacitus, Jordanes, Procopius of Caesarea, etc.—speak about the large tribe of farming people called the Wends, the eastern section of which were known as Antes, the western, Sklavini. Archaeological research by Soviet scholars has shown that the Antes were an important sedentary farming people. The level of their farming was high and they cultivated extensive areas of the black soil belt. They worked the land with a *ralo* with an iron mould-board, complete with a device for cutting furrows and piling up the earth alongside of them, besides merely loosening the soil. This implement was not capable of turning over and cutting up the soil, but it was the closest predecessor of the plough. The main crops cultivated were wheat and millet, together with a certain quantity of rye and barley. Grain was exported in large quantities to Ancient Rome, as shown by the Roman objects and coins found in the tombs belonging to these tribes, and also by the amazing similarity between the old Russian and Roman grain measures (both the Russian *chetverik* and the Roman *quadrantal* equal 26.24 litres) (Rybakov [40]).

About the fifth-sixth century A.D., the first great Slav State—that of the Rūs Antes, the forerunner of Kiev Rūs—made its appearance. Farming and stockbreeding played an important part in the economy of this great State. The territory of the Antes also included the forest-steppe zone which was successfully farmed by the hewing method (the forest was cut down and burnt on the spot, the soil was then ploughed and broken up, and strewn with ashes).

The second half of the first millennium A.D. saw the appearance of a more advanced type of plough, capable of cutting the soil horizontally, so destroying grass and weeds; this plough made it easier to bring virgin land under cultivation and considerably increased crop harvests. At about this period, the patriarchal tribal community disintegrated, and was replaced by individual family groups forming a farming community. Individual landownership was introduced.

Kiev Rūs, in the eighth-ninth centuries, was a large feudal State with an even more highly developed system of farming, stockbreeding and vegetable cultivation. Here we already find the three-field system of farming predominating (winter crops, spring crops, fallow). The farmers of Kiev Rūs used a large plough, complete with ploughshares and mould-board, of a very advanced type, and cultivated winter and spring wheat, rye, millet, barley, peas, hemp, flax, *Brassica napus oleifera*, poppies, buckwheat, lentils, beet, onions and garlic. Owing to the use of the plough and the use of fallow farming became less vulnerable to drought; since the soil was ploughed deeper, the weeds were destroyed and the moisture was able to accumulate in the soil left fallow, the grain harvest increased. This enabled the Eastern Slavs, during the Kiev Rūs period, to spread field-crop cultivation eastwards and southwards into the more arid steppe regions.

The economy of Kiev Rūs was destroyed in the eighth century by the Mongolian invasion of Genghis Khan. The historical centres of the Russian State shifted northwards, to Novgorod, Vladimir and Moscow. A large part of the population took refuge in the forests of the northern part of the Russian Plain; many settlements were abandoned altogether and cultivated land was left to deteriorate. The remaining people maintained the standard of farming already reached; but, naturally, nomadic stockbreeding, introduced by the Mongols, began to play a more important part in agricultural economy of the steppe regions.

To sum up, after 200 years' stagnation, when the country was under the Mongolian yoke, the main centres of farming shifted to the forest and forest-steppe regions. Farming was not resumed in the steppes until long after the expulsion of the Mongols under the tsarist serf system in Russia, the Ukraine and the bordering lands whither people fled in search of freedom.

The tree-hewing system in the forest areas, and the three-field system with fallow strips, and the long-term fallow system in the steppes were still in the sixteenth, seventeenth and eighteenth centuries, as before, the main farming systems. With the small-peasant serf-labour economy, no technical progress was possible, since peasants were the slaves of feudal landowners who were not interested in progress. This system was based on the principle of plundering the natural fertility of the soil, and during this period Russian farming was always characterized by small harvests, crop failures and famine. At the same time, certain progressive statesmen, owners of model estates and agronomic experts strove to raise the level

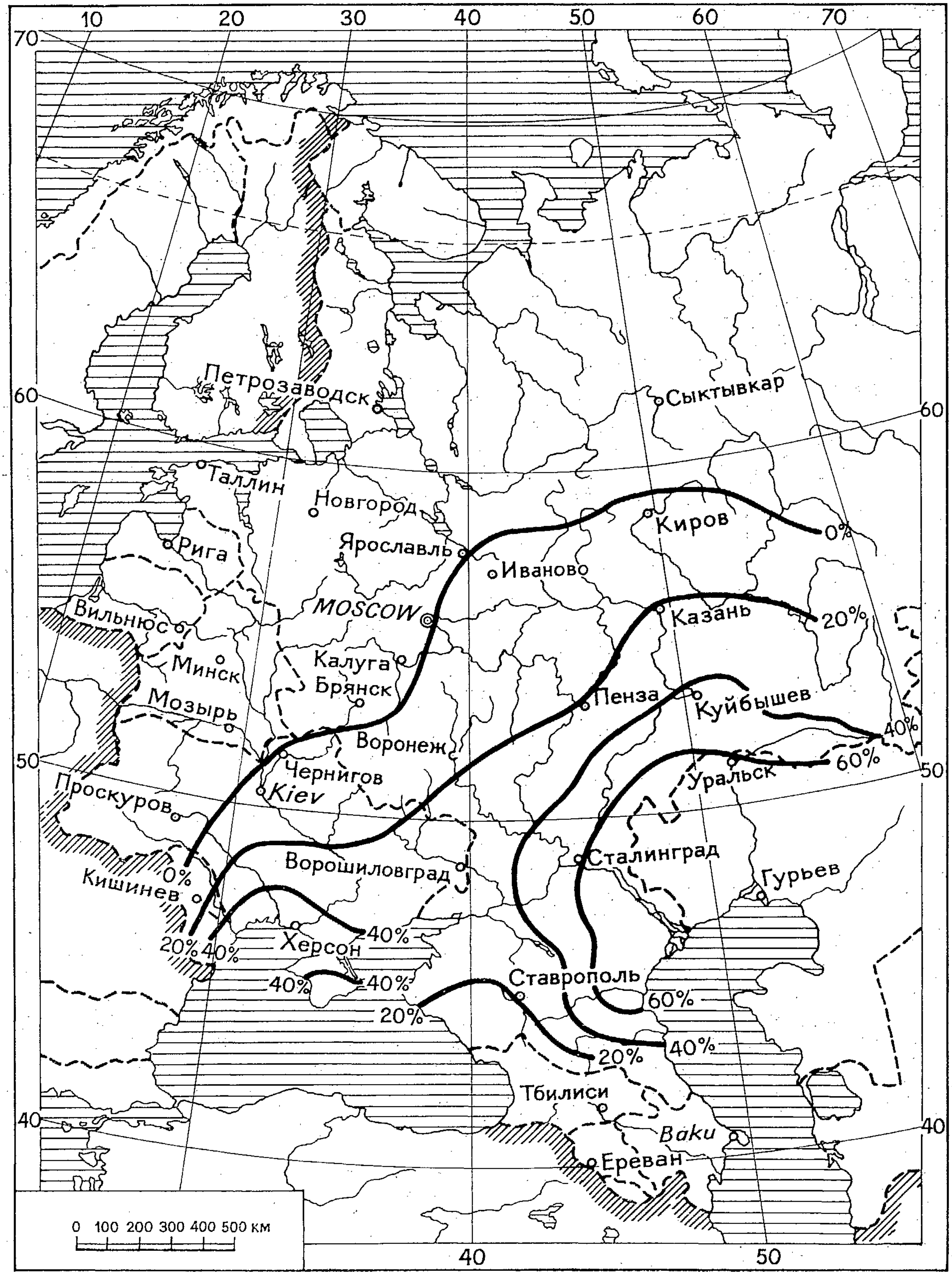



FIG. 4. Drought frequency in the European parts of the USSR (Chart drawn up by A. M. Alpatyev.)

of agriculture, recommending and introducing the use of fertilizers, multi-field rotation of crops and grass sowing. Thus Russian scientific periodicals in the eighteenth century were full of articles and discussions about improving the productivity of farming. The articles by A. T. Bolotov, an agronomic expert, published in the proceedings of the Free Economic Society and in the periodicals *The Villager* and *The Journal of Economics*, which he himself founded, are of special interest and importance; they discussed Russian and foreign experiments in farming, and recommended the use of fertilizers, multi-field crop rotation and land improvement measures. At the end of the eighteenth century landowners began to adopt a more or less improved system for the use of local manure and grass sowing.

As capitalism developed in the agricultural economy of pre-revolutionary Russia and with the advance of technical methods in field-crop cultivation, farming spread from the original black earth steppes of the Ukraine and central Russia. Into the dry steppes of the Crimea, the Caucasus, the Volga area and Siberia went thousands of settlers seeking freedom from the oppression of the land property system.

In the eighteenth and nineteenth centuries, large tracts of virgin land in the southern Ukraine, northern Crimea (Taurus steppes) the Volga area and the Orenburg, Don and North Caucasian steppes were brought under cultivation. In addition to the mighty, fertile black earth lands, the southern black earth areas and the chestnut soil of the dry steppes also began to be cultivated. With the development of capitalism in town and country, the growth of industry and the entry of Russia into the world grain market, the area of the arable land was substantially extended, though still with the old technical methods, i.e., on the strength of the natural fertility of the soil only. New ploughs, horse-drawn harvesters and threshers were introduced; but the actual farming system remained the same: long-term fallow in the south, and in the north the three-field system with little grass sowing and scarcely any chemical fertilizers. In the steppe lands no manure at all was used (not even dung). More progress was made in the nineteenth century in the matter of sugarbeet growing in the Ukraine and northern Caucasus, where rational crop rotation and fertilizers were used on the large private estates. A large part of the area under field-crop cultivation in the eighteenth and particularly the nineteenth century was in the arid steppes, subject to very frequent drought. Natural conditions in the black earth steppes and forest steppes deteriorated: the southern border of the forests land moved several hundred kilometres northwards as a result of tree felling; the forest steppes became completely de-forested, turning into antropogenous steppe lands; the forest strips along the river terraces and on the sands were cut down; forest groves, and clumps of birches and blackthorns in the steppes disappeared altogether. The ploughed slopes of the high right banks of the Don, Dnieper, Donetz and Volga suffered from water erosion; the plains began to be broken up by ravines; black dust storms began to occur regularly in the south and south-east of the country; and the sands of the Volga, the Don and the Dnieper basins began to shift, constituting a threat to fields, villages and roads alike.

We know from the records of chroniclers and travellers that there were 38 major droughts on the Russian Plain in the period from 994 to 1774, and 23 major droughts in the nineteenth and the first half of the twentieth century. The frequency of these droughts increased in the fifteenth and sixteenth, and especially in the nineteenth century. The worst were in 1885, 1889, 1890, 1891, 1892, 1897, 1901, 1906, 1911, 1914, 1917, 1920, 1921 and 1934 (See Buchinsky [9]). The drought frequency increased sharply south-east of Moscow towards the Caspian Sea (Fig. 4). Thus to the south of the towns of Uralsk and Stalingrad, more than 60 years in 100 might well be drought years (A. M. Alpatyev). During drought periods, there may be two to three months on end without rain, with exceptionnally high temperatures (up to 40° C.) and a very low moisture index. The summer rain of up to 5 mm. a day which sometimes falls in the steppes is completely useless in these conditions.

In the view of Soviet climatologists, the occurrence of drought and the form it takes is determined mainly by the penetration of anticyclones from the Azores or of Polar air-masses moving south-east into the steppe regions. Thus Evseev [15] plotted diagrams of the movements of currents of dry air at various altitudes on the basis of observations and figures (Fig. 5). These diagrams show that the air-masses moving towards the south-east parts of European Russia and the Caspian depression come from the north, north-west and sometimes the north-east. The Russian peasants call a sudden drought accompanied by dry, hot winds laden with fine dust *sukhovei* (dry winds). When these sukhovei blow, even if the soil is moist, crops may fade or even be destroyed altogether within a few days. The relative moisture of the air in dry wind periods sinks as low as 4-7 per cent, the wind-speed rises as high as 5-8 m. per sec. and Wild's evaporation index rises to 5-6-8 mm. per 24 hours. In the arid steppe areas the sukhovei may blow for as long as 20-30 days on end.

In the deserts of the Aral-Caspian depression there may be as many as 50-80 days sukhovei in the vegetative season (April-September). Soviet experts have shown that, south of the 48th parallel towards the Turanian depression, the prevalence of the sukhovei has increased steadily over the years as indicated in Table 2.

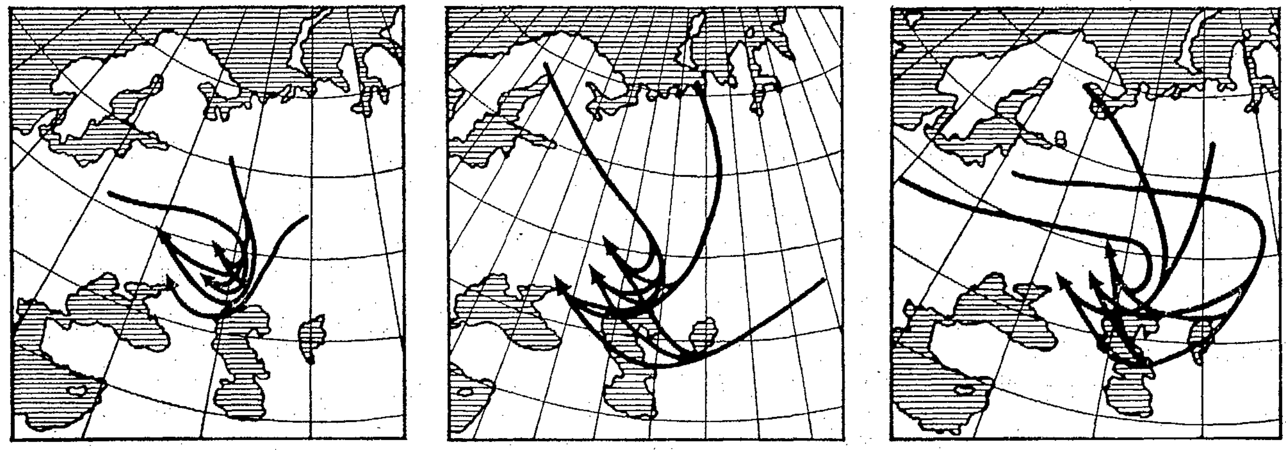


FIG. 5. Charts showing trajectory of air currents in periods of sukhovei (hot dry winds), prepared by M. K. Evseev: (a) at ground level; (b) at an altitude corresponding to 900 millibars above ground level; (c) at an altitude corresponding to 700 millibars above sea level.

TABLE 2. Number of days of sukhovei per 10-year period in Kazakhstan (after Samohvalov [41])

| Meteorological station | Period observed | Number of days (period April-September) |
|---|---|---|
| Burnoe (experimental station) | 1923-1927 | 16.5 |
| | 1928-1937 | 20.2 |
| | 1938-1947 | 27.1 |
| Kazalinsk | 1888-1897 | 6.0 |
| | 1898-1907 | 2.0 |
| | 1908-1917 | 4.5 |
| | 1918-1927 | 8.0 |
| | 1928-1937 | 17.6 |
| | 1938-1947 | 19.1 |
| Turkestan | 1888-1897 | 5.2 |
| | 1898-1907 | 10.0 |
| | 1908-1917 | 17.6 |
| | 1918-1927 | 56.7 |
| | 1928-1937 | 42.7 |
| | 1938-1947 | 84.1 |

According to data collected by the Turkestan meteorological station the number of sukhovei days in the 10 years 1938-1947 was twice as high as in the previous 10-year period, and 16 times as high as in the first 10-year period for which data were collected. At Kazalinsk also the number of dry wind days increased sharply. Similar results were obtained in most parts of southern and south-eastern Kazakhstan, down to the line Kazalinsk-Zaisan.

## PRINCIPLES AND METHODS OF CULTIVATION OF ARID ZONE SOIL IN THE USSR

The area covered by arid desert steppes in the USSR is about 3 million $km.^2$ or 14 per cent of the total area of the country.

The peoples of the USSR have important achievements to their credit in the cultivation of desert and arid steppe regions. Fleeing from the wrath of princes and tzars and the despotism of landowners, Russian and Ukrainian peasants in search of freedom and land migrated to the Terek and the Don, beyond the Volga and the Ural, into the Taurus, Caspian and Kirghiz steppes; settled on the plains of the Caspian and Kazakhstan, on the foothills of the Tien Shan mountains; and penetrated into the Transcaspian deserts, Semirechye and the northern parts of Khorezm, taking their knowledge of farming with them. The Uzbek, Tadjik, Turkmen and Azerbaijan peoples have inherited centuries of experience of building irrigation canals, and have created irrigated oases in the middle of the deserts.

To subjugate and cultivate the deserts and boundless sandy, saline plains, bring them moisture and cover them with the verdure of gardens, crops and pastures —such has been the dream of millions of toilers, the ideal of patriotic scientists devoting their lives to the study and conquest of the desert.

In the middle of the fifteenth century, the Russian merchant Afanasia Nikitin, at the head of a group of fellow merchants, journeyed to the desert shores of the Caspian, whence he proceeded alone to India sometime before Vasco de Gama reached that country by the sea route.

In the period between the middle of the fifteenth century and the middle of the sixteenth, lively diplomatic contacts were established between Russia and Bukhara and Khiva. In 1694, from the office of the Treasury, a merchant named Semyon Malenkii was sent to Persia and India with his servant Andrei Semyonov. In 1697, according to data collected by functionaries, merchants and envoys, Semyon Remezov drew a map of 'the earth and the whole of the waterless, impassable stony steppe region'. This map showed all that was then known about the Aral Sea area, the Amu Darya and the Sir Darya basin.

In the reign of Peter I large expeditions made an intensive study of North Kazakhstan, the Caspian Sea area, the territory of Turkmenistan and the Amu Darya delta.

The expedition led by A. Bekovich-Cherkassky which, on instructions from Peter I, investigated the possibility of diverting the waters of the Amu Darya into the Caspian, met with a tragic fate. This expedition was sent to Khiva at the request of the Turkmen chief Hadji Nepess; but the Khan of Khiva, who enclosed the waters of the Amu Darya in the canals running through the Turkmen Plains, treacherously murdered Bekovich-Cherkassky.

A more successful expedition was carried out a little later by Florio Beneveni, to Bukhara, Persia and Khiva. Expeditions organized by the Russian Academy of Sciences in the first half of the eighteenth century made a useful contribution to the study of the Central Asian desert. The results of these expeditions were used in drawing up the 'General Map of the Russian Empire', an outstanding achievement at that period.

The famous Russian geographers of the late eighteenth and nineteenth centuries, P. S. Pallas, N. P. Rychkov, G. S. Karelin, I. I. Lepekhin and many others besides also made valuable contributions to the study of desert conditions.

In the second half of the nineteenth century came the important expeditions made by the outstanding Russian biologist N. A. Severtsov, by I. G. Borshchov, by A. I. Konshin, by the eminent Russian geographer, P. P. Semyonov-Tien-Shansky, and by the well-known traveller N. M. Przhevalsky. Outstanding work was done during this period also by A. I. Glukhovsky, who was the first to investigate means of diverting the waters of the Amu Darya, via the Uzboi, into the Caspian Sea. Tzarist Russia was incapable of appreciating the brilliant thinking of Glukhovsky, who put forward a plan for linking up the Baltic, the Caspian and Aral Seas—tzarist officials regarded him as a dreamer and put every obstacle in the way of the execution of his plans. The works of this great research engineer are of value even in our day.

The outstanding geographers and geologists are : P. P. Semyonov-Tien-Shansky, I. V. Mushketov, N. M. Przhevalsky, G. E. Grum-Grzhimailo, M. V. Pevtsov, P. K. Koslov, L. S. Berg, and V. A. Obruchev —famous for their tireless research on the deserts of Asia, their natural wealth and methods of exploiting them.

After the October Revolution, the eminent hydro-technical engineers M. N. Yermolaev, F. P. Morgunenkov and I. G. Aleksandrov investigated the possibility of using the waters of the Amu Darya, the Sir Darya, the Dnieper and the Volga for irrigating the south-eastern steppe regions and the deserts of the Aral-Caspian depression. F. P. Morgunenkov and I. G. Aleksandrov took part in the hydro-technical construction work done in the pre-war five-year plan for the industrialization of the USSR.

The soil scientists and botanists S. S. Neustruev, L. I. Prasolov, B. A. Keller, N. A. Dimo and B. B. Polynov, and the land reclamation specialists M. M. Bushuev and A. N. Kostyakov also made valuable contributions to the study of desert and methods of developing and bringing them under cultivation as part of the socialist reorganization of agriculture.

The deserts and steppes have always exercised a fascination for Russian research workers. The deserts preserve as it were in their outward appearance all the features of ancient times. A scholar looking at the deserts can decipher the history of the past in the open, bare stretches, the dried-up beds of former rivers, the banks and terraces of ancient seas, the nature and structure of the soil, and the well-preserved remains of buried plants, shells, etc.

The limits and dimensions of the ancient Ice Age waterways; the numerous changes in the level of the Caspian Sea, measured in decades of metres; the problem of the discharge of the waters of the northern Arctic Ocean which in ancient times ran across the Turghai steppes into the Aral Sea, thence to the Caspian, and via the Manych, into the Black Sea; the recent and contemporary processes of mountain formation; the problem of the natural 'desiccation' of the rivers and lakes of Asia; and the laws of salinity of soil and water—all these are evident in the dry steppes and deserts which provide vivid evidence of processes both past and present.

But the main reason why Russian scientists were drawn to the desert was the desire to study the laws of desert formation and devise methods for exploiting the desert in the interests of the people. They have long worked on the problem of transforming nature and raising the yield of agricultural crops. The Malthusian doctrine of the 'over-population' of the earth with its pessimistic conclusions regarding the inevitable decrease of fertility of the soil, and the 'limited productiveness' of the earth were entirely alien to Russian science, and met with implacable resistance from the best Russian experts.

The pioneer Russian physiologist, K. A. Timiryazev, made a careful study of the nature of drought-resistant plants and of methods for dealing with drought and revealed the falsity of the Malthusian doctrine. In his famous paper on 'A hundred years study of the physiology of plants' Timiryazev (1901) showed that, during the preceding century (nineteenth), whilst the world's population had increased three-fold, the food production had increased four times, but that the increase in the means of production of foodstuffs in the current social system was in conflict with the means of distribution of those foodstuffs. Timiryazev returned repeatedly to those problems. In an article on 'The main features of the history of the development of biology in the nineteenth century', published in 1907, he wrote that the practical application to agriculture of biology and chemistry would bring about a complete transformation in agronomy.

The geologist, Academician V. A. Obruchev, who spent more than 50 years studying the geology and mineral products of Asia, made an important contribution, by his research on the Kara-Kum sands, to the solution of the most important problem of the cultivation of the deserts. He devised and proposed measures for dealing with the shifting of sands. These measures, which include preserving the natural vegetation of the desert, creating an artificial vegetative cover and erecting different kinds of shields to provide protection against sand deposits, are still valid to this day. But even earlier, in the first half of the nineteenth century, Russian scientists had done a considerable amount of research and practical work on the problem of sand stabilization.

The pioneer as regards practical methods for dealing with the shifting of sand in the deserts, V. A. Paletzky, had introduced sand stabilization methods along the Central Asian railway as early as 1896, and along the Ryazan-Ural railway in 1905.

The climatologist, A. I. Voeikov, made a first-hand study of the problem of irrigation in the desert. He pointed out repeatedly that irrigation would give man a powerful means of controlling vegetation and producing large crops. He worked out a number of important measures for the development of cotton growing in Turkestan, and showed that natural conditions in Central Asia and South Kazakhstan were exceptionally favourable for the creation of new irrigated oases where conditions for cotton growing would be better than in Egypt.

Contrary to the views of his contemporaries, Voeikov contended that man can exercise an active influence on the climate. In order to improve the climate, he recommended building various kinds of reservoirs, pools and irrigated areas. He stressed the importance of reducing the useless evaporation of water from the surface of reservoirs and of the soil, and insisted that water before evaporating must be made to do useful work for man: it must be absorbed by the roots of plants and, passing through growing plant organisms, enter the atmosphere through the leaves, thus participating in the creation of organic substances (raw materials, foodstuffs, fuel, etc.). It was for this reason that Voeikov insisted on the importance of using river water for large-scale irrigation and planting trees round pools and reservoirs.

V. V. Dokuchaev—eminent scientist and founder of modern soil science—devised a plan for changing the natural conditions of the steppe regions of Russia. This plan included: regulating the flow of the large and small rivers of the Russian Plain; regulating the flow of water in ravines and gulleys by making pools surrounded by trees; regulation of the water régime of steppe watersheds by using pools and hollows and planting trees round them; establishment of hedges (forest strips) to help collect the snow and spring floodwaters; planting forests on sands and hillocks; using artesian waters for irrigation; regulation of the use of arable land, meadows and forests, with a view to establishing optimal crop correlation; improvement of methods of working the soil with a view to the preservation and use of moisture. Dokuchaev was the first to point out that it was essential, in order to develop irrigation, to take account of all local natural conditions (hydro-geological conditions, condition and nature of soil, chemical composition of irrigation waters).

A. A. Izmailsky, a contemporary of Dokuchaev, made a study of the water régime of the Russian steppes, and showed that the private property farming system of tzarist Russian was plundering the natural wealth of the country and so causing the gradual desiccation and exhaustion of the soil. In his book *How our Steppe has Dried Up* he wrote: 'If we continue to disregard the continuous change occurring in the surface on the Russian steppes and the gradual desiccation of the steppe soil, there is no doubt that the steppes will be transformed before very long into an arid desert.'[1]

Izmailsky worked out a series of nation-wide measures designed to prevent the desiccation of the Russian black earth plains, transform the character of the arid steppes and eliminate drought. This plan included: building artificial reservoirs; measures for retaining the snow and lessening the surface run-off of water; creation of large reserves of groundwater; planting of tree strips, etc. But both Dokuchaev and Izmailsky were perfectly well aware that the political and economic conditions of tzarist Russia were not conducive to the execution of the measures they recommended.

The Soviet agronomist and soil scientist, V. P. Williams, showed that it was possible, by regulating all the conditions governing the life of plants, and providing simultaneously all the nutriment, water, light and warmth they required, to exclude all 'limiting' factors and through the gradual increase of the fertility of the soil, produce ever-larger crops.

1. A. A. Izmailsky, *Selected works*, Moscow, 1949. p. 71.

With simultaneous control of all the factors governing agricultural production, Williams contended that the 'law' of diminishing productivity after expenditure (decrease of fertility) does not and cannot operate. In his doctrine regarding the formation of the soil, great importance attaches to the problem of the encroachment of deserts and steppes on to former black soil and forest regions. Examining the geological and biological cycles of minerals, he came to the conclusion that the preservation of mineral combinations in the biological metabolism system slows down the accumulation of salts in oceans and continental depressions; that the best means of preserving substances in this rotation system on arable lands, of reducing surface discharge and preserving moisture in the soils and subsoils of steppe watersheds, and of protecting fields from being washed or blown away (erosion) was to introduce grassland agriculture. The grassland agriculture, recommended by Williams for preventing drought, includes features proposed by Voeikov, Dokuchaev and Izmailsky (forest strips planted round fields and reservoirs, forest plantations on watersheds); it also includes the introduction of crop rotation (planting arable fields periodically with cereal and leguminous plants, which enrich the soils with organic substances and substances required for the mineral nutrition of plants, besides giving the soil the capacity to retain water and improving the water régime of the region) and the rational use of soil and fertilization.

Another leading Russian agronomist, D. N. Pryanishnikov also laid great emphasis on the important changes obtainable in the topsoil by judicious grass sowing and use of fertilizers. On the basis of the work of Russian soil scientists and of his own classical research on the nutrition of plants and the part played by fertilizers in increasing their yield, Pryanishnikov worked out a theory for the biological improvement of the soil by nitrogen, involving the use of leguminous plants in correct crop rotation, and a fertilization system applicable to the various types of soil and agricultural economy in the USSR. He showed that the Malthusian doctrine underestimated the importance of agrotechniques and in particular of fertilization in producing higher agricultural productivity.

Finally, mention must be made of the very important research done by the Soviet soil scientist, physicist and chemist, Academician K. K. Gedroits, who solved the theoretical problem of transforming the acid podsol soils of forest zones by chalking, and so increasing their fertility. For the arid zone, he worked out a method for improving the alkaline saline soils found in many parts of the steppes and semi-desert areas, large tracts of which are now irrigated by the waters of the Volga, the Dnieper and the Don. After establishing the chemical and physico-chemical character of the alkali soils, Gedroits showed that these soils could be quickly and radically improved by application of gypsum. This is now being done in the steppe areas of the Soviet Union.

The dreams of pre-revolutionary Russian scientists are coming true in the Soviet Union. The research done by Russian scientists with a view to transforming natural conditions and increasing the yield of plants has been developed and the results obtained put into practice on a wide scale. Collective and State farms equipped with the latest techniques, as well as hundreds of experimental stations and institutes are now dealing with the problem of bringing new lands under cultivation in the steppes and deserts of the USSR. From the very earliest times, in the irrigated farming areas of Central Asia, trees were planted along the irrigation canals, and the irrigated fields were skilfully levelled out so as to distribute the irrigation waters more evenly. For improvement of the sandy soils, people in these parts from ancient times used clayey, earthy fertilizers, and improved the takyrs by the addition of sand.

Man has a centuries-long experience of detecting fresh underground water and there are many different methods of obtaining such water, building underground conduits and small irrigation canals, irrigating various types of soil, producing good strains of agricultural plants, building earth works on irrigated lands, and improving irrigated solonchaks. Soviet scientists are now making a careful study of this local practical experience, and striving to make use of all the lessons man has learned in his fight against the desert.

The network of experimental stations set up in the Ukraine, the Caucasus, Central Asia, the Black earth areas and the Volga area since the revolution, work in close co-operation with the State and collective farms in these regions. Thanks to this co-operation, many practical projects for the transformation of steppe and desert lands have been based on and developed by the scientific work of the experimental stations and scientific research institutes, which, in their turn, have had their theories put into practice by progressive collective and State farms. The close co-operation between theory and practice has resulted in the solution of many problems concerning the transformation of natural conditions and the improvement of the vegetative cover of the steppe and desert areas.

The USSR has now adopted a definite theory on the principle of transforming the arid zone in the interests of a socialist society. Although the determining factor in the development of a society is not the geographical environment but the method of production, the geographical environment can affect the speed of a society's development.

In solving the problem of the general progress of the country as a whole, based on the building of communism, the Soviet Union is radically changing the geographical environment, artificially creating a more favourable climate and more fertile soils, building new reservoirs and waterways, and introducing new types of plants and a new vegetative cover.

The natural environment, under the influence of the transformations brought about by man in a socialist society, becomes a factor which accelerates the rate of development of the country's productive forces, and leads to the production of an ever-increasing quantity of material goods, and to the creation of universal plenty.

## PRINCIPLES OF A SIMULTANEOUS ALL-ROUND ACTION ON NATURAL CONDITIONS

The only way in which it is possible to transform natural conditions completely and lastingly is by carrying out a whole series of measures influencing the various natural factors of a region, simultaneously and in accordance with a co-ordinated, scientific programme covering a considerable area.

The new hydro-technical works, the giant reservoirs on the Volga, Dnieper, Amu Darya and Don, the irrigation and watering of areas as large as 30 million ha. will exercise an immense and beneficial influence on the physical and geographical conditions, the geochemical processes and the biological situation of a large part of two of the world's continents—Europe and Asia.

Europe and Asia have an area of 51.6 million $km.^2$. The Caspian and Aral Sea basins have a total area of about 4 million $km.^2$. If we add to these the basins of the Dnieper, the Don and other rivers which it is also proposed to use for purposes of irrigation, the irrigated area will represent some 5-6 million $km.^2$, i.e., over half the total surface of Europe and about 10 per cent of the surface of Europe and Asia combined.

## CONTROL OF PROCESSES IN THE BIOSPHERE

Radical and beneficial changes are being brought about in the biosphere. Agriculture and forestry are based on the exploitation of the biosphere, i.e., on the use of the vegetative cover, plants and living organisms and microbes for the production of organic substances for food and industrial purposes.

In the extensive measures being taken for the radical improvement of natural conditions in the Soviet Union great importance is attached to the control of processes occurring in the biosphere. In solving the problem of transforming and controlling the biosphere, Soviet science acknowledges that it is both possible and inevitable for living organisms to inherit changes brought about by factors in their environment.

Thanks to the Michurin school of agro-biology the limits of agriculture in the USSR are being extended far to the north and into the dry steppes in the south, and making it possible to select and create new types of high yield crops capable of developing and bearing good crops even in adverse environments.

Thanks to agrotechnological measures aimed to satisfy all the requirements of growing plants, it is possible to bring out the best features in various types of plants and make them produce maximum crops.

Consequently, Soviet agriculture now possesses new types of cotton plants, rice, beet, millet and flax with an exceptionally high crop capacity, as well as new types of wheat and rye with a crop capacity and quality better than ever before.

It is now possible also to influence the biosphere by extensive afforestation transforming natural conditions. As a result of the planting of eight giant State forest belts, carefully distributed over a distance of 5,320 km. along the watersheds and floodlands of the country's largest rivers, of the planting of forest shields round collective farms, and of the stabilization of shifting sands by the creation of a grass and tree cover, the local surface microclimate of the steppes is being substantially improved. Green plantations are being formed along all the large irrigation canals, also round the edges of irrigated oases, along the sides of roads, around farmsteads, etc. The universal introduction of correct crop alternation will produce a new unbroken grass cover on the surface of arable lands.

In the dry steppes, formerly uncultivated or used as pasture land, 30-32 million ha. have now been ploughed and brought under cultivation; a snow retention system has been introduced, anti-erosion measures are being taken, and wheat crops are being grown.

To sum up, a new vegetative cover is now being created in the biosphere of our continent, within the borders of the USSR, skilfully planted an sand soils, on the river floodlands and terraces and on the slopes and plains of watersheds; this vegetative cover is producing vast quantities of surface and underground organic matter, and exercising a far-reaching influence on the soil, on the surface and underground water discharge, and on the surface microclimate.

## PRESERVATION AND TRANSFORMATION OF THE UPPER HORIZONS OF THE GEOSPHERE

All these measures for the transformation of the nature of arid zones will have far-reaching effects on the upper horizons of the earth's crust and on the soil. With respect to the topsoil, the most important and effective means will be anti-erosion measures and crop rotation, which will enrich the soil with organic substances and bring about the formation of a water-resisting lumpy granular structure making for greater fertility. Moreover, the water régime of the soil will be improved owing to the elimination of useless evaporation of soil moisture, the surface run-off of atmospheric waters will be decreased, the permeability and moisture capacity of the topsoil will be enhanced with a consequent rise in the moisture stored in the soil stratum. The now barren saline and solonchak soil in the steppes and deserts will, as a result of land improvement and irrigation, be transformed into completely new cultivated, fertile soils producing large grain and industrial crops. Extensive areas of shifting sands will be stabilized and cultivated. As a result of correct fertilization, the reserves of valuable nutritional mineral substances will be enlarged. The roots left in the soil from the grass sown and the use of organic fertilizers will lead to an increase of the quantity and effectiveness of useful soil micro-organisms.

The rational utilization of land in collective and State farms, the adoption of a correct crop rotation system and the planting of forest shields will prevent the washing or blowing away of the top fertile arable layers of soil (erosion); decrease the run-off of surface waters; decrease the loss of substances dissolved in these waters (chemical denudation); and protect the vegetative cover against the loss of elements providing mineral nutrition for plants, which will be retained in the tissues of the plants' roots.

Besides extending the sphere of action of the biological cycle of mineral substances and lessening the processes whereby mineral combinations essential to plants escape from soils, the extension of the area of vegetative cover on arid lands will also provide the topsoil with new elements of mineral nutrition.

## CONTROL OF THE HYDROSPHERE AND THE WATER RÉGIME OF ARID LANDS

The creation of an extensive new area of vegetative cover on dry lands will have important effects on the country's water régime. As a result of the vegetative cover on fields, the new forest belts and the improved structure of the soil, the moisture of the surface water run-off will be retained. The high waters of rivers will be reduced and their discharge rate will be more regular.

In the subsoil horizons, thanks to the retention of the snow and the reduced water discharge, new volumes of fresh groundwaters will be stored, which will supply moisture to plants through their roots.

At the same time, a large network of hydro-geographical works is being established. Thousands of pools and reservoirs in the higher parts of gorges and ravines will serve as sources of moisture for the surrounding dry country, as a result of infiltration and the formation of groundwaters which will supply moisture to strips of trees planted round the reservoirs.

Large areas of giant new reservoirs have already been built on the Volga and the Dnieper, the Amu Darya and the Don, above dams and hydrostations; and a network of deep water canals (including the Kara-Kum, Donets and Volga-Don) combined with the large dams and canals constructed in the pre-war period (Stalin and Moscow White Sea-Baltic Canals) will provide a regular transport system between the six seas. In addition, a vast new network of irrigation canals has been and is to be built—the Southern Ukraine and North Crimea Canal, the Ergeni Canal, the Don Canal, the Stavropol Canal, etc. In the steppes and deserts where previously there was no natural water, there are to be distributory canals tens of thousands of kilometres in length.

The level of two inland seas (Caspian, Aral) will be lowered as a result of the drawing-off of large quantities of river water for irrigation and watering purposes. Since the level of the Caspian Sea has already sunk during the last geological period, it will presumably dry up more quickly than the Aral. But Soviet scientists and engineers have already worked out various plans for diverting the waters of the northern rivers (Pechor, Ob, Yenisey) into the Aral and Caspian basins.

The map published by the USSR Academy of Sciences in 1958 shows one plan for complete transformation of the whole hydro structure of Siberia in order to irrigate the Cental Asian desert and regulate the level of the Aral and Caspian Seas (Fig. 6).

These vast hydro projects, which are to be executed in the next 20-30 years, will make it possible to irrigate a further 20-25 million ha. of land in the deserts of Asia.

Great quantities of irrigation water will flow into the parched soil of the semi-deserts and deserts. In places where the annual atmospheric precipitations at present total only 75-250 mm., irrigation will add a further 500-700 mm., and up to 100 billion $m^3$ of water annually will flow onto the dry land as a result of irrigation. This moisture will then fall again repeatedly in the form of rain and dew, bringing about important changes in the water régime of the arid lands. The old evaporation points of river, lake and sea waters will disappear, and be replaced by a new and far more evenly distributed network of small reservoirs, ponds and canals to exhale moisture into the atmosphere.

The nature of the processes of evaporation of water on dry land is also to be changed. The predominating process of evaporation in the desert and dry steppes, serving no purpose for man, is to be replaced by evaporation through living organisms, or transpiration,[1] which is accompanied by the formation of large

1. Evaporation of water through the leaves of green plants.

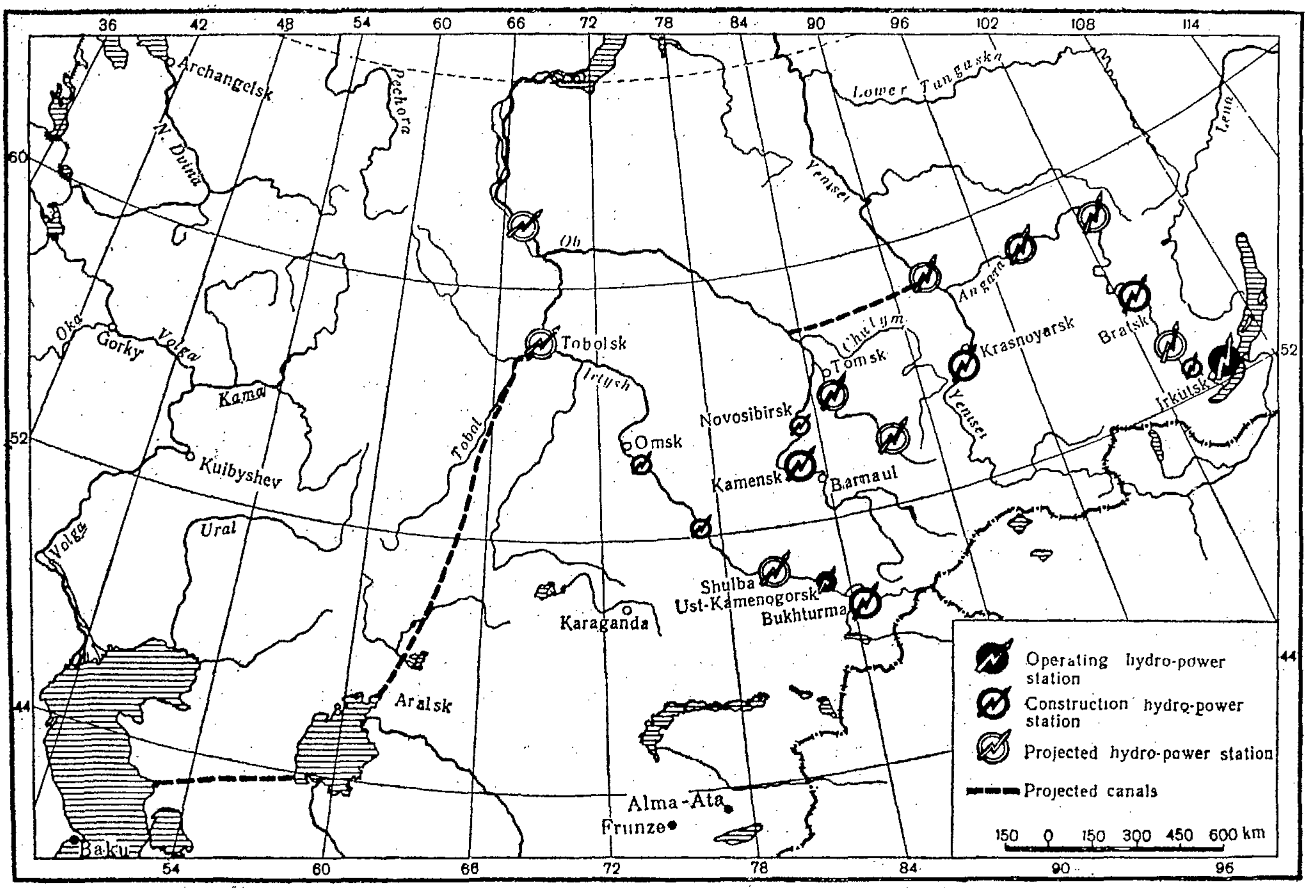



FIG. 6. Chart of Siberia hydro-projects. (USSR Academy of Sciences.)

masses of new organic substances providing food, or raw materials for industry and fuel.

TRANSFORMATION OF THE GROUND CLIMATE IN DRY REGIONS

The transformation of the biosphere, geosphere and hydrosphere will give rise to radical changes in the local microclimate of the dry regions. The network of State forest belts, forest shields planted round collective farm fields and along irrigation canals, the vegetative cover on sand areas and newly planted forests will all have important effects on the ground stratum of dry regions. The destructive effects of the sukhovei, mists and khamsins which now desiccate the unprotected fields and crops will be mitigated. Owing to the transpiration of moisture and irrigation, the moisture content in the air will increase, so improving the resistance of plants during the hottest and driest summer period. Important changes, though at present difficult to calculate precisely, will take place in the country's internal moisture cycle characterized by an increase in local atmospheric precipitations. According to Voeikov, it is probable that the eastern Asiatic regions of Soviet Russia in particular will receive an increased quantity of atmospheric precipitations. The beneficial changes in the internal moisture cycle will become more marked as the rivers of the Black Sea region and the north are more extensively integrated into the irrigation system.

The new quantities of moisture passing out through the leaves of plants, together with moisture exhaled by flooded fields, canals, new reservoirs and ponds, will produce an increase in the moisture content of the air at ground level. This will soften the microclimate and decrease the effects of drought.

The changes in the water régime of dry regions will affect the heat régime of the topsoil and the air stratum at ground level. The surface of irrigated, vegetation-covered ground in the former deserts will no longer be heated up to temperatures of 60-70° C. as now happens in the case of the denuded surfaces of sands and deserts.

The extent to which local climate can be changed by irrigation and artificially planted vegetation is indicated by the data for the Pakhta-Aral State Farm in the 'Hungry Steppe' (see Table 3).

TABLE 3. Average air temperatures in °C. at 1 p.m. (P. A. Vorontsov)

| Observation point | Altitude in kilometres | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.0 | 0.10 | 0.20 | 0.30 | 0.50 | 0.57 | 0.64 | 0.75 |
| Hungry Steppe | 36.9 | 34.5 | 33.4 | 32.4 | 30.6 | 30.0 | 29.5 | 28.6 |
| Pakhta-Aral | 32.7 | 32.7 | 32.1 | 31.3 | 29.8 | 29.3 | 29.5 | 28.6 |
| Difference | 4.2 | 1.8 | 1.3 | 1.1 | 0.8 | 0.7 | 0.0 | 0.0 |

According to P. A. Vorontsov's observations, the temperature of the air during the day in July above the Hungry Steppe was always higher than at Pakhta-Aral. Up to 50 m. the temperature above the Hungry Steppe was about 4° C. higher; at 400 m. the difference was only 1-1.5°; and at about 500 m. the temperature, at both points was practically identical.

During the night, the difference between the air temperature above the dry steppe and Pakhta-Aral was reduced to 1°, and this difference existed only at less than an altitude of 50 m.

The creation of a luxuriant vegetative cover over a wide area will cause changes in the oxygen and carbonic acid contents both of the topsoil and of the air at ground level. The quantity of oxygen in the atmosphere will increase, and the carbonic acid turnover in the synthesization and mineralization of organic substances will be accelerated.

## CONTROL OF THE EXCHANGE PROCESSES IN NATURE

Karl Marx, in studying the laws of the development of agriculture under capitalism, felt that the main cause of the decrease in soil fertility under a capitalist system was the destruction of the balance of mineral and organic metabolism in nature as a result of the widening gap between town and country. '. . . large landed property reduces the agricultural population to a continually decreasing *minimum*, and induces on the other side a continual increase in the industrial population crowded together in large cities. In this way it creates conditions, which cause an incurable break in the inter-connexions of the social circulation of matter prescribed by the natural laws of life. As a result the strength of the soil is wasted, and this prodigality is carried far beyond the boundaries of a certain country by commerce.'[1]

This 'incurable break' can only be healed if the character of society and the means of production are changed : '. . . socialized man, the associated producers, regulate their interchange with nature rationally, bring it under their common control instead of being ruled by it as by some blind power . . .'.[2] Under a socialist system, the conflicts between town and country disappear, as do also the causes for the destruction of the normal metabolism in nature occurring under a capitalist system. The vast expansion of socialist industry supplies the country's agriculture with the chemical fertilizers it requires and brings into the metabolism cycle inexhaustable quantities of mineral nutriments for plants which have been stored away for millions of years in the recesses of the earth's crust.

Rational farming and forestry also exercise a favourable influence on organic and mineral metabolism, a factor in the preservation of soil and the increase of its fertility. With correct crop rotation and afforestation, vast quantities of mineral elements for the nutriment of plants are preserved in the biological metabolism cycle by being extracted from the geochemical stream bearing them away into the ocean.

With carefully planned development of all branches of agriculture, and rational exploitation of agricultural by-products, ploughed back into the soil together with new fertilizers, the metabolism cycle in nature can be regulated as required.

We describe below some technical methods for increasing the moisture content of the soil and using arid lands for non-irrigated, dry farming.

### *Deep autumn ploughing*

It has been proved that the storage of moisture in the soil improves with the depth of ploughing, and that the amount of moisture lost by evaporation decreases accordingly. In pre-revolutionary times horse-drawn ploughs were able to plough down to a depth of 8-12 cm. only. When thus ploughed, the permeability of soil to water remains low, weeds grow up more quickly, and unabsorbed moisture runs away causing erosion, or evaporates quickly. Deep ploughing at the beginning of the autumn enables the soil to hold, absorb and retain the moisture from the autumn rain, winter snow and spring thaw. The universal introduction of autumn ploughing, with powerful tractor ploughs, to a depth of 20-25 cm. in collective and State farms throughout the USSR has brought about a radical improvement in the water régime of soils. In places where, with shallow ploughing, crops died of drought, deep ploughing now enables fine crops to be harvested (southern Ukraine, Volga area, southern Urals).

During the past decade a number of Soviet scientists have been working on the construction of new ploughs to enable the soil to be ploughed periodically to a depth of 50-70 cm. Dr. G. Chikaliki's many years'

1. K. Marx, *Capital*. Translated into English from the first German edition, 1909. Vol. III. p. 945.
2. Ibid. Vol. III. p. 954.

experience in the Crimea, southern Ukraine and the Caucasus showed that super-deep ploughing is exceptionally effective in black earth soil in drought conditions. Further, the practical experience of T. Maltsev, the collective farming expert, in western Siberia, showed that deep ploughing (up to 50 cm.) is one of the best remedies against drought. In alkaline, saline southern steppe soils, deep ploughing, turning over and mixing up the soil horizons, destroys salinity and constitutes one of the best methods of improving alkaline soils so far tried out in the southern Ukraine and the Volga area (V. Kovda, A. Antipov-Karataev, G. Sambur).

*Snow retention on fields*

The steppes of the southern and south-eastern Russian plains, southern Siberia and Kazakhstan are covered in winter with a blanket of snow and the soil freezes hard to a considerable depth. Snow and wind storms sweep the snow from the flat surface of the fields into ravines, valleys and depressions; snowdrifts form against fences and buildings, on the borders of forests, in gardens and round trees. The shallower the snow blanket, the greater the depth to which the ground freezes. Damp frozen soils have a low water permeability with the result that the snow water in spring flows away. When the snow carpet is thick, the soil absorbs a greater quantity of moisture, which then seeps farther into the ground. Winter crops thrive better under a blanket of snow. It has been proved both in practice and by scientific experiment that crops in the arid zones are always better the longer the snow is retained on the ground. Soviet farmers and agronomists have devised various methods of retaining snow on the fields. If the earth from autumn ploughing is left to form piles, it produces an uneven surface conducive to snow-retention. Leaving rows of high stubble lying on the fields when ploughing up fields of maize, sunflowers and Manchurian millet is another very effective way of retaining snow on the fields; so is the erection in fields, in winter, of shields made of straw, branches or planks. Ploughing up the snow surface with tractor-drawn snow-ploughs makes it uneven so that more snow piles up; and less of the melted snow in spring drains off the fields.

*Dead fallow and strip-sown fallow*

Dead fallow, which consists in a repeated loosening of the soil, constitutes a well-tried method for destroying weeds and is particularly effective in dry farming. Dead fallow not only destroys the weeds, which suck up the moisture from the soil, but also makes it possible to store up, in fallow periods, the moisture from the rain falling during the year and place it at the disposal of winter or spring crops. Dead fallow fields always produce abundant crops; in drought years, crops are always better there than when grown on ground used the previous year for other crops. The dead fallow system is particularly effective against drought when used in conjunction with deep ploughing and snow retention. For snow retention, fallow fields are sown with widely spaced-out strips of sunflower, maize, sorghum and Manchurian millet, which yield crops and also improve the water régime of the soil. The effectiveness of the dead fallow system is due not only to the storing-up of moisture but also to other factors including the storage of nitrogen in the form of nitrates, the thermic processing of the earth under the influence of the rays of the sun, and the destruction of pests and weeds.

*Forest strips for protection of fields*

Even before the October Revolution, Russian scientists following the example of the most progressive landowners, and using the results obtained by experimental stations, discovered that it was possible to improve the local microclimate and protect the fields from drought by planting forest strips along the edges of fields in the steppe areas. Some fifty or sixty years ago, Dokuchaev planted forest shield strips experimentally in the Stone Steppe (Voronezh province). The Dokuchaev Agricultural Institute has now been established in this region. The forest strips have grown into large patches which have substantially improved the local ecological conditions. The crop harvest on fields protected by these forest strips is always larger (especially in drought periods) than in the surrounding areas.

Since the Revolution, Soviet farmers have acquired a great deal of new scientific and practical knowledge in this field. Forest strips and the fields they protect have been discussed and examined by climatologists, physiologists, soil scientists, agronomists and forestry experts. It has frequently been proved in practice and confirmed by minute scientific research that forest strips slow down the wind speed at ground level over a distance of 15-20-30 m., i.e., 25-30 times the height of the trees. Forest strips also cause snow to pile up on fields and increase the moisture content of the soil and the air above it by several per cent. The temperature of the air above fields protected by these shields is from 1° to 2° C. lower than the surrounding air. All these are important factors in protecting plants against dry winds and ensuring good crops.

Establishing forest strips is not easy. During the first few years the young shoots are vulnerable to pests and weeds, they suffer from drought and need careful attention. After 4-5 years, however, the position changes. The growing trees already begin to hold the snow and thereby create a more favourable microclimate. Year after year more forest strips are being planted in the fields of State and collective farms in the forest steppe and steppe regions of the Soviet

Union. Fine examples of forest shields are to be seen in large parts of the arid steppes around Stalingrad and Salsk, in the Volga steppes, in the southern Ukraine and in the northern Caucasus. As part of a grandiose experimental project, State forest strips are being created along the watersheds of the Volga, Ural and Don. This is a long-term project. In the arid Volga steppes near the village of Djanybek (north of Lake El'ton) this work has been in progress since 1949 under the scientific supervision of the USSR Academy of Sciences (Soil Institute, Forestry Institute, etc.). In these semi-desert steppes remarkable results have been obtained. State forests and shield strips have been planted, and saline steppes brought under cultivation and made to produce crops. The scientific works published by the USSR Academy of Sciences containing details of these operations deserve careful study as exact factual records. The experts of the main geophysical observatory of the USSR came to the conclusion that forest shields should be sufficiently sparse to allow the wind to seep through them rather than leap over them. Forest shields on this pattern ('open-work shields') give maximum effectiveness in slowing down the wind speed, and do not create violent local air currents and funnels, so enabling the snow to pile up more evenly (M. I. Yudin). Zakiev [52], after studying the experiments in tree-shield planting in the Salsk steppe (northern Caucasus-Don), came to the following conclusions : 'The present position as regards forest strips indicates that it is essential to carry out the following measures, which should be borne in mind in future : (1) the distance between forest strips in the Salsk steppe should be increased to between 450 and 500 m.; (2) the width of the forest strips should be reduced to between 15 and 20 m.; (3) the number of rows of trees in the forest strips should be between 5 and 7 (instead of 9 and more as at present); (4) the edge of the forest strip should be rounded off with bushes; (5) forest strips must be systematically cleared; (6) the meteorological effects of forest plantations in the Salsk steppe could be increased if combined with irrigation of the fields between them.' These conclusions are of general significance.

On the basis of the experience of the Soviet Union, protective forest strips are now being widely planted in the steppes of north-western China, the plains of Manchuria and western China, Rumania and Hungary.

*Stabilization of ravines and formation of small pools*

Ravines, besides harming arable areas by washing away soils and sub-soils are detrimental to farming because they dessicate the soil, increase the depth of the groundwater (like drains) and intensify the effects of drought. Measures for dealing with drought must therefore necessarily include stabilizing ravines and transforming them wherever possible into small reservoirs or pools. It is possible, by leaving the soil on the slopes near the top of ravines unploughed and planting grass there, by planting young trees on the steep slopes of the ravine, and by planting young willow shoots in the bottom of the ravine to act as a stopper, to prevent the top of the ravine from being washed away and turn it into valuable land. Another useful measure is to build small dykes in ravines and gullies in order to contain and preserve the flowing water, and provide drinking water for men and cattle, as well as for vehicles—a very important point in the desert and steppe areas. Fish and water-fowl can be reared in these reservoirs; and the water is used for irrigation of fields and small allotments. Lastly, these pools feed the underground waters which supply water for wells and for the roots of trees.

Thousands of pools fed by local water sources have been and are being built by collective and State farms in the steppe regions of the USSR, Hungary and Rumania. Extensive work on the afforestation of ravines and the building of small reservoirs is being done in the north-western forest areas of the People's Republic of China.

*'Depression farming'*

The semi-desert dry plains in the south-eastern part of the USSR are dotted with flat, oval, shallow depressions called by the Russian peasants in the past *padiny*, formed as a result of a 'subsidence' process (*suffossio*). The size of these depressions varies between 0.25-0.5 and 10-12 hectares, and their total area constitutes 3-5 per cent of the surface of the dry steppe region. Snow, rain and the melting snow water in spring in the semi-desert collect in these depressions; they thus receive an extra 300-500 mm. of moisture in addition to the atmospheric precipitations, which in this area total 250-300 mm. a year. For this reason, the soil in these depressions contains no salts, has a 4-5 per cent humus content, is 100-120 cm. thick and resembles black earth soil. Wells sunk in these depressions usually yield good fresh water; they are planted with fields and vineyards and trees. With the ordinary agrotechnical methods they produce excellent crops of wheat, beet, maize and melons. The agricultural activities carried on in these depressions include cattle-breeding, the main agricultural occupation in the dry steppe areas.

*'Liman' irrigation*

The experience of depression farming in the arid zones in the south-east of the USSR gave farmers and scientists the idea of attempting to redistribute and regulate the discharge of rain and snow water so as to provide more moisture for arid lands. On the long gentle slopes, in the Trans-Volga steppes, measures were taken as long as 75-100 years ago to build a system of ramparts, running horizontally along the sides of the slopes. These ramparts were 2-2.5 m. high and about 4-5 m. wide. In some cases they were accompanied by a second and a third row of lower, narrower ramparts, and they were often equipped with drain-holes. The snow and rain water flowing down the long slopes is caught and held by these ramparts, and gradually distributed over the topmost tiers of the field. This system is known as ordinary or multi-tier *liman* irrigation (multi-tier if there are several rows of ramparts, one above the other). Along each rampart a considerable quantity of water collects, seeping deep into the soil and washing away noxious salts. Crops on fields irrigated in this way are always more abundant than in the surrounding areas. This type of irrigation usually produces good pasture and hayfields.

However, since the moisture is unevenly concentrated (large quantities along the ramparts, less up the slopes) the crops are not evenly distributed. In very dry years when there is no snow, crops on these fields naturally yield a smaller harvest; but this method or irrigation is, generally speaking, so effective and cheap that collective and State farms in the south and south-east of the USSR are using it over an area covering thousands of hectares, and there are plans for applying it to a further 2 million hectares of arid land.

Another variety of depression farming found in the desert of Turkmenistan is the so-called *khaki* farming (Dzhumaev [13]). After rain in the mountains, streams course down the slopes of the Kopet Dag Mountains on to the desert foothills, pouring their waters always into the same places, known as khaki. When they have dried out a little, these khaki are ploughed-up and used for cultivation of crops.

### Trench agriculture

Up to 80 million ha. of the deserts and dry steppe areas of the USSR consist of sand soil. Of this area, up to 5 million ha. have fresh groundwaters near the surface. In these areas we find *Lasiagrostis splendens*, *Eragrostis arundinacea*, *Elymus aralensis* and other plants growing in the meso-relief depressions amidst the sand ramparts. The Soviet scientist E. Malyugin [33], in 1937-1939, devised and put into practice a method for cultivating vegetables (cabbage, cucumbers, tomatoes, etc.) in wide trenches (1.5-3 m.) and 1.2-1.5 m. deep. Figure 7 shows the preparation of these trenches and gives Malyugin's descripton of the process. Crops grow and give an excellent yield in a very arid climate, sucking up the capillary moisture of the water-bearing horizon through their roots.

An even more interesting project is that of growing plants on sand along the seashore by using the lens

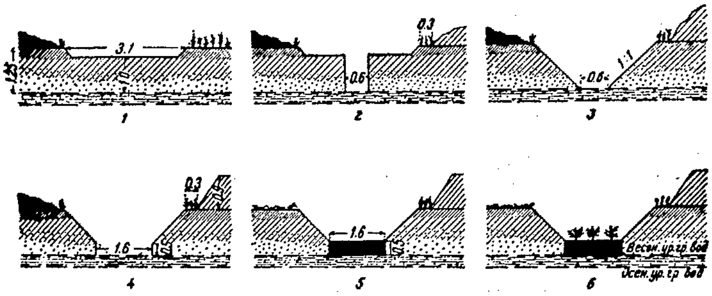



FIG. 7. Successive stages in the digging of trenches on meadow calcarous soils in sandy areas by the method devised at the Aral Experiment Station. (After E. Malyugin, 1939.)

1. The top humus layer of the soil (0.2-0.3 m. thick) is removed from the whole of the trench area and piled up on a narrow strip (3-4 m. wide) between the trenches.

2. The main trench, 0.6-0.7 m. wide (never narrower than 0.5 m. in any case) and reaching down to the spring level of the groundwater is dug out; the subsoil thus removed is piled up on a wide strip between the trenches (6-10 m. wide) and firmly rammed down; a ledge 0.3 m. wide is left between the piled-up subsoil and the edge of the trench.

3. Slopes (1 : 1 or 1 : ¾) are then cut; the subsoil removed in this process is likewise placed on a wide strip between trenches and rammed down.

4. The bottom (0.5-0.6 m.) section of each trench is cut vertical so that the width of the trench at the bottom is 1.6 m.; the subsoil dug out in this process is likewise rammed down; the embankment formed by the piled-up subsoil is cut out in a 1 : 1 gradient; the height of this embankment must not exceed 1 m.

5. The trench is then filled in with a 50-60-cm. layer, up to the level of the vertical section of the trench, of the top humus soil which had been piled-up, temporarily, on a narrow strip between the trenches. All shoots and roots are removed from this layer of soil, and it is levelled out.

6. The sowing and planting of agricultural crops is done 3-5 days after this top soil has been damped and levelled down; when there is not sufficient earth, the top layer of the narrow inter-trench strip is taken; a trench should, when properly filled, have a top planting layer of dry earth 2-3 cm. thick.

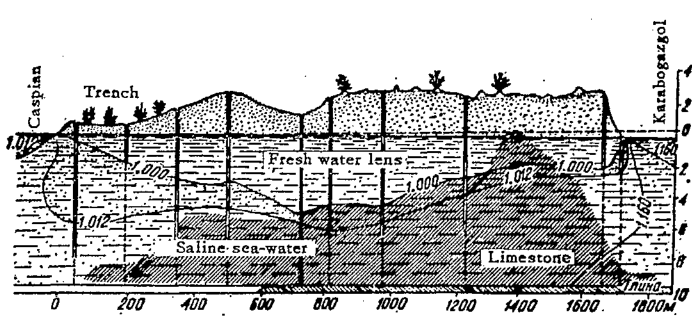



FIG. 8. Section of groundwaters in the seashore belt of the eastern Caspian (Elovskaya).

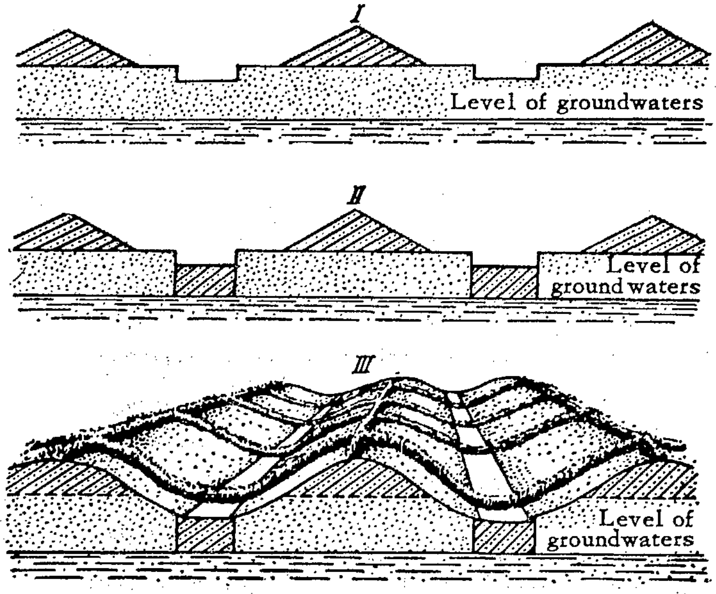



FIG. 9. Successive stages in the digging of a trench in seashore cockle-shell sand by the method worked out at the Karabgazgol base (E. I. Kalashnikov).
I. The top layer of sand is removed along the whole length of the trench and piled up on the strip between the trenches.
II. The sand remaining in the trench (not more than 80 cm. above the level of the water) is spread all over the bottom of the trench together with a mineral fertilizer (absolutely essential).
III. Mechanical shields are erected along the embankments in order to prevent the trench from being filled up by sand.

of fresh groundwater usually found as it were 'floating' on top of the heavier saline groundwater. The existence of a surface layer of fresh water 2-3 cm. deep on the top of groundwaters in the sands of the Caspian and Aral shores is well known (Fig. 8). Similar fresh-water layers are likewise found in the sand along the shores of North Africa. The formation of this fresh-water film on top of the horizon of salt groundwaters may be due both to the condensation of vapour and to the infiltration of rainwater. The best results are obtained on this sand when the groundwater lies at a depth of 1-1.5 m.

For growing melons, potatoes, tomatoes, onions, beet, cabbages, etc., trenches are dug (Fig. 9). Vines, figs, berry plants and trees may be cultivated in either trenches or deep pits.

The crop yield in relation to the area of the trenches is fairly high : potatoes, 70,000-80,000 kg. per ha.; beet, 50,000-80,000 kg. per ha.; cucumbers, 80,000 kg. per ha.; onions, 29,000 kg. per ha.

However, the reserve of fresh water is very small and is quickly absorbed by the plants, with the result that the trenches have to be moved to another place in two or three years. Trees, apples, figs and vines can be grown for longer periods, provided the area is sufficient to provide them with nutriment.

In the sandy deserts of Turkmenistan, water-melons and melons, planted in deep holes, grow excellently on the shifting sandhills without any kind of irrigation. Each plant requires a large intake area (75-100 $m.^2$), when this is available they are able to make use of the tiny quantities of condensed moisture stored in the sand.

### '*Kair*' *farming*

Since earliest times people have cultivated grain and vegetable crops on the flood terraces of the large rivers which cross the deserts of Central Asia (Amu Darya, Sir Darya, Zeravshan, etc.) without any form of irrigation. The narrow strips of non-saline alluvial soil with fresh groundwaters in the vicinity are called *kairs*. Agricultural crops growing on these kairs use the fresh underground water filtering into the flood terraces from the river-beds, which they absorb through their roots.

Depression and khaki, farming, estuary irrigation and kair farming are in fact primitive forms of irrigation farming. In the remote past, it was probably these types of farming which gave man the idea of trying larger scale irrigation.

## DEVELOPMENT OF 30 MILLION HA. OF VIRGIN LAND IN THE ARID STEPPES OF THE USSR

In tzarist times, every drought was accompanied by famine. It was impossible, with the small peasant system to counteract drought. At the same time, practical and scientific experience of dealing with drought was gradually being accumulated, but neither this experience nor the scientific work of Russian agronomists could be put into practice in the backward conditions of pre-Revolutionary Russia. The change came only after the October Revolution, and in particular after the establishment of large collective and State farms using technical equipment, fertilizers and scientific farming knowledge.

Thus in pre-Revolutionary Russia the southern limit of non-irrigation farming roughly followed the isohyet for 350 mm. annual rainfall, but after the Revolution, during the thirties, the limit was pushed farther up into the dry steppes, until it coincided, roughly, with the 250-mm. isohyetal line (Makaroff, 1926; Selyaninov, 1933). During the forties and the early fifties, dry farming on sandy soils (which have a more favourable water régime) was extended, thanks to the work of the scientists and farmers, to the 150-mm. isohyet (Fig. 10), and thousands of hectares in these areas are now successfully used for the cultivation of millet and spring wheat.

When ploughing virgin sandy loam however, attention must be paid to the danger of the deflation

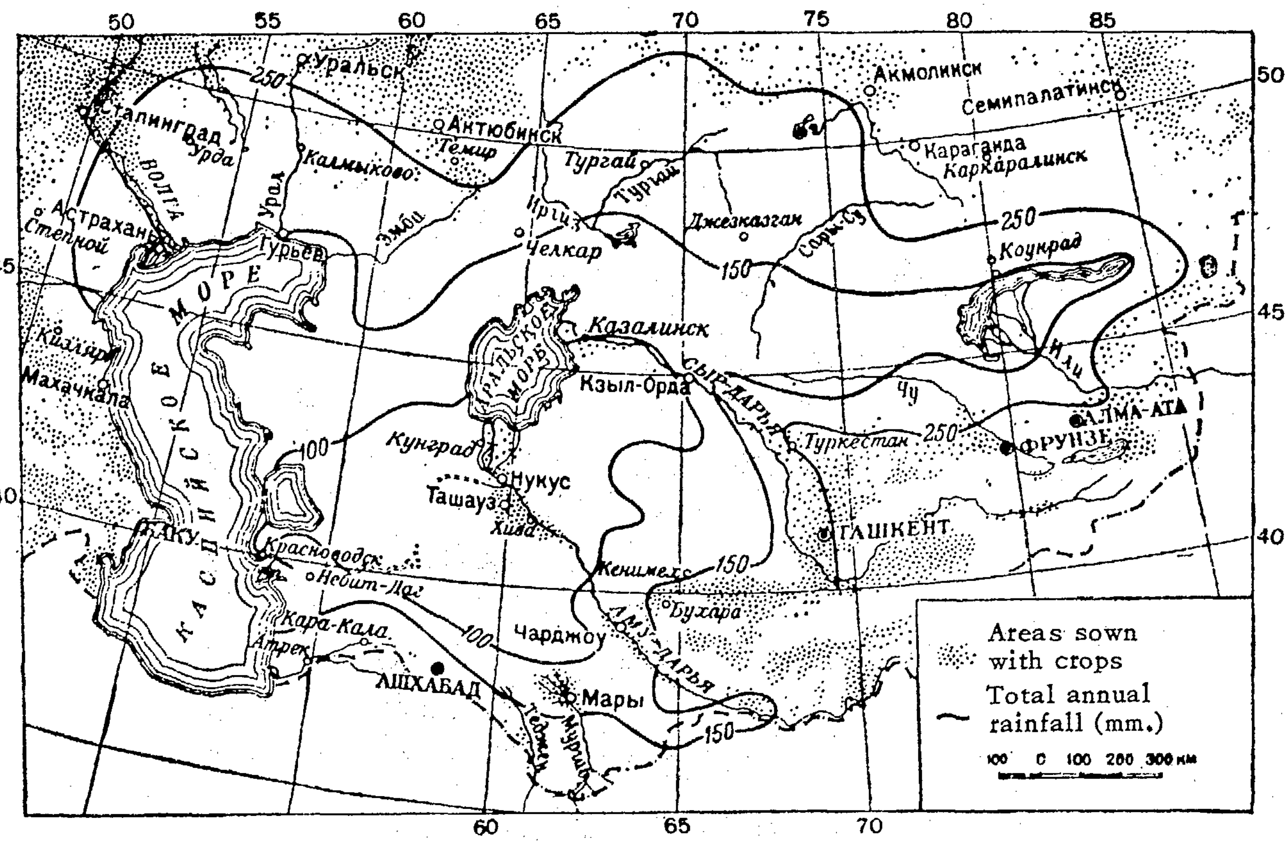



FIG. 10. Map of farming in the desert and semi-desert regions of the USSR (Drawn up by I. F. Makaroff and completed by E. A. Malyugin.)

of the arable soils. It is essential to take all measures to prevent deflation, including planting forest strips, strips of high plants, grass sowing, and leaving stubble lying on the ground either over the whole of the field or on strips of it.

Extensive areas of virgin and long-disused lands were successfully brought under cultivation in the Volga, Ural, south Siberian and Kazakhstan steppes in the 1954-1957 period. During this very short period, the Soviet Union, owing to thorough research and preparation, succeeded in ploughing up a vast tract (30-32 million ha.) of virgin land and planting it with spring wheat and other grain crops.

Thousands of large, new, mechanized State farms were set up throughout the southern black earth and dark chestnut earth belts, and on the brown and light chestnut earth areas previously not used for field-crop cultivation on account of the dryness of the climate and the uncertainty of the harvests.

Soviet meteorologists proved that there is, in the dry steppes of the Asiatic part of the USSR, a very definite maximum summer rainfall. Research carried out at the agricultural experimental stations in the Ural, Siberia, Volga regions and Kazakhstan showed that spring wheat can be successfully planted in these regions and yield good crops given certain agro-technical conditions. In these conditions too, maize produces an abundant leaf crop for fodder or grain fodder of a milky, waxy consistency; millet also produces an excellent crop in these areas. The cold climate in the north of the Asiatic steppes, and the aridity and salinity of the soil in the southern steppes, of course, make field-crop cultivation more difficult.

The territory whereon the new 30-32 million ha. of virgin land were brought under cultivation has been divided up, as regards agro-climatical conditions, into six zones (Fig. 11). L. N. Razumova [39] describes these zones as follows :

For each of these zones, details are given of the water supply for spring wheat when sown on land ploughed in autumn, fallow and spring-ploughed land together with an assessment of the water supply for wheat with each of these agronomic types of soil. Since it is impossible to describe the characteristics of each zone in detail, we shall confine ourselves to the main points.

Zone 1. Very poor water supply—less than 15 per cent of optimal supply. The cultivation of spring wheat is possible only in depressions or with irrigation.

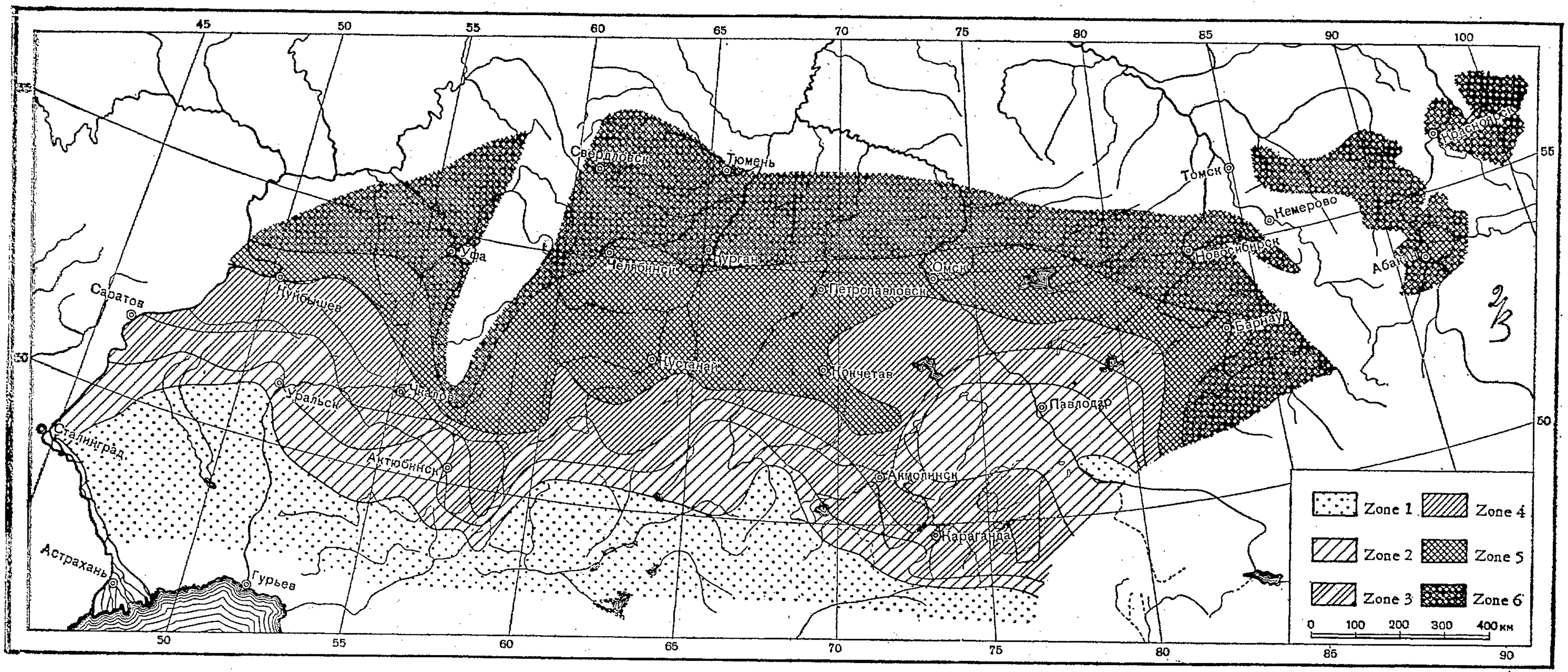



FIG. 11. Water supply (given as a percentage of the optimal supply for spring wheat sown on autumn-ploughed fields with loamy soil unaffected by groundwaters in the newly cultivated, virgin and long-disused land.

Zone 2. Poor water supply—15-30 per cent of optimal supply. The supply of moisture for spring wheat is insufficient or barely sufficient even when sown on dead fallow.

Zone 3. Insufficient water supply—30-35 per cent of optimal supply. The moisture supply for spring wheat is sufficient when sown on bare fallow fields.

Zone 4. Water supply satisfactory—45-60 per cent of optimal supply. Moisture supply for wheat satisfactory when sown on autumn-ploughed land; on bare fallow land, sufficient and in some places good; on spring-ploughed land, poor and insufficient except in a few places, where it is satisfactory.

Zone 5. Water supply sufficient—60-75 per cent of optimal supply. Moisture supply for spring wheat satisfactory and sufficient even when sown on spring-ploughed land.

Zone 6. Water supply good—over 75 per cent of optimal supply. Wheat can be sown in all agronomic conditions, so that it never has to be grown on bare fallow land. In the north and north-eastern parts of this zone however, late sowing is impossible as it becomes too cold.

The most important agro-technological factors for improved crops are maximum speed in all farming operations, deep autumn ploughing, snow retention on fields and the use of dead fallow land. The experience of the years from 1955 to 1959 inclusive, showed that the newly cultivated lands in the dry steppes of the Asiatic part of the USSR are capable of providing the Soviet Union with an extra quantity of wheat totalling between 0.3 and 0.5 million metric tons a year, depending on weather conditions.

The credit for this extraordinary achievement in the history of agriculture—the cultivation of dry steppe areas—lies with socialist production methods, characterized by an exceptionally high level of mechanization, and a scientific approach to farming and agro-technology.

## IRRIGATION IN THE DESERTS AND STEPPES OF CENTRAL ASIA AND THE CAUCASUS

The irrigation systems along the Amu Darya, Sir Darya, Zeravshan, and Murghab rivers are as ancient as those used in the deltas of the Nile, the Tigris and Euphrates. Owing to the peculiar geomorphology and hydrology of these river deltas, they were used from very early times for irrigation farming.

The ancient and contemporary deltas of the Amu Darya cover a vast territory, totalling approximately 50,000 km.². In the early Quaternary period, the waters of the Amu Darya filled the Sary Kamysh and Aral hollows. At that time, extensive floodplains were formed on which primitive man settled.

The researches of the Soviet archaeologists Kastalsky, Tolstov, Gulyamov and Andrianov show that, in the fourth to third millennia B.C., the vast ancient delta of the Amu Darya was already being used by sedentary tribes engaging in fishing and hunting. This was in late Neolithic times. Primitive hoe farming on flooded delta land began later, not before the third to second millennium B.C.

The extensive network of naturally formed river arms and shallow streams (a formation characteristic of all deltas) facilitated artificial flooding of the lands used for crop growing. Water flows automatically into shallow river arms and channels of the deltas when the water level rises during flood periods; it follows the natural streams of the delta, and is then distributed through artificially constructed canals. In the later stages of the development of delta settlements, steps were gradually taken to improve the natural channels and transform them into large artificial canals. Each of these canals was fitted with several primitive sluices by means of which the water could be distributed through irrigation systems when the level of the river water varied (even when it sank very low).

Gulyamov [18] points out that the irrigation builders on the Amu Darya, even in remotest times, had already discovered the best angle at which to build canals in order to give the maximum water supply and to protect the irrigation canals against deposits of river silt.

The lower reaches of the Amu Darya delta formed the centre of one of the most important ancient farming civilizations of Central Asia, the 'Khorezm' civilization, part of whose history can now be reconstructed thanks to the research done by Soviet archaeologists (Tolstov [47-50] and his followers). Links have been established between the ancient peoples inhabiting the Khorezm area and other ancient peoples belonging to civilizations of the East—China, India, Arabia, Africa and also peoples of Eastern Europe, Siberia and Kazakhstan—that practised irrigation. As early as the Bronze Age (the end of the third and during the second millennium B.C.) the semi-sedentary inhabitants of this area engaged in stockbreeding and irrigation hoe farming similar to that pursued by the civilizations of the Near East and Central Asia. It is possible that the earliest type of farming here was the so-called 'kair' farming (still used in some parts to this day) i.e., cultivation of agricultural crops on the non-saline soils along the river floodlands in places where fresh groundwater exists near the surface. In these conditions no irrigation is necessary, and good reliable crops can be grown using the underground water supply.

Hecataeus of Miletus and Herodotus, in the fifth and sixth centuries B.C., reported that the predecessors and ancestors of the Kara-Kalpaks and Khorezm Uzbeks now living in the Amu Darya depression engaged in nomadic stockbreeding, hunting and fishing and had a well-developed farming system. This is further confirmed by some of the Kara-Kalpak epics. Thus for instance, we know that the Kara-Kalpak amazons went in for farming as well as war and hunting (Tolstov). However, the development of irrigation farming in ancient Khorezm dates only from the middle of the first millennium B.C., one of the earliest names of the Khorezm State, 'Konga', also dates from this period.

The uneven depositing and accumulation of alluvial deltaic silt continually changed the relief and hydrology of the deltas of the large rivers such as the Amu Darya, Sir Darya, Murghab, and Kura. Asa result, gradual changes occurred in the hydrographical network; some parts of the delta were flooded, whilst others suffered desiccation or salinization (Andrianov [1]).

Generally speaking, both the settlements and the irrigation canals followed the beds of the delta channels. Man attempted to preserve the channels by deepening them artificially, and by building primitive dams and water-distributing devices. Silt and sand are deposited in delta channels in such large quantities that they eventually fill up, so that they no longer allow the water to flow through in sufficient quantities. In order to obtain water, man builds rudimentary dams and devices to direct the water flow, and deepens the channels; but eventually the water flows off in another direction, cutting new channels in the delta, and the old ones dry up completely. The settlements and irrigated fields along the old delta channels are abandoned, and the soil dries up and salinifies. Such changes occurred regularly and repeatedly in the deltas of the Amu Darya, Sir Darya, Kura and Hwang Ho. But man gradually obtained more control over the hydrology of deltas. This is clearly illustrated by Fig. 12, taken from Tolstov's monograph [50].

By about the second quarter of the first millennium B.C., an extensive, ancient irrigation network already existed in the Amu Darya delta (Tolstov); by that time, irrigated oases were even protected to some extent against flooding; the irrigation network was shaped like the branches of a tree; every large canal had several well reinforced and equipped sluices. All the old irrigation works, in particular dams and sluices and the heads of canals, were carefully protected by the population against enemy attack. Fortresses were built near them and a garrison of warriors was always stationed there.

The chart of the delta soil irrigated in the sixth to fourth centuries B.C., prepared under the supervision of Tolstov, showed that a very large area was covered by these irrigation systems, altough little use was made of the agricultural land. As the population grew and society developed, the area of irrigated land was extended and irrigation techniques improved.

The first large irrigation canals of ancient times were simply natural arms of the delta (channels), and were therefore extremely wide and shallow.

In mediaeval Khorezm, narrow and relatively deep canals were already being built (Tolstov) and fine, regular irrigation networks were being used; in the ninth and tenth centuries, water-wheels with pails (*čigir*) were already in use.

The development of irrigation farming along the large rivers requires strict, centralized supervision, a fact which was largely responsible for the appearance

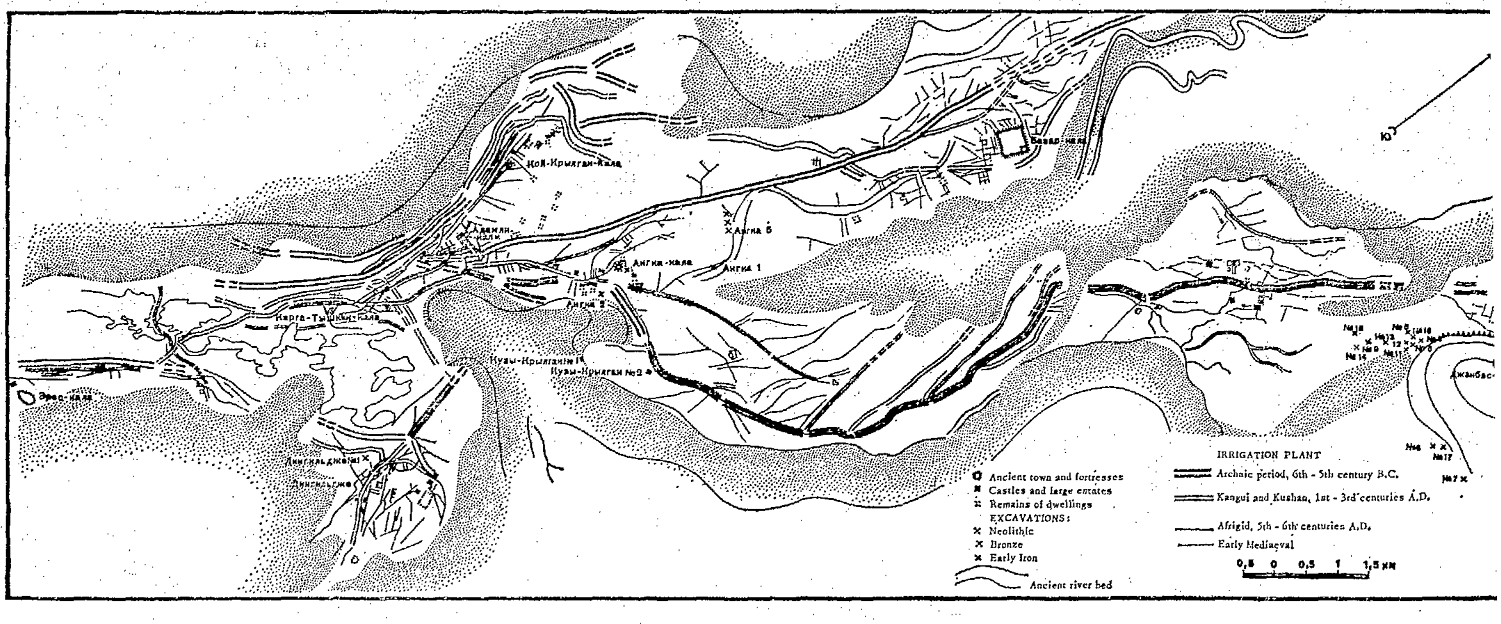



FIG. 12. Ancient irrigation system of the Kelteminar civilization (T.N. 4-3 century B.C.; so named after the village of Kelteminar, near Turtkul) in the Amu-Darya delta.

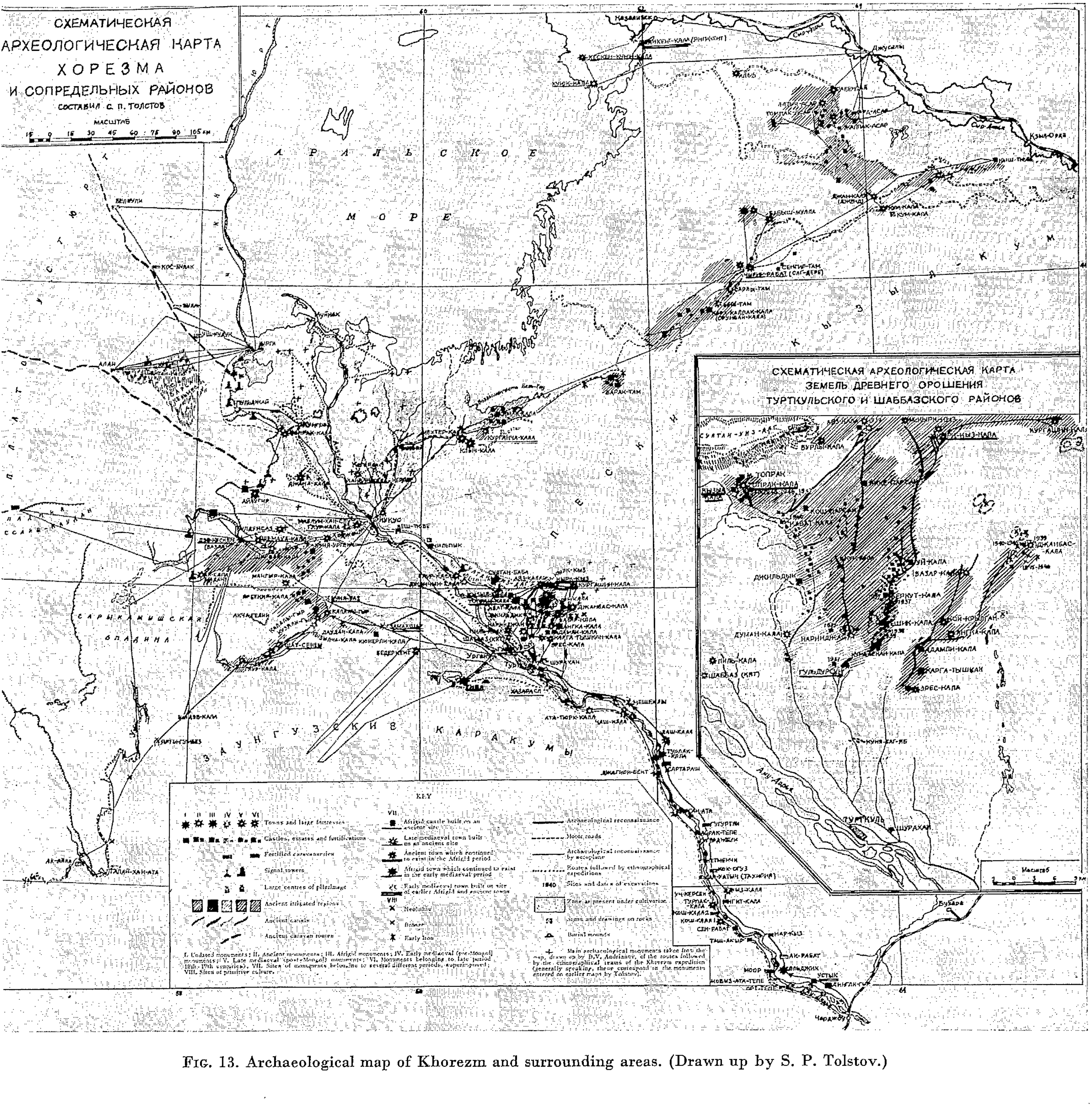



FIG. 13. Archaeological map of Khorezm and surrounding areas. (Drawn up by S. P. Tolstov.)

in the Amu Darya delta of a centralized slave-owning State, simultaneously with or possibly slightly earlier than the birth of the State of Western Iran (Tolstov, 1948; Andrianov, 1955).

The main towns of eastern Iran—Balkh, Samarkand, Merv and Herat—were the centres of the ancient civilization of Iran. In the sixth century, the territory of eastern Iran included ancient Bactria, ancient Murghab (Merv), Sogdiana (along the Zeravshan River), and Khorezm along the Amu Darya. In each of these States there was, combined with semi-nomad settlements, a highly-developed system of irrigation farming and a well-organized irrigation system.

Ancient Khorezm on the Amu Darya with its remarkably highly-developed civilization and agricultural system and its numerous hydro-technical works and irrigated lands, had two main periods of prosperity, in the fourth century B.C. and the first century A.D.

Alexander the Great's campaigns into Central Asia showed his contemporaries that there existed in Central Asia, along the Zeravshan, Amu Darya, Sir Darya and Murghab rivers, a highly-developed system of irrigation farming. For instance, irrigated rice was extensively cultivated in these parts. The fall of the empire of Alexander the Great was followed by the rise of the independent Graeco-Bactrian Kingdom, which covered all the same territory, together with the basins of the Sir Darya, Zeravshan, Murghab and Amu Darya.

In the fourth to sixth centuries A.D., the area of irrigated land was substantially decreased, a fact attributed by Tolstov to the disintegration of the slave-owning system, the development of a feudal economy, and the Hun and Turk invasions. After that came another period of prosperity of the farming civilization of ancient Kohrezm.

In the Middle Ages, ancient Khorezm enjoyed two periods of prosperity. There were, according to the reports of Arab geographers, very large irrigation canals in various part of the delta. Along the banks of the Amu Darya were extensive oases, where the people engaged in irrigation farming, and the large city of Kyat, the capital of Khorezm. The main irrigation canals, including the Heri, Kurder and Baghdad, were built in the first centuries A.D. However, the Arab invasions in the seventh to ninth centuries resulted in the destruction of the irrigation canals and the abandonment of irrigated lands. The Arab conquerors found here an immensely rich and civilized country, with large cities, numerous villages and an extensive irrigation system. This civilization subsequently recovered and, according to Kastalsky, an area of up to 200,000 ha. of land in Central Asia was irrigated at that period. The irrigation systems of ancient Khorezm and Sogdiana were entirely destroyed in the thirteenth century by the Mongol invaders; as a result of this, during the thirteenth and fourteenth centuries, the position of the Amu Darya delta shifted considerably, and the Amu Darya again flowed into the Sary Kamysh depression, transforming it into a vast reservoir.

In ancient times the irrigation of the Amu Darya delta was combined with that of the Sir Darya delta; in the area covered by the two deltas, there were channels and arms, the water of which was used for irrigation in the Aral Sea area. Archaeological excavations show that these channels existed, and were used for watering the land. The Kara-Kalpaks built huge weirs of clay and wood which fed main canals hundreds of kilometres long (Tolstov). Thus for instance the Zhan-Darya channel in the second half of the eighteenth century was fed by large hydro-technical works built by the Kara-Kalpaks at that period.

Subsequently, during several decades of wars and in particular as a result of the devastating campaigns of Mohammed Rakhim Khan (1809-1811), the Zhan-Darya channel ceased to exist, and irrigation farming in these parts disappeared.

The old canals on the Amu Darya and Sir Darya, as well as other canals, were equipped with complicated, carefully designed sluices, constructed of brushwood, earth and wood (haloxylon). They required constant attention to keep them in working condition. In wartime, of course, the destruction of this equipment ruined the entire irrigation system. The alluvial and irrigation deposits which raised the level of the land in deltas also, of course, had important effects on the distribution of the water flowing into the canals. Military and purely political events sometimes led to unexpected, major disasters involving the destruction of the canals and of the irrigation system. Thus on orders from the Khan of Khiva, who was striving to terrorize the Turkmens living on the channels branching out from the left bank of the Amu Darya, these channels were in some periods closed completely, depriving the population of water. As a result of this, large stretches of cultivated land in Turkmenia (border region) were completely abandoned.

Apart from this, serious floods sometimes occurred, caused by allowing the waters of the Amu Darya to pour uncontrolled into the irrigation canals which were thus washed away.

After many years of archaeological research, Professor Tolstov and his pupils prepared a master map showing the history of irrigation in the Amu Darya delta. The results of this research were published by the USSR Academy of Sciences (1950-1956). The gist of this information is given on the archaeological map (Fig. 13).

The history of irrigation on other Central Asian rivers—the Murghab and the Tedzhen—goes back even farther.

There is a theory, based on the archaeological research of Pompelli (1904) at Anau (near Ashkabad) that farming began on the foothills of the Kopet Dag Mountains in the seventh to ninth millennia B.C. Though this theory is disputed by many experts, it must be admitted that farming has been carried on in this area since very early times. On the foothills of the Kopet Dag Mountains, where the ancient Turkmenian irrigation systems are located, we now find wild cereals, the predecessors of modern agricultural crops such as wild wheat and wild barley. Apparently ancient man way back in the Stone Age used to gather the crops of these wild grain plants on the alluvial cones and dry deltas of the mountain streams and rivers that irrigated the land along their lower reaches. (Dzhumaev [14].)

Archaeological monuments and the remains of ancient irrigation farming have been found in the foothills of the Kopet Dag Mountains along the Kelt-Chenar, Anau, Ashkhabad, Ak-Tepe and Kassgan Chai rivers. This type of primitive irrigation obviously needed neither hydro-technical devices nor canals; it was based on the use of rainwater streams flowing down from the hills and exists to this day in some hilly parts of Turkmenistan.

In connexion with the Kopet Dag Mountains, special mention should be made of the now non-existent 'Parthian Oasis' which belonged to the ancient Parthian Kingdom, possibly being its main centre. Excavations which have been carried out here for more than 50 years by various experts have revealed the ancient capital of Parthia, Nissa (not far from Ashkhabad) and the remains of irrigation farming dating back to the fourth millennium B.C. The Parthian Oasis, with its rich agriculture, is mentioned in the notes of King Darius, in the writings of Herodotus and the historians of Alexander the Great, who conquered Parthia.

In the third to second millennium B.C., in the Bronze Age, came the development of irrigation farming in the dry deltas of large rivers such as the Murghab and the Tedzhen. At that period, primitive canals were built on the ancient arms of these river deltas. Herodotus noted that there existed on the Akess (Tedzhen) in the fifth to fourth centuries B.C., extensive reservoirs equipped with sluices which distributed the irrigation waters in the lower reaches of the river.

About the end of the B.C. period and the beginning of the A.D. period, vines, gardens, cereals, rice, cotton, water-melons and melons were cultivated along the Murghab River. Despite various wars and disturbances resulting in the destruction of part of the irrigation system, irrigation farming continued to develop. The ancient Persians and Greeks called the Marysk Oasis 'Margiana' (from the Greek name for the Murghab River—the Marg). At that time (in the first millennium and more particularly the third century B.C.) Margiana ranked in prosperity with Egypt and Mesopotamia. This continued right up to the thirteenth century A.D. after which came several centuries of eclipse due to the Mongol invasion and the destruction of the irrigation system.

The dams and irrigation works on the Murghab were partially restored in the fifteenth century, but the standard of irrigation never again reached the same level as before the Mongol invasion. In south-west Turkmenia the people had since earliest times used a special form of temporary irrigation based on the use of the flow of mountain rainwater into various kinds of flat depressions. Thus we find in south-west Turkmenia what the Turkmens called *Urochische Bugdaily*—the 'granary' or simply 'wheat'. Here we find thousands of hectares of land where wheat is grown using the moisture of the rainwater flowing down from the mountains.

An interesting point is that the thickness of the fertile soil layer deposited by irrigation on the ancient irrigated foothills of the Kopet Dag is up to 7 m., which indicates the antiquity of irrigation in these parts.

In addition to the large rivers, the inhabitants of Central Asia (Uzbeks, Tadjiks, Turkmens, Kirghizes) also made use of the shallow streams and rivers flowing down the hills, by means of primitive works. There are large numbers of examples of ancient and modern primitive hydro-technical constructions, some of it now forgotten and partially destroyed, on the hill plains along the crests of the Nur-Ata and Kopet Dag Mountains.

According to the findings of geographers, soil scientists and archaeologists, this area was much better watered than others. We find here long strips of solonchak depressions which, according to popular legend, are sections of the ancient river of Sir Darya. Relics of the late Bronze Age indicate that this area was thickly populated in the past; and the name of these depressions—Kolgan-Sir (the channel of the Sir Darya)—indicates, as Gulyamov points out, that the people still had memories of the time when this area was well watered.

Geographical and archaeological research alike show that the main reason for the destruction of the ancient irrigation systems on the main rivers of Central Asia and Transcaucasia was the Mongol invasion in the thirteenth century and the campaigns of Tamerlane, which also resulted in the destruction of numerous towns and irrigation works in Turkestan, the Middle and Near East, and the Caucasus. The ancient regions of Khorezm and Merv suffered particularly; the Mongol conquerors not only conquered these countries and sacked their capitals, but also completely destroyed their irrigation systems.

Lands formerly irrigated and fertile were transformed into deserts and became salinified. Parts of them were buried by shifting sands; extensive areas were transformed into takyry. The irrigation system on the

Amu Darya was gradually reconstructed; but in the fourteenth and fifteenth centuries, repeated invasions by Tamerlane destroyed the ancient irrigation system in Khorezm completely. There exist, on the territories of the States destroyed first by the Mongols and later by the Seljuks, numerous ancient architectural monuments, remains of aqueducts and beds of old irrigation canals sanded over. It was only in the seventeenth, eighteenth and nineteenth centuries that the Kara-Kalpaks, Turkmens and Uzbeks began to build irrigation canals again and restore the irrigated lands.

Irrigation has also been practiced from earliest times in the arid steppes of Siberia and Kazakhstan. Archaeological research has revealed, in the steppe region of Khakass, the remains of ancient irrigation systems which existed in the middle of the third millennium B.C.; and archaeological data and Chinese written sources alike show that the ancestors of the present inhabitants of Khakass cultivated barley, millet and other crops. Granite weirs were built to feed the canals, some of which were 30 km. and more in length (Tanzybaev [46]).

The Mongol conquerors in the thirteenth century destroyed these irrigation systems, and farming in Khakass revived only in the eighteenth and nineteenth centuries with the arrival in the area of Russian migrants.

Irrigation farming in Transcaucasia, along the Kura, Arake and small mountain rivers also dates back to ancient times. Thus in the ninth to eighth centuries B.C. there existed in Transcaucasia the Urartu State, where water reservoirs and canals were built and artificial irrigation was extensively practised.

If we take the archaeological data and compare the irrigation methods used in various regions, the development of irrigation techniques may be summed up as follows : (a) Use of the natural floodwaters of rivers in deltas and floodlands; (b) artificial diversion of high floodwaters into hollows and depressions; (c) hydro-technical engineering works and irrigation by regular flooding of fields; (d) application of narrow streams of water by means of channels or furrows; (e) sprinkling irrigation. The method most commonly used at present is irrigation by means of furrows.

At the time when the Central Asian territories were joined to Russia (at the end of the nineteenth century) there were about 3 million ha. of irrigated land in those territories, and about 800,000 ha. in the Caucasus. Since tzarist Russia was interested in the nineteenth century in acquiring its own cotton growing area, the government organized measures for irrigating the territory. In 1894 a special section for agricultural reclamation was set up in the Department of Agriculture to deal with the development of irrigation; but political and economic conditions in pre-Revolutionary Russia slowed down the development of irrigation, and by 1917 the total increase of irrigated land in the country was only 260-280 thousand ha.

At the time of the entry of the Central Asian territories into the Russian Empire, the marked social inequality in regard to irrigation farming was maintained. Thus in 1914 the irrigated land in Turkmenia was distributed as follows amongst the various social groups :

| | Proportion of population | Proportion of irrigated land owned |
|---|---|---|
| | % | % |
| Farm labourers | 10.8 | 0.0 |
| Poor peasants | 50.0 | 26.0 |
| Middle peasants | 27.9 | 40.0 |
| Rich landowners | 11.3 | 34.0 |

The poor peasants rented land from the rich landowners on very disadvantageous terms, receiving only one-third to one-tenth of the harvest. No real revival of farming occurred in Central Asia until after the great reforms following the October Revolution. From the moment of its access to power, the Soviet Government carried out extensive irrigation works designed to abolish drought and its consequences.

In the troubled period of the Civil War in 1918, the Council of People's Commissars passed a resolution allocating 50 million roubles for irrigation measures in Turkestan and for the development of irrigation over an area of a million hectares.

In the period from 1924 to 1942, approximately 6 milliard roubles were spent on land improvement and irrigation works in the USSR; whereas in pre-Revolutionary Russia, in the period 1867 to 1917, the sum spent on this work totalled only 100 million roubles.

Under the Soviet régime, vast new irrigation systems have been established in Uzbekistan, Kazakhstan, Tadjikstan, Azerbaijan, Armenia, the Volga area, the Terek area, southern Siberia, southern Ukraine, Crimea and the northern Caucasus.

The wealthy collective farms of the Ferghana Valley, the Tashkent Oasis, Samarkand, Vakhsh and Azerbaijan, and such State farms as the Pakhta-Aral, Bayaut, and Kara-Chala are famous all over the Soviet Union for their traditional crops of vines, cotton, rice, sesame, and fruits, amply repaying the work of the farmers.

Shortly before the last war, the USSR had become a great cotton producing country; at the present time, the USSR produces 4 million metric tons of raw cotton every year.

The huge hydro-electric power stations constructed on the Volga, the Dnieper, the Amu Darya and the Don in 1950-1958 provided a further 22.5 milliard kWh. electric energy per year. At the same time, new irrigation and water works were being constructed over an area of about 30 million ha. in the arid and desert regions of the Volga, Don, southern Ukraine, northern Crimea; and in the deserts of Caspian, Turkmen and Kara-Kalpak. The increase in the area of irrigated land in the Soviet Union in the post-revolutionary period is indicated in Table 4.

TABLE 4. Development of irrigated farming in the USSR

| Year | 1917 | 1929 | 1937 | 1940 | 1958 |
|---|---|---|---|---|---|
| Irrigated area (thousands of ha.) | 4 080 | 4 470 | 5 620 | 6 150 | 12 000 |

Irrigation was then extended from desert and semi-desert zones into the steppes and forest steppes of the Volga area, Ukraine, Crimea, northern Caucasus and central black earth belts. The irrigated areas produce exceptionally good crops as the following figures indicate (the production is given in kilogrammes per hectare): cotton, 4,000-6,000; wheat, 4,000-4,500; alfalfa, 25,000-30,000; rice, 6,000-8,000; sugar beet, 50,000-100,000.

As we know, irrigation farming sometimes has the unfortunate consequence of causing salinization of the irrigated soil, which ruins its fertility and destroys the crops. Before the October Revolution, the farmers of Central Asia and Transcaucasia were incapable of dealing with this problem; and with private ownership of land and water it was difficult to carry out extensive land improvement schemes. Irrigation farming was not pursued on rational lines; the Khans and rich landowners strove to gain possession of larger quantities of waters, and drew them away from the land owned by the peasants; the surplus water infiltered into the soil, with the result that the saline groundwaters rose to the surface and made the soil salty through vigorous evaporation. Drainage was not installed on a sufficient scale. As a result there were in the ancient irrigated areas of Ferghana, Bukhara and Khorezm many large patches of secondary solonchaks, found in places that were formerly fertile watered soils.

After the October Revolution, facilities for the carrying out of extensive land improvement measures were created. As a result of the work undertaken in the Caucasus, the Volga area and Central Asia, scientists, agronomists and engineers were faced with the task of preventing the salinization of irrigated soils and applying extensive land improvement measures to saline soils.

All kinds of field and theoretical research was done on saline soils and methods of improving them. An important contribution in this field was made by the vast network of land improvement institutes and laboratories organized under the Soviet régime, and in particular by the experimental stations set up in Azerbaijan, Uzbekistan, Tadjikistan, Turkmenia and Kirghizia. A study was also made of the age-old experience in dealing with salinization acquired by the Uzbek, Turkmen and Tadjik peoples in Ferghana, Bukhara, Khorezm and Tadjikistan.

The farmers of Ferghana, Bukhara and Khorezm had from earliest times been accustomed to washing saline soils and constructing drainage canals to draw off saline groundwaters, called *zaury*, *zeikeshi*, etc. The experience of the peoples of Central Asia, developed in the new land improvement centres, was incorporated in the land improvement measures for treatment of solonchaks. A measure of special interest was the growing of rice crops on drainage beds in order to improve particularly bad solonchaks on belts remote from the main irrigated territories.

Measures for eliminating the causes of the salinization of irrigated soils in the USSR were devised and applied. The first step was to rationalize the use of water, replacing the faulty old methods (flooding) by more economical furrow watering. At the same time crop rotation, intensive mechanization, improved agricultural methods, widespread fertilization and new crops were introduced in collective and State farms.

In the irrigated oases of the Soviet Union, subject to secondary salinization, an extensive State network of deep collector drains (3-4 m. deep) was installed, to draw off the salts from the soil and groundwaters in subsoil horizons into the lakes and rivers.

Meantime a deep network of drains of uniform depth (2-3 m. over distances of 500-800 m.) is steadily being built. After drainage, saline soils are washed for purposes of desalinization; forest strips are being planted along canals everywhere.

The above anti-salinization measures have resulted in a general lowering of the level of groundwaters and reduction of the salinization of irrigated soils. In many cases, these phenomena have been completely eliminated. The 30 years' experience of the giant State cotton-producing farm Pakhta-Aral in the Hungry Steppe has shown that it is possible to eliminate the salinization of irrigated soil. This collective farm set up in the desert produces up to 3,000-4,000 kg. per ha. of cotton. The experience acquired by the Pakhta-Aral State Farm has been widely applied in the construction of new irrigation systems elsewhere.

The many years' work of the Mughan Experimental Station in Azerbaijan confirms that it is possible, with deep drainage combined with soil washing, skilful irrigation and correct agro-technical methods to make even the worst solonchaks, containing as much as 3-5 per cent of harmful chlorous and sulphate salts, fit for cultivation in the space of 2-3 years and use them, subsequently, for producing abundant, reliable crops of grain (4,000-4,500 kg. per ha.) and cotton (3,500-4,000 kg. per ha.). Similar results have been obtained by the experimental land-improvement stations for growing cotton and beet on solonchaks set up in the Hungry Steppe (Golden Horde Experimental Station), in the Ferghana Valley (Phedchenkov Experimental Station) and in the Kirghiz SSR (Kantsk Station).

The work of developing the deserts must not however be confined to farming : huge deposits of mineral products are located in these areas. For instance, a large proportion of the world's oil deposits are to be found in and around the steppe and desert belts; so are the raw materials of many branches of the chemical industry, including in particular deposits of natural soda, saltpetre, sulphate, sulphur, iodine, boron and bromine. Large deposits of ferrous and non-ferrous metals, coal and phosphorites are also located in waterless desert areas.

The irrigation and water supply of desert and steppe areas make it possible to develop industry in the arid zone, and the Soviet Union has done a great deal to industrialize the desert. The prosperous oil industry at Nebit-Dag and Emba; the coal mines in Karaganda; the chemical industry at Kara-Bogaz-Gola; the non-ferrous metallurgical works at Pribalkhash and Dzheskazgan; and the Kara-Kum sulphur works—such are only a few of the major industrial undertakings constructed by the Soviet people in the desert.

A general picture of the irrigation system already existing in the arid zone of the Asiatic part of the USSR and of projects for the next few years has been published by the USSR Academy of Sciences (Zvonkov [53]) and the following information is quoted from that publication which contains the relevant maps.

*Central Asia and the southern part of the Kazakh SSR*

The main water resources in this region are provided by three rivers, the Sir Darya, Amu Darya and Il and their tributaries which are used mainly for irrigation and hydro-electric projects and also to some extent (in their middle and lower reaches) for navigation. The irrigated area in these regions at present totals 6.1 million ha., and there are plans for more than doubling this area.

The main hydro-electric works in the Sir Darya basin are concentrated along the upper reaches of the river—in the Ferghana Valley and the valleys of its tributaries, the Chirchik, Angren and Keless; there are also hydro-electric works in the Hungry Steppe.

The main multi-purpose hydro-electric works are as follows : The Pharkhad dam on the Sir Darya which provides water for the surrounding countries by means of a supply channel, supplies electrical power and is equipped with a sluice for irrigation of the Dalverzin and Hungry Steppes; the Kairak-Kum dam on the Sir Darya, feeding the largest water reservoir in Central Asia, with a capacity of 5.6 $m.^3$ for irrigation and electric power; the Kamyr-Ravat dam on the Kara-Darya, which supplies water for the irrigation system and the hydro-electric power plants of the Ferghana Valley; the Gazalkent dam on the Chirchik River, providing water for the hydro-electric power station on the Chirchik Cataract, and equipped with a sluice for irrigating the lands and valleys of the Chirchik, Angien and Keless and supplying water for the towns and industries in the region.

During the past few years, large irrigation canals have been constructed in the Sir Darya basin for irrigation of new lands and improvement of the water supply for poorly irrigated regions by drawing on other water sources in times of drought. These works, which also include the great Ferghana Canal (350 km.), the North Ferghana Canal (160 km.), the South Ferghana Canal (108 km.), etc., enable effective use to be made of the waters of various tributaries of the Sir Darya.

In addition to the above, a dam has been built in the Sir Darya basin on the lower reaches of the river; a second dam in the Kzyl-Orda region to feed the irrigation canals; and the Urta-Tokai water reservoir on the Kassan-Sai River together with a dam to control the water discharge; besides various other works for irrigation and the supply of hydro-electric power.

The most important event in the field of irrigation during the past few years in the Sir Darya basin has been the development of irrigation in the Hungry Steppe, made possible by the building of the Pharkhad dam and hydro-electric power station, and by the construction of the Kairak-Kum water reservoir.

The works constructed for the irrigation of the Hungry Steppe include three main canals : the reconstructed Kirov Canal and two new canals, the Central Canal and the Southern Canal; electrified pumping stations; hydro-electric power stations at the point where the waters of the main canal fall into the Sir Darya; and a network of irrigation and drainage canals. It will be possible to extend the area of irrigated land in the Hungry Steppe to 800,000 ha.

Various hydro-electric works have been constructed in the Amu-Darya basin also, designed mainly for irrigation of land in the Tadjik, Uzbek and Turkmen Republics.

In the Turkmen SSR, the 500-km. long Kara-Kum Canal is being constructed, with its head sluice on the Amu Darya, at the village of Bassago. By means of this sluice, water is already being diverted into the Murghab River basin, not for the irrigation of new land only, but also for improving existing irrigation systems at present with an inadequate water supply.

In the Tadjik SSR, work is to be continued on the construction of the large hydro projects in the Bakhsh and Beshkent valleys, using the water supply of the Bakhsh and Kaphirnigan. In this area, a network of canals for natural and mechanized irrigation is being built, in addition to two large hydro-electric power stations, one on the Bakhsh, the other on the main canal of the Bakhsh irrigation system.

Extensive water works for irrigation and hydro-electric power are being constructed in the Surkhan-Darya, Kashka-Darya and Zeravshan river valleys.

One of the largest multi-purpose water plants is to be a hydro-electric station on the Amu Darya for the irrigation and water supply of large areas on both banks of the Amu Darya in Turkmenistan and Uzbekistan, and the supply of hydro-electric power along the middle reaches of the river. This station can also serve for the irrigation and water supply of the pasturelands in Afghanistan, and for the supply of electric power.

Subsequently, in connexion with the major irrigation projects in Central Asia, hydro-electrical power resources with a total potential capacity of 600 milliard kWh. will be used.

At the same time, measures are being taken to improve the navigability of the Amu Darya and Sir Darya. The shortage of water in Central Asia and the destruction of the water balance of the Caspian Sea made it imperative to consider the possibility of diverting the waters of the Ob and even the Yenisey, which now flow into the Karsk Sea, into this area.

Investigations are being made regarding the possibility of building large dams on the Ob in order to direct its waters along the Irtysh and Tobol, through a canal linking the two basins (the Turgai Gates) into the Aral Sea and thence by canal to the Caspian Sea. (See also Fig. 6.) This water is to be used for the supply and irrigation of arid lands in western Siberia—between the Turgai Hollow and the Aral Sea—and the lands in Central Kazakhstan.

It is possible too that the diversion of the waters of the Siberian rivers into the Aral-Caspian basin will also solve the problem of exploiting hydro-electric power resources and constructing a large inland waterway system to cross the central part of the USSR from the Karsk to the Caspian Sea.

Thorough technical and economic research will be necessary in order to solve the problem of the construction of the proposed new giant waterway system.

*The Northern Caucasus*

A centre for the growing of grain and rice (Kuban); it is also a large stockbreeding centre, supplying fine fleece wool (Stavropol region).

In order to guarantee the water supply of the vast waterless Stavropol and Nogai steppes, and provide stable cattle fodder, major water and irrigation works are being constructed in this area : the Kuban-Egorlyk, Kuban-Kalausk and Terek-Kum water works whose canals are to extend over a vast area.

The western and north-western arid regions of the Stavropol plateau (5.5 million ha.) at present obtain their water supply and irrigation water from the Kuban-Egorlyk waterworks, fed by the Kuban at Nevinnomyssk (at the rate of 75 $m.^3$ per sec.).

Work is shortly to begin on the construction of the Kuban-Kalausk waterworks designed to supply the central parts of the Stavropol region.

The Nogai Steppe covers an area of 2.5 million ha. between the Terek and Kum (north-eastern part of the Checheno-Ingush Antonomous Soviet Socialist Republic). The main water resources for this area come from the Terek-Kum Canal, 150 km. in length (completed in 1957) and three main irrigation channels. At the beginning and end of the canal, on the Terek (near the town of Mozdok) and the Kum are two dams designed to raise the level of the water; the water flows out of the Terek into the Terek-Kum Canal at the rate of 200 $m.^3$ per second.

The Terek-Kum Canal is to be prolonged, beyond the Kum dam, by the Kum-Manych Canal at the end of which is the Chograi storage lake, supplied by the Manych reservoirs.

These works will make it possible to irrigate and supply water to vast parts of the Nogai steppes, the Stavropol region and the Caspian depression, which are at present waterless, and turn them into a mighty agricultural region.

*Transcaucasia* (Azerbaijan, Georgian and Armenian Soviet Socialist Republics)

This area has potential hydro-electric power resources totalling 145 milliard kWh.; the size of the area of agricultura lland at present irrigated is 1.7 million ha.

The most important irrigation works in Transcaucasia are those at Mingechaursk (Azerbaijan Republic) where there is a large multi-purpose hydro-electrical station which supplies power and water for land improvement, and makes navigation possible. On the River Kura, near Mingechaursk, is the highest earth dam in Europe (77 m.) forming a storage lake with a capacity of 16 milliard $m.^3$; and a hydro-electric station with a capacity of 357,000 kw. with an annual electric power output of 1.4 milliard kWh. The power produced by this hydro-electric station supplies the oil industry at Baku, the Transcaucasian metallurgical industry, and the pumping stations for irrigation. This dam is also an important factor in the prevention of flooding.

From the storage lake at Mingechaursk run two canals, one along the right bank, the Verkhne-Karabakh Canal (discharge 140 $m.^3$ per sec.), and one along the left bank, the Verkhne-Shirvansk Canal (discharge 50 $m.^3$ per sec.). There is another network of canals running along the Kura and Arax.

A dam has also been constructed on another river, the Samur, which flows into the Caspian Sea; from this dam runs the Samur-Divichinsk Canal, running almost parallel with the shores of the Caspian Sea.

This canal, besides improving the water supply of the inadequate irrigation system in this region, supplies water to the Apsheron Peninsula, which is now being transformed into a food-growing area for Baku.

The most important hydro-electric works in the Armenian SSR are the seven hydro-electric stations on the Sevan-Razdan Cataract, using the waters of the mountain lake of Sevan with a fall of over 900 m. The works on the Sevan-Razdan Cataract have a capacity of 575,000 kw. with an average annual output of 2.5 milliard kWh. A large proportion of the hydro-electric stations on the cataract are already completed. The Sevan-Razdan Cataract also makes an important contribution to irrigation, since its waters are used, by way of canals, for irrigation of the Ararat Valley.

In the Georgian SSR the main water problem is the irrigation of the Samgor steppes (near Tbilisi). The main irrigation water here is provided by the Yuri River on which the Sion reservoir, to store up the summer floodwaters, is now being built; below this reservoir is a dam for raising the level of the water, from which runs the main Verkhe-Samgor Canal with three hydro-electric stations in operation. The water collects in the Tbilisi water reservoir, from which runs the Nizhne Samgor Canal. Both these canals are to be used for irrigating gardens, vineyards and vegetable plots in the Tbilisi area.

In addition to major hydro-electric plants the USSR is also building hydro-electric works, mostly multi-purpose ones, on the vast network of so-called small rivers. The tributaries of the main rivers serve as approach waterways leading to the main national canals, and are used for providing electric power, irrigation, water supply and fisheries.

Serious efforts are being made in the USSR to introduce automation, remote control and telecontrol in hydro-electric plants.

Some large hydro-electric plants are already automated : they are fitted with remote-control apparatus operating over large distances, and automatic 'recorders' which, when questioned by telephone, indicate the factors needed for the operation of the system.

## IRRIGATION IN CHINA

According to Chinese legend, over 4,000 years ago the River Hwang-Ho, which rises in the mountains of Kwanlung, burst its banks and began to rush across its delta like a wild animal. The river was tamed by a man called Wei thereafter surnamed the Great. For nine years, under his supervision, men worked to clear up the silt and river channels; they cleaned the river and led it into the sea, and gave over the reclaimed land to farmers.

In centuries of struggle to tame the Hwang-Ho, the Chinese learned to build hydro-electric works and produced skilful irrigation specialists who used genuinely scientific methods in their construction works. In 1360 a systematic account of methods of hydro-technical works in China was given in a book by Sian-Suan called *Notes on Methods of Controlling High Flood Waters* (Chi Chen ho fan tsi).

The first large irrigation system in China, in the Province of Szechwan (Dutzyanan) was constructed about 2,200 years ago on the River Ming Tsiang (a tributary of the Yangtse). Two other large irrigation systems—on the Tsintsui and the Khangtsui in the Province of Kansu belong to the same period (Fu Tso-I, 1957). The Dutzyanan system played an important part in the development of irrigation systems in Asia, serving as the prototype for other systems. However, the total area of irrigated land in China in the past was very small. Major irrigation systems measuring 700 ha. and more covered about 2.2 million ha. throughout the country, i.e. only 7 per cent of the total watered area of the country (Voronin, 1955; Budarin, 1957).

In the North Chinese Plain and in the deltas of the Yangtse, the Chuchiang (Pearl River) and other rivers, the groundwaters lie fairly near the surface—3 m., 5 m. and 10 m. In most cases the groundwaters are fresh (non-saline) with the result that the Chinese peasants from time immemorial, with shallow wells and the simplest of water-raising equipment, used artificial irrigation to supplement the natural moisture provided by atmospheric precipitations. There are millions of these wells in China. Extensive use was also made of very shallow reservoirs constructed by the Chinese people with consummate skill; also of the areas round shallow lakes, fenced off with a special kind of dyke ('water-gates'). The skill shown by the Chinese in the building of small low-pressure dams is indicated by the fact that there still exist, in the province of Hunan, small reservoirs constructed four to five hundred years ago (Hu Tsi-Lu, 1957).

Since the distribution of atmospheric precipitations in the monsoon areas of China is unfavourable for the cultivation of winter crops, the introduction of irrigation results in a great increase in the size of the crops (Table 5).

TABLE 5. Effects of irrigation on the increase of agricultural crops in China (Voronin, 1955)

| Type of crop | Harvest in hundreds of kg. per ha. | | Increase of crops as a result of irrigation, in percentages |
|---|---|---|---|
| | On irrigated land | On non-irrigated land | |
| Wheat | 10-22.5 | 6-12.9 | 38-150 |
| Maize | 15-20.4 | 7.5-14.2 | 44-100 |
| *Setaria italica* (var. *maxima*) | 18.8-19.5 | 8.3-10.2 | 91-127 |

The crop capacity of cotton plants, when irrigated, increases from 1.5 to 3 times (Offengenden, 1957).

West and north-west China (Sinkiang, Inner Mongolia) belong to the semi-desert and desert zone, with saline soils. Agriculture here is only possible with irrigation and the area of irrigated land in these parts is at present not large. There are however extensive tracts of bare land and reserves of river and underground waters which could be used for irrigation. In the People's Republic of China, important research and construction work has been started for the establishment of new irrigation systems for the cultivation of cotton plants in the western regions of the country.

The vast irrigation works of China include the famous Sinkiang *kanats* (underground tunnels, *kyagrizy* ditches).

Western China, remote from the sea, consists of a desert with a sharply continental climate and low rainfall. The mountains in this region, however, have a permanent snow blanket which in melting produces surface and underground waters; a large part of the snow water filters into the soil and collects in aquifers at the foot of the mountains in the form of streams of groundwater. This water is captured and distributed over the fields by means of the cave wells. The Chinese, locating these aquifers, dig deep wells; then establish the upper and lower level of the aquifer, and proceed to sink a whole series of vertical shafts—at intervals of 80-100 m. apart—in the top of the aquifer and in the bottom, 10-20 m. apart. They then dig a gently sloping tunnel, about 2 m. high and 1 m. wide to link up all the vertical shafts, and the water collected in the tunnel rises to the surface into an open canal. All that is usually visible on the surface of the desert is a row of open wells descending a slope, and a stream of water flowing out of the bottom-most well. The tunnels in this system are sometimes as much as 10-15 km. in length.

No one knows exactly who first devised this clever system for the collection of groundwaters, or when. Chinese historical documents relate that a system of this kind was already operating in the basin of the Wei Ho River (the largest tributary of the Hwang Ho) in the Shansi Province in the Han epoch. The network of these kanats in western China (Sinkiang) is very extensive. According to the geologist Huan Chi Tsin, who investigated this system, these horizontal shafts total 2,500 km. in the Turfan depression alone. In his view, this system ranks in importance with the Great Wall of China and the Great Canal. Even now, the kanat system is still the most important irrigation system in Sinkiang, where there are as many as 1,500 underground tunnels, irrigating a total area of 20,000 ha.

Kanats are also widely used in Turkmenia and Azerbaijan where, too, they were built from earliest times in order to capture the underground waters coursing down the slopes of the Kopet Dag and Caucasian mountains, and use them for irrigation purposes.

The average life of a system of cave wells is between 100 and 150 years. The underground tunnels gradually become silted up, and the water channels blocked by ferric oxide, calcium carbonate, or gypsum. The flow of water into the wells becomes so small that a new line of wells has to be dug alongside the old one—in some places there are as many as six or seven lines of old wells which gives some indication of the age of irrigation in these parts of the world.

At the present time, China possesses the largest area of irrigated land in the world. In 1958, the total area of irrigated land in the People's Republic of China was 53.37 million ha. constituting 48 per cent of the country's total 112 million ha. of arable land (Table 6).

TABLE 6. Increase in the area of irrigated land in China (in thousands of ha.)

| Year | Increase | Total area |
|---|---|---|
| 1949 | — | 20 000 |
| 1950 | 520 | 20 520 |
| 1951 | 1 000 | 21 520 |
| 1952 | 1 600 | 23 120 |
| 1953 | 660 | 23 780 |
| 1954 | 780 | 24 560 |
| 1955 | 1 300 | 25 860 |
| 1956 | 8 500 | 34 360 |
| 1957 | 3 510 | 37 870 |
| 1958 | 1 550 | 53 370 |

At the present time, irrigation systems are being constructed over an area of approximately 5 million ha.; 9,000 new electric pumps for distributing water over the fields have been installed, catering for an area approximately 370,000 ha.; and there is the vast new Inhwan irrigation system on the River Hwang-Ho (50,000 ha.). In the Shantung Province, the Tao Kiang irrigation system caters for 220,000 ha. Large irrigation systems have also been constructed in western China.

This great increase in the area of irrigated land in China is made possible by the vast State hydroelectric power stations built on the rivers, and by the active work of the Chinese peasants. Since 1949, the Kwangtung, the Panvang, the Fuzilin, the Meihsien, the Baishai reservoirs have been built in China; the large sluices built include the Sanhochi, Dienheitze, Sheliho and Chenhotze; large irrigation and transport canals have also been constructed.

Thanks to government support, approximately 300 major irrigation plants have been built or reconstructed in various parts of the country during recent years (Fu Tso-i, 1957).

During the past few years also, thanks to the efforts of co-operative and State farms, over ten million small dams, canals and other installations have been built or reconstructed in various parts of China (Fu Tso-i, 1957). In this period too, over five million new wells and vast numbers of shallow reservoirs and pools for irrigation have been constructed (Budarin, 1957).

The area of irrigation farming is to be further greatly increased—to a total of about 100 million ha.

Research is being carried out and plans made for the construction of major irrigation systems on the Yangtse, on the middle and lower reaches of the Hwang Ho, on the lower reaches of the Hwai Ho; and on the Sungari and Nonni. Irrigation is the most important measure for dealing with erosion, flooding and drought.

Together with new irrigation systems, China's hydro-electric installations are being developed and the country is being electrified. Thus in the Hwang Ho basin, as part of the measures for the prevention of flooding, a cataract is being constructed out of 46 reservoirs, to supply power for the hydro-electrical plants and irrigation water for approximately 8 million ha. of land. The scheme for exploiting the resources of the Hwang Ho includes the production of 23 million kWh. of electric energy, the irrigation of large areas and the navigation of about 1,800 km. of the river (Fu Tso-i, 1957).

In the Yangtse Basin, it is planned to increase the irrigated area by about 18-20 million ha. The Dutzyanan irrigation system is eventually to cater for an area of 340,000 ha. (Malinovsky, 1956).

The Chinese Government is carrying out a vast scheme for the development of cotton growing. Cotton plants are cultivated in a wide geographical zone stretching from the 46th to the 17th parallel. The main cotton-growing area in China is the Hwang Ho basin, about 56 per cent of which is now sown with cotton plants. The main obstacles to the development of cotton growing are the irregular distribution of the atmospheric precipitations, the spring drought and the soaking and fattening of the cotton plants in autumn. Over 37 per cent of the whole cotton-growing area is in the Yangtse basin. Cotton plants are grown in conjunction with wheat, beans or rape as secondary crops. Here too, excess of rain soaks the cotton plants in autumn whereas summer drought often leads to shedding of the bolls.

In the tropical parts of China perennial cotton plants are often cultivated together with annual cotton plants, but the cotton-growing area in this zone is not large. Cotton growing is being developed in the lower parts of the Liao Ho Basin, but, since the frost free period here is short (150-170 days) only early-ripening types of cotton plants can be cultivated.

Cotton has been grown in China for about 1,300 years. In the past, the crop was small—150-200 kg. per ha. only. Nowadays, the average crop is 230-260 kg. per ha., and the gross yield of cotton yarn has increased from 849,000 metric tons in 1936 to 2.5 million tons in recent years. In places where sufficient mineral and organic fertilizers are used, the crop capacity is as high as 3,700-7,600 kg. per ha. or even, in some places, 10,000 kg. per ha.

Thanks to improved agro-technical methods, adequate fertilization, correct irrigation, measures for destruction of pests and abolition of plant diseases, together with the introduction of improved strains of cotton plants, it will be possible to raise the average crop capacity of cotton plants by 1967 to 300, 500, or 750 kg. per ha. in different parts of China (Yan Siang Tun, 1957).

The cotton-growing area in western China is at present small, only about 3 per cent of the whole cotton-growing area of the Republic. But, in view of the relatively long frost-free period (up to 200 days), the abundant sunshine and the dryness of the atmosphere it will be possible, with skilful irrigation and treatment of saline soils, to make this the second great cotton-growing area of China.

## USING ARID ZONES FOR STOCK BREEDING

As indicated above, man has used the arid land of Eurasia from very earliest times not only for farming but also for nomadic stockbreeding, an essential part of every primitive civilization.

Stockbreeding in the arid zone played an exceptionally important part in the history of the development of mankind at the dawn of civilization.

The domestication and use of camels, horses, horned cattle and sheep was every bit as important, at the time, as the invention of steam engines, and led to great progress in man's fight against the desert. Man's dependence on nature was greatly decreased, although it assumed new forms. In the dry steppes and waterless deserts where man could not otherwise exist, animals, subsisting on xerophytic and halophytic vegetation and saline water provided an excellent means of transport, milk for drinking, proteins and fats of various kinds, and raw materials for clothing, shoes and domestic purposes. The most valuable in this respect are camels and sheep, which can eat xerophytic vegetation that is apparently totally unsuitable as fodder, can go without water for long periods on end and can drink saline water which neither men nor horses can touch. And it is these animals which are most useful and productive in arid zones.

In possession of a herd of sheep and camels, men can exist in steppe and desert zones hitherto regarded as uninhabitable. The art of nomadic stockbreeding was developed by dint of centuries of experience.

The inhabitants of the arid zones of Asia and south-eastern Europe acquired great skill in exploiting the ability of steppe animals to adapt themselves to life in dry, waterless areas. Herds moved from one pasture to another with the changing seasons, sometimes travelling thousands of kilometres between mountains and sands, floodlands and river deltas, ranging far to the north or south.

In spring, when feeding on the fresh juicy spring pastures, cattle are able to go without water completely for two to three weeks on end, a fact which cattle-breeders used very skilfully to great advantage; and herds can be pastured without water in winter if the dry autumn grass is damped by seasonal rains. Water-supply places for sheep located at intervals of one, two or three days' distance apart are used extensively all through the year, making it possible to move herds round the country in search of pasture. An example of this is the experience of the collective farm 'Erbent' in Kara-Kum (Yarov, 1949; Nechaeva, 1944; Minervin, 1949).

'During the first year of its existence (August 1941) the Erbent State Farm used the same water-supply places daily all the year round; as a result, by the summer of 1942, all pastures within a day's march of the water-supply places were bare although there were only half as many sheep as the size of the territory and the amount of fodder could, theoretically, support. During the second half of the summer extra fodder had therefore to be provided for the sheep. . . . In 1943 another system was adopted, with spaced-out water-supply places; and the State Farm began to function much better. In 1945 it was at the top of success; and it now possesses twice as many sheep as in 1942. All difficulties regarding lack of sufficient pastureland have been completely overcome despite the fact that the size of the herds has increased.'

Nevertheless, the main factor governing the success of stockbreeding in arid zones is the water supply—the existence and the quality of water. From a study of the practical experience of the people living in the deserts of Asia, V. N. Kunin (1944) gave the following figures for the assessment of drinking water for human consumption, according to salt content (Table 7).

TABLE 7. Salt contents in drinking water for man (Kunin)

| Quality of water | Maximum salt content (mg. per litre) | | | | | | Hardness (in German degrees) |
|---|---|---|---|---|---|---|---|
| | Dry residue | Na | Ca | Mg | Cl | $SO_4$ | |
| Good | 1 500 | 400 | 150 | 75 | 600 | 600 | 30 |
| Satisfactory | 2 000 | 500 | 250 | 125 | 700 | 805 | 45 |
| Passable | 2 500 | 700 | 300 | 125 | 800 | 900 | 60 |
| Very poor | 3 000 | 800 | 350 | 150 | 900 | 1000 | 80 |

In dry steppes and semi-desert areas, a supply of satisfactory drinking water (salt content, 1-2 gr. per litre) is not always available. In desert areas, lake waters and groundwaters always contain a much higher concentration of salts (10, 20, 100 gr. per litre). Local experience shows that water with a salt content of 5-6 gr. per litre can only be used for drinking in emergencies; after a few days of drinking such water, people are liable to fall ill. Animals are able to adapt themselves much more easily to drinking the salt water found in the deserts—they can very well drink water with a salt content of 5-7 gr. per litre, or in emergency even as much as 15-20 gr. per litre, particularly in the winter. Young unweaned animals cannot of course stand such a high concentration of salt, a fact which stockbreeders always take into account.

The following table, drawn up by Kunin, gives figures for the salt contents of water used for drinking by herds in the deserts of Turkmenia (Table 8).

TABLE 8. Salt contents in drinking water for cattle (Kunin)

| Quality of water | Maximum salt content (mg. per litre) | | | | | | Hardness (in German degrees) |
|---|---|---|---|---|---|---|---|
| | Dry residue | Na | Ca | Mg | Cl | $SO_4$ | |
| Good | 3 000 | 800 | 350 | 150 | 900 | 1 000 | 80 |
| Satisfactory | 5 000 | 1 500 | 700 | 350 | 2 000 | 2 500 | 150 |
| Passable | 7 000 | 2 000 | 800 | 500 | 3 000 | 3 000 | 200 |
| Passable in emergency during spring and summer | 10 000 | 2 500 | 900 | 600 | 4 000 | 4 000 | 250 |
| Passable in emergency during autumn and winter | 15 000 | 4 000 | 1 000 | 700 | 6 000 | 6 000 | 250 |

During the winter, camels or sheep can sometimes be seen drinking the water of the Caspian Sea, which has a salt content of 12-13 gr. per litre. An interesting example of this is the Ust Urt desert plateau lying between the Caspian and Aral seas. Stockbreeding has existed in this area since time immemorial, using as watering places the pools of rainwater (in spring) and in particular the groundwaters. There are also hundreds of wells of 5-10 m. or more often 15-25 m. deep, sometimes as much as 30-60 m., containing water with a high salt concentration (5-10 gr. per litre), suitable for cattle but not for humans. In a few places the salt concentration in the well-water is only 1-3 gr. per litre, making it suitable for humans (Fig. 14). The Ust Urt pasturelands provide pasture for up to 2 million animals, mainly sheep producing Persian lamb (astrakhan) fur.

The Soviet scientists N. N. Pelt and V. F. Chervinsky are of the opinion that, by constructing a further 950 deep wells on the Ust Urt plateau and improving winter conditions, it would be possible to

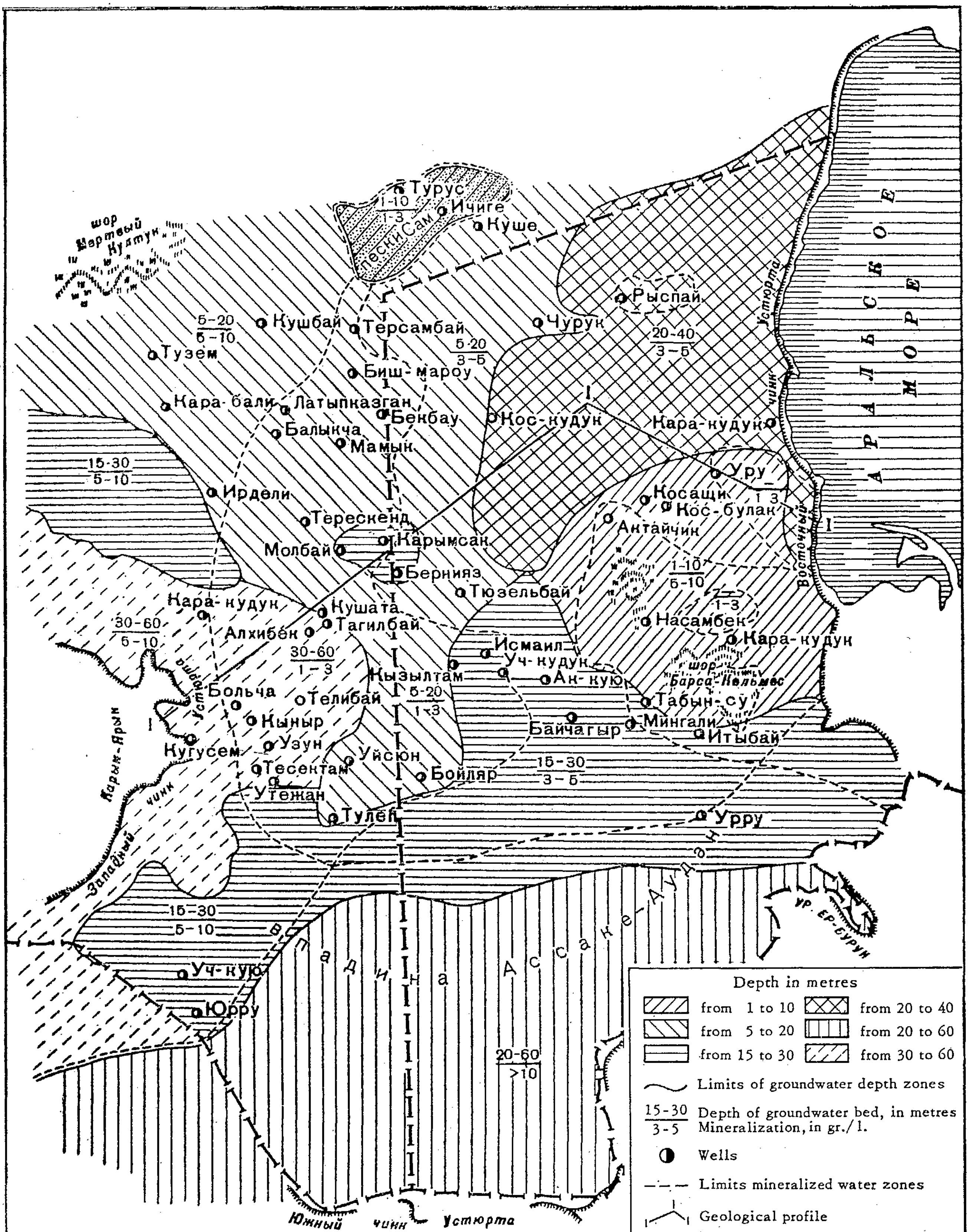



Fig. 14. Map showing the depth of the groundwater strata on the Ust Urt plateau, and their mineralization. (N. N. Pelt, V. F. Chervinsky.)

raise the number of animals pastured here to 3.3 million. This is now being done.

The original inhabitants of the Ust Urt Desert (Kazakhs, Kara-Kalpaks) are past masters in the art of finding water supplies. They are able to judge where water may exist from the topography and the vegetation (*Alhagi camelorum, Peganum harmala*). They dig wells to a great depth (as much as 50-70 m.) reinforcing them with stone or wood (haloxylon). In order to increase the water capacity of the wells, they dig 4-6 supplementary underground collector-shafts alongside each other, and bring the water up to the surface by a simple mechanism operated by camels.

Nowadays the water of wells in the steppes and deserts of the USSR is raised by a highly perfected type of wind turbine. The wind power specialist N. V. Krassovsky (1934, 1939) calculated that, with an average wind speed in the desert of 6-7 m. per sec., the annual total of electric power produced in the deserts of the USSR could easily be brought up to 6.5 trillion kWh.

This quantity of electric power would fully cover the needs not only of water supply and irrigation equipment in the desert, but also of industry, transport and domestic usage. The power specialists and industry of the USSR now design and manufacture wind turbines of various types (A. V. Vinter and N. M. Tikhomirov). Steps are being taken everywhere to provide water for pasturelands in the arid zones of the USSR, China and Mongolia. Wells and pools are being built and deep borings made. Thus, for example, at the beginning of 1958 there existed on the pastureland of Kazakhstan over 27,000 shaft wells, over 3,000 pools and pits and 2,740 deep borings, fully watering 61 million ha., and partially watering a further 21 million ha. of pasture lands [11].

Thanks to the deep borings, vast quantities of fresh artesian waters have been discovered in the sandy pasturelands of Kazal-Kum and Kara-Kum. Large irrigation works have been installed also in the Caspian steppes, into which the waters of the Kuban and the Terek have been diverted by means of a canal system.

A very important factor for the development of pasture stockbreeding is the temperature régime of the area [11]. Camels (and Persian and fat-tailed sheep to a slightly lesser extent) thrive excellently in the high temperatures of the desert area (+ 40° C. to + 45° C.). Fine-fleeced sheep already begin to flag at temperatures between + 25° C. and + 30° C.; large-horned cattle are also bad at adapting themselves to high temperatures. The animals which thrive best in the cold winters in the deserts are horses and fine-fleeced sheep.

Pasture cattle-breeding plays an extremely important part in the economy of the arid regions of the USSR, the People's Republic of China and the Mongolian People's Republic. The total area of natural pastureland in the arid regions of the USSR is about 225 million ha.

The yearly stock of natural cheap fodder in this area runs into several million metric tons; the cheapest of all is pasturable fodder. According to the calculations of Academician I. V. Larin, one unit of pasturable fodder is several times cheaper than one unit of grass, grain, silus or root crop fodder. Kazakhstan may be taken as an example of the special characteristics of stockbreeding in arid zones. According to the data given by Chervinsky, the pasturelands of the Kazak SSR, with an area of 130 million ha., produce approximately 17 million units of fodder, which is equivalent, in nutritive value, to 25 million metric tons of grain. Used rationally, this fodder will suffice for 50 million sheep, producing up to 500,000 metric tons of meat and 150,000 metric tons of wool per year. It will subsequently be possible to increase the number of cattle in this area to 75 million.

The natural fodder growing in the arid steppes and deserts of Asia is entirely different from that growing in humid zones. One of the best and most important plants is wormwood (in particular *Artemisia terrae alba* and *A. herba alba*). Cattle eat wormwood all the year round, and it contains large quantities of carbohydrates, fats and proteins. Another important plant is the saltwort, *Salsola laricifolia*, which grows in the deserts of Central Asia; cattle eat the leaves and young shoots of this bush which grows nearly all the year round. Another plant, eaten in autumn and winter only is the *Salsola gemmascens*, which contains large quantities of salt in the dry matter, and is less rich in fats; its nutritive value improves, naturally, after the autumn and winter rains which wash away some of the salts it contains. The *Anabasis salsa*, of which there are large quantities, is not good for fodder and is used only in the autumn and winter seasons. Extremely useful fodder, on the other hand, especially in wet years, is provided by the winter and spring ephemerals found in large quantities in the southern, warmer parts of the Central Asian deserts (the cereal *Eremophyrum orientale* the sedge *Carex physodes, Malcolmia africana* etc.).

The seasonal availability of natural pasture differs very much in different parts of the arid zone. In the coldest steppe regions of the arid zone, provision has to be made, in winter, for 150-180 days when cattle have to be provided with rudimentary shelter and fed with specially prepared fodder.

In the semi-desert zones of Kazakhstan and Mongolia, there are only about 80-90 days when cattle cannot be put out to pasture; in the deserts of Central Asia the number of non-pasturing days is even smaller, i.e., 30-40. In the southernmost, hottest parts of the deserts of Tadjikistan, Uzbekistan and

Turkmenia there may possibly be, during some winters, 5-15 days when cattle have to be taken into heated shelters and fed with special fodder. But in the hot deserts of Asia and south-east Europe cattle as a rule feed on winter ephemerals, wormwood and saltwort, including the pulpy halophytes and the shoots of haloxylons.

In spring and summer the most common fodders are wormwood and wormwood-grass associations. In the autumn cattle eat wormwood, xerophytes and halophytes (dry and pulpy saltworts) of various types.

In sand deserts, cattle and wild herds have always eaten all kinds of desert grasses, and the leaves and shoots of bushes and trees (*Haloxylon persicum*, *Haloxylon aphyllum*, *Calligonum*, etc.) as fodder. The pasturing period in the southern sand deserts constitutes 11-12 months of the year. The sand pastures are particularly valuable during the autumn and winter, when there is little natural fodder available on the flat clayey deserts. It is easier in the desert to find shelter from hard frosts, and pasturage is always available. This explains why huge herds of antelopes and gazelles (*dzhairany*) are always to be found even now in the *Haloxylon* thickets in the sand deserts.

In order to give an idea of the typical vegetation of the Kara-Kum sand desert in Turkmenia, the following data have been taken from N. Nechaeva's report [35]:

The vegetation here consists of large shrubs, semi-shrubs and annual and perennial grasses.

Most of the large shrubs are 1-2 m. high and they form the first layer of shrubs. There are a few tree-type shrubs as much as 5-7 m. in height.

The arboreous-shrub layer is formed on white haloxylons or 'sasak' (*Haloxylon persicum*) interspersed with black haloxylons (*Haloxylon aphyllum*), various types of 'kandym' (*Calligonum setosum*, *C. densum*, *C. caput medusai*) and 'čerkez' (*Salsola richteri*); in the shifting-sand areas, Paletsky 'čerkez' (*Salsola paletzkiana*) and 'bordžok' (*Ephedra strobilacea*); on the sand hills, sand acacia or 'syuzen' (*Ammodendron conollyi*).

Semi-shrubs are much rarer as regards both quantity and type. The most common are two types of astragal: the *Astragalus unifoliolatus* on fixed sands and on shifting sands the *Astragalus paucijugus*.

The most prevalent types of large grass plants growing on the fixed sands are 'uročki-selin' (*Aristida pennata* var. *minor*), 'kert' (*Convulvulus divaricatus*) and 'ketgen' (*Salsola pellucida*); round the edges of the takyrs, and also sometimes near patches of bushes, pulpy saltwort are found (*S. lanata*, *S. transoxana*, *S. turcomanica*). Large grasses and semi-shrubs constitute the second layer of vegetation in the sand. The main vegetative cover of the sand is however formed by the third, grassy layer, of small grasses consisting of perennial sand sedge or 'ilak' (*Carex physodes*)—the most prevalent type of vegetation, highly important from the economic standpoint—and a whole series of spring annuals, frequently called ephemerals on account of their brief flowering period. Of the spring annuals the most prevalent are as follows: cereals—*Eremopyrum orientale*, *E. buonapartis*, *Bromus tectorum*; miscellaneous grasses—*Hypecoum parviflorum*, *Arnebia cornuta*, *Nonea picta*, *Malcolmia grandiflora*, *Streptoloma desertorum*, *Isatis emarginata*, *I. minima*, *Meniocus linifolius*, *Ceratocephalus falcatus*, etc.

Pasturage, including areas where shrub pasturage predominates, covers over 50 per cent of the total area of Turkmenistan, measuring approximately 25 million hectares. The distribution into biological groups (totalling 71 species) observed on given experimental plots, is as follows:

Perennials: shrubs 5; semi-shrubs 1; grasses, spring (ephemeroids) 11, summer-spring (long-growing period) 7. 24 species.

Annuals: spring (ephemeroids) 43; summer 4. 47 species.

Economically speaking, the most important plants from the pasturage point of view are spring perennials, ephemeroids, including 'ilak' or sand sedge (*Carex physodes*) after which come the spring annuals and finally, shrubs.

The local population, being fully familiar with the geographical and botanical features of their pasturage, moved their herds round continually year by year in order to take advantage of the cool and better pasturage in summer, and provided grass pasturage and protection against cold in winter. In the case of deserts in the vicinity of mountains, the herds grazed in the mountains in late spring and in summer they went up to the alpine zone meadows (Caucasus, Tien Shan); in winter they grazed in the valleys, in the foothills and on the sand.

In the flat desert plains we find a meridional type of nomadism, with the herds kept in the warm southern parts and on the sands in winter and in summer migrating northwards, to return again to the south at the end of the summer, descending from the plateau into the depressions. A point to be borne in mind is that the fertility of the pasturage in the arid zones varies greatly from year to year, being much decreased in drought years. For this reason, stockbreeding must be combined with farming so that supplementary, concentrated fodder can be produced.

The probable frequency of fodder shortage in the Kazak SSR, for example, is indicated by the following figures: steppe zone, 10-20 years out of 100; semi-desert zone, 20-30 years out of 100; desert zone, 50-70 years out of 100.

Pasturing stockbreeding is much better adapted

TABLE 9. Proportion (in millions of ha.) of arable and pastureland in Kazakhstan (Chervinsky [11])

| Zone | Total area | Divided into | | | | | | Others | |
|---|---|---|---|---|---|---|---|---|---|
| | | Arable land | | Hay | | Pasture | | | |
| | | | % | | % | | % | | % |
| Steppe and arid steppe | 78.9 | 25.0 | (31.6) | 3.8 | (4.8) | 33.6 | (42.6) | 16.6 | (21.0) |
| Semi-desert | 96.4 | 2.7 | (2.8) | 3.5 | (3.6) | 64.9 | (67.3) | 25.3 | (26.3) |
| Desert | 77.3 | 1.1 | (1.3) | 1.1 | (1.4) | 51.4 | (66.7) | 23.7 | (30.6) |
| Foothills | 23.3 | 2.9 | (12.5) | 0.9 | (4.0) | 15.8 | (68.0) | 3.6 | (15.5) |
| Total | 275.9 | 31.7 | (11.5) | 9.3 | (3.4) | 165.8 | (60.1) | 69.1 | (25.0) |

to arid zone conditions than dry farming. Hence, as the climate gets drier stockbreeding becomes more prevalent and dry farming less prevalent, with a corresponding increase in the importance of irrigated farming. This is clearly illustrated by the following figures for types of farming in the Kazak SSR (Table 9).

Chervinsky divided the pasturage of the semi-desert and desert zones of Kazakhstan into seven main types, according to the vegetation : (i) grasses (on non-saline light-chestnut soils); (ii) grass-wormwood association; (iii) grass-wormwood-saltwort association (on stony and flinty soils); (iv) wormwood-saltwort association; (v) ephemerals-wormwood-saltwort association (semi-turfed sands and light grey soils); (vi) wormwood (on saline soils); (vii) ephemeral-wormwood-saltwort association (with haloxylon). Wormwood-saltwort and saltwort associations cover as much as 55 per cent of the pasture lands of Kazakhstan.

On the basis of the analysis of the natural features governing the use of the territory and the possibilities of development, Kazakhstan may be divided into the following zones :

Steppe : dairy and beef-cattle breeding, breeding of fine-fleeced sheep and farming as the basis of the agricultural economy.

Dry steppe : dairy and beef-cattle breeding, sheep-breeding for meat and wool, and dry farming.

Semi-desert : breeding of sheep for wool, breeding of horseherds, and irrigated farming.

Desert : sheep-breeding for wool and fur, and irrigated farming as the basis of the agricultural economy.

Foothills : dairy and beef-cattle breeding, sheep-breeding for meat and wool, dry farming.

Despite many centuries' experience, nomadic stock-breeding in the past, productive though it was, had many weaknesses. After a thousand years of unplanned exploitation of pasturages, the natural vegetation was largely destroyed and impoverished as a result of excessive use, besides which the vegetation had been taken by man for use as fuel. The sands had begun to shift. Dust storms were frequent on the pasturelands; and in winter millions of cattle died as a result of lack of water, ice crusting of the ground, snowstorms and shortage of fodder.

The people engaging in nomadic stockbreeding were cut off from the amenities of society. All this has now been changed, thanks to the introduction of socialistic principles of economy and the achievements of science. Through the use of the radio, cars and aeroplanes, stockbreeders are provided with food and with technical and cultural amenities. The water supply has been improved by a network of canals, wells and borings. Bases are being established, containing concentrated fodders and shelters. Vast areas are planted with haloxylon, *Euagropyrum* and other vegetation by aerial sowing for 'phytoamelioration' of the sands and improvement of the grass crops on pasturages. A network of new settlements is being established, complete with schools, medical services and irrigation systems; also a series of scientific institutes and a zoo-veterinary service with regional teams of zoo-technicians. The cattle strains are being improved; and pasturelands and herds are now owned either by collective farms or by the State farms. As a general rule, pasture cattle-breeding is systematically planned, and combined with field crop cultivation in collective and State farms. All these measures have resulted in a substantial increase in the productivity of desert-steppe stockbreeding.

# APPENDIX

*List of the most common plants found on the Ust Urt Plateau Desert and the Kara-Kum Desert with their local names (N. N. Pelt, V. F. Chervinsky)*

| LATIN NAME | LOCAL NAME |
|---|---|
| *Acanthophyllum olatius* Bge. | Ak-tken' |
| *Aeluropus litoralis* (Gauan.) Parl. | Čair |
| *Agriophyllum latifolium* F. et M. | Zaruk |
| *Agropyrum sibiricum* (Willd.) P.B. | Erkek |
| *Alhagi pseudoalhagi* (M.B.) Desv. | Jantak |
| *Alyssum minimum* Willd. | Majadane |
| *Amberboa turkestanica* L. | Japyr |
| *Ammodendron conollyi* Bge | Sjuzen |
| *Ammodendron karelini* F. et M. | Kujan-suek |
| *Anabasis aphylla* L. | Ul'druk |
| *Anabasis brachiata* F. et M. | Kyrk-bugun |
| *Anabasis eriopoda* (Schrenk) Benth. | Kyrk-bojun |
| *Anabasis ranosissima* Minkw. | Kyrk-bojun |
| *Anabasis salsa* (C.A.M.) Benth. | Bijurgun |
| *Anabasis truncata* (Schrenk) Bge. | Kyrk-bugun |
| *Aristida karelini* (Trin. et Rupr.) Roshev. | Erkek-selin |
| *Aristida pennata* var. *minor* Litw. | Urkači-selin |
| *Arnebia decumbens* Fisch. *et* Mey. | |
| *Arnebia orientalis* (Pall.) Lipsky | |
| *Arnebia turanica* M. Pop. | |
| *Artemisia dimoana* M. Pop. | Porsy-bozogon |
| *Artemisia eriocarpa* Bge. | |
| *Artemisia herba-alba* Asso. | Evšan |
| *Artemisia karelini* Krasch. | |
| *Artemisia majkara* N. Pav. | Evšan |
| *Artemisia santolina* Schrenk | Bozogon |
| *Artemisia taurica* Willd. | Adži-evšan |
| *Artemisia terrae albae* Krasch. | Evšan |
| *Asparagus breslerianus* Schult. | |
| *Astragalus breslerianus* N. Pav. | |
| *Astragalus erioceras* F. et M. | |
| *Astragalus filicaulis* F. et M. | Nah-hotak |
| *Astragalus macrotropis* Bge. | Evšan |
| *Astragalus paucijugus* C.A.M. | Singren |
| *Atraphaxis spinosa* L. | Tue-sygar |
| *Atriplex cana* C.A.M. | Kokpek |
| *Bromus tectorum* L. | Epelek |
| *Calligonum aphyllum* (Pal.) Gürke | Kandym |
| *Calligonum* sp. L. | Kandym |
| *Caragana grandiflora* (M.B.) DC. | |
| *Carex physodes* M.B. | Ilak |
| *Ceratocarpus arenarius* L. | At-da-mak |
| *Ceratocarpus turkestanicus* Sav. Rycz. | At-da-mak |
| *Ceratocephalus falcatus* Pers. | Čeryk |
| *Convolvulus divaricatus* Bge. *et* Schmalh. | Ak-kert |
| *Convolvulus fruticosus* Pall. | |
| *Cousinia bipinnata* Boiss. | Derne-davan |
| *Cutandia memphitica* (Spreng.) Richter | |
| *Delphinium camptocarpum* F. et M. | Ag-gjuli |
| *Delphinium rugulosum* Boiss. | |
| *Descurainia sophia* (L.) Schur. | Sygyr-kuirjuk |
| *Diptychocarpus strictus* Trautv. | |
| *Dorema sabulosum* Litw. | Iljan |
| *Elymus giganteus* Vahl. | Kijak |

| LATIN NAME | LOCAL NAME |
|---|---|
| *Ephedra strobilacea* Bge. | Bordžok |
| *Epilasia hemilasia* Bge. | |
| *Eremopyrum buonapartis* (Spreng.) Nevski | Arpagan |
| *Eremopyrum distans* (C. Koch) Nevski | Arpagan |
| *Eremopyrum orientale* (L.) Jaub. *et* Spach | Arpagan |
| *Eremurus anisopterus* (Kar. et Kir.) Rgl. | Širjaš |
| *Erodium cicutarium* (L.) L'Hérit. | Čuluk |
| *Euphorbia turczaninowii* Kar. et Kir. | Suttegen |
| *Eurotia ceratoides* (L.) C.A.M. | Teresken |
| *Ferula fœtida* (Bge.) Rgl. | Čomuč |
| *Ferula karelini* Bge. | Kosjuk |
| *Gagea reticulata* R. et Sch. | It-adžuva |
| *Goldbachia laevigata* (M.B.) DC. | Kekre |
| *Halimocnemis karelini* Moq. | Jarmanlyk |
| *Halimocnemis villosa* Kar. et Kir. | Tomalatba |
| *Halocnemum strobilaceum* M.B | Šorotan |
| *Haloxylon aphyllum* (Minkw.) Iljin | Kara-sazak |
| *Haloxylon persicum* Bge. | Ak-sazak |
| *Haplophyllum bungei* Trautv. | |
| *Haplophyllum obtusifolium* Ldb. | |
| *Heliotropium argusioides* K. et K. | Gjunoik |
| *Horaninowia ulicina* F. et M. | Sary-tken |
| *Hypecoum trilobum* Trautv. | |
| *Isatis minima* Bge. | Četyr |
| *Isatis violascens* Bge. | Četyr |
| *Kalidium caspicum* (L.) Ung.-Sternb. | Tjube-sorang |
| *Kochia prostrata* (L.) Schrad. | Izen' |
| *Kœlpinia linearis* Pall. | Pišik-derne |
| *Lachnoloma lehmannii* Bge. | |
| *Lallemantia royleana* (Wahl.) Benth. | Narpyzyk |
| *Lappula echinophora* (Pall.) Ktze. | Mavi-gulli |
| *Launea korovini* Bge. | |
| *Leontice incerta* Pall. | |
| *Lepidium perfoliatum* L. | Četyr |
| *Leptaleum filifolium* (Willd.) DC. | Buinuz |
| *Malcolmia africana* (L.) R. Br. | Kizyl-kizylok |
| *Malcomia scorpioides* Bge. | |
| *Matricaria lamellata* Bge. | Tat-baši |
| *Matthiola chenopodiifolia* F. et M. | |
| *Nanophyton erinaceum* (Pall.) Bge. | Tas-bijurgun |
| *Nitraria schoeberi* L. | Ak-tken' |
| *Peganum harmala* L. | Adraspan |
| *Petrosimonia glauca* (Pall.) Bge. | Kojdželjuk |
| *Plantago lagocephala* Bge. | |
| *Poa bulbosa* var. *vivipara* Koeler | Kyrtyč |
| *Polygonum aviculare* L. | Kzyl-tomar |
| *Psammogeton setifolium* Boiss. | |
| *Ranunculus leptorrhynchus* Aitch *et* Hemsl. | |
| *Reaumuria fruticosa* Bge. | Issek |
| *Reaumuria oxiana* (ldb.) Boiss. | |
| *Rheum turkestanicum* Janisch. | Eshen |
| *Rhinopetalum karelini* Fisch. | |

| LATIN NAME | LOCAL NAME | LATIN NAME | LOCAL NAME |
|---|---|---|---|
| *Roemeria hybrida* (L.) DC. | | *Smirnovia turkestana* Bge. | Patlak |
| *Salsola arbuscula* Pall. | Bojalyč | *Statice suffruticosa* L. | Kokpekte |
| *Salsola carinata* C.A.M. | Pešmek | *Stipa hohenackeriana* Trin. et Rupr. | Dele |
| *Salsola chivensis* M. Pop. | | *Stipa holosericea* Trin. | Dele |
| *Salsola gemmascens* Pall. | Tetyr | *Stipa sareptana* Becker. | Dele |
| *Salsola lanata* Pall. | Kuš-gezy | *Stipa szowitsiana* Trin. | Dele |
| *Salsola laricifolia* (Turcz.) Litw. | Bojalyč | *Tamarix* sp. | Ilgyn |
| *Salsola praecox* Litw. | Ketgen | *Tetracme quadricornis* (Steph.) Bge. | Čemyr |
| *Salsola richteri* Karel. | Čerkez | *Tortula desertorum* Broth. | Kara-harsang |
| *Salsola rigida* Pall. | Kevryik | *Tragopogon krascheninnikowii* Gmel. | |
| *Salsola subaphylla* C.A.M. | Čogon | *Tulipa sogdiana* Bge. | Čigil'de |
| *Schismus arabicus* Nees. | Čair-epelek | *Veronica campylopoda* Boiss. | Kujan-žin |
| *Senecio coronopifolius* Desv. | Japyr | *Zygophyllum macropterum* C.A.M. | |

# BIBLIOGRAPHY


1. ANDRIANOV, B. V. K voprosu o geografičeskih izmenenijah v del'te Amu-Dar'i [On the subject of the geographical changes in the Amu-Darya Delta]. *Problems of geography.* 1951. (Collection 24.)
2. ——. Ak-džagyz (K istorii formirovanija sovremennoj etnicčeskoj territorii karakalpakov v nizov'e Amu-Far'i) [Ak-džagyz. The history of the formation of the present Kara-Kalpak ethnical region along the lower reaches of the Amu-Darya]. *Records of the Khorezm expedition.* Moscow, 1952. Vol. 1.
3. ——. K voprosu o pricčinah zastuplenija zemel' drevnevo orošenija na Kunja Dar'e i Žany Dar'e [The reasons why the former irrigated lands along the Kunja-Darya and Žany-Darya were allowed to go to waste]. *Proceedings of the All-Union Geographical Society,* vol. 86, no. 5, 1954.
4. ARTAMONOV, M. I. O zemlevladenii i zemledel'českom prazdnike skifov [Land ownership and agricultural festivals amongst the Scythians]. *Academic notes, University of Leningrad.* No. 15.
5. BART'OLD, V. V. *K istorii orošenija Turkestana* [History of irrigation in Turkestan]. St Petersburg, 1914.
6. BERG, L. S. *Aral'skoe More* [The Aral Sea]. St. Petersburg, 1908.
7. ——. *Klimat i Žizn* [Climate and life]. Moscow, 1922.
8. BLAVATSKII, V. D. *Kratkii očerk antičnovo zemledelija v severnom Pričernomor'e; abornik materialy po istorri zemledelija SSSR* [Short account of the ancient system of farming along the northern shores of the Black Sea; notes on the history of farming in the USSR]. Moscow, 1952.
9. BUCHINSKY, I. E. *O zasuhah na russkoi ravnine za poslednee tysjačeletie* [Droughts on the Russian Plain during the past thousand years]. Moscow, USSR Academy of Sciences, 1957. (Collection *Suhovei.*)
10. BUKINICH, D. D. Istorija pervobytnovo orošenija i zemledelija v Zakaspiiskoj oblasti v svjazi s voprosom o proishoždenii zemledelija i skotovodstva [History of primitive farming and irrigation in Transcaucasia and the light they throw on the origins of farming and stockbreeding]. *Hlopkovoe delo* [Cotton-growing], nos. 3-4. 1924.
11. CHERVINSKY, V. F. *Pastbiscnoe životnovodstvo v polupustynnoj i pustynnoj zonah SSSR (na primere Khazakhskoj SSR)* [Pasture stockbreeding in the semi-desert and desert regions of the USSR, taking the example of the Khazakh SSR]. Leningrad, 1958.
12. DOVZHENOV, V. I. *K istorii zemledelija u vostočnih slavjan, v I tycjačeletii n.e. i v epohu Kievskoj Rusi* [History of farming amongst the Eastern Slavs in the first millenium B.C. and in the Kiev Rūs era]. Moscow, 1952. (Collection *Materialy po istorii zemledelija SSSR* [Notes on the history of farming in the USSR].)
13. DZHUMAEV, O. M. *Kratkii očerk orošaemovo zemledelija v Turkmenistane* [Brief account of irrigated farming in Turkmenistan]. Ashkhabad, 1949.
14. ——. *K istorii orošaemovo zemledelija v Turkmenistane* [History of irrigated farming in Turkmenistan]. Ashkhabad, Academy of Sciences of the Turkmen SSR, 1951.
15. EVSEEV, P. K. *O prorode letnyh suhoveev ha jugo-vostoke Evropeiskoj časti Sovetskovo Sojuva* [The nature of the hot dry summer winds in the south-east regions of the European part of the Soviet Union]. Moscow, USSR Academy of Sciences, 1957. (Collection *Suhovei.*)
16. GAIDUKEVICH, V. F. K istorii drevnevo zeledelija v Srednei Azii [The history of ancient farming in Central Asia]. *Vestnik drevnej istorii* [Ancient history], Moscow-Leningrad, no. 3, 1948.
17. GREKOV, B. D. *Krest'jane na Rusi c drevnejših vremen do XVII veka* [Peasants in Rūs from earliest times to the seventeenth century]. Moscow, USSR Academy of Sciences, 1946.
18. GULYAMOV, Y. G. K Istorii irrigacii v Karakalpakii [History of irrigation in Kara-Kalpak] *Bulletin of the Academy of Sciences of the Uzbek SSR,* no. 9-10, Tashkent, 1945.
19. ——. *Istorija orošenija Jorezma s drevnejsih vremen do naših dnej* [History of irrigation in Khorezm from earliest times until the present day]. Tashkent, 1949. (Author's abstract of doctorate thesis.)
20. ——. K izučeniju drevnih vodnyh sooruženij v Uzbekistane [History of ancient irrigation works in Uzbekistan] *Proceedings of the Academy of Sciences of the Uzbek SSR,* no. 2, 1955.

21. *International seminar and study tour on flood control, drainage and irrigation.* Czechoslovakia, 1958.
22. Kastal'sky, B. N. Istoriko-geografičeskii obsor Surhanskoj i Širobadskoj dolinx [Historico-geographical survey of the Surkhan and Shirobad valleys]. *Vestnik irrigacii* [Irrigation news], nos. 2, 3, 4, 1930.
23. Khvoiko, V. V. Gorodišča Srednevo Pridneprov'ja [Sites of ancient towns along the middle reaches of the river Dnieper]. *Proceedings of the Twelth Archaeological Congress.* Moscow, 1905.
24. Kiselev, S. V. *Drevnjaja istorija Jušnoj Sibiri* [Ancient history of Southern Siberia]. Moscow, 1949.
25. Kostyakov, A. N. *Pazvitie orošenija v SSSR* [Development of irrigation in the USSR]. 1951.
26. Kovda, V. A. *Proishoždenie i režim zasolennih počv* [Origin and character of saline soils]. Moscow, USSR Academy of Sciences, vol. 1, 1946; vol. 2, 1947.
27. ——. *Velikij plan preobrazovanija prirody* [Great plan for the transformation of nature]. Moscow, USSR Academy of Sciences, 1952.
28. ——. *Geohimija pustyn' SSSR* [Geochemistry of the deserts of the USSR]. Moscow, USSR Academy of Sciences, 1954.
29. ——. Landšafty orošaemyh territorij SSSR [Landscapes of the irrigated territories of the USSR]. *Priroda* [Nature] Moscow XI, 1956.
30. ——. *Očerki prirody i počv Kitaja* [Notes on the natural features and soils of China]. Moscow, USSR Academy of Sciences, 1959.
31. Larin, I. V. *Osnovnye puti sozdanija ustoičivoj kormovoj bazy dlja životnovodstva* [Basic methods for the provision of a reliable fodder supply for stockbreeding]. Moscow USSR Academy of Sciences, 1954. (Collection *Pustyni SSSR* [Deserts of the USSR].)
32. Liberov, P. D. *K istorii zemledelija u skifskih plemen Podneprov'ja epohi rannevo železa v VI-II v.v. do n.e.* [History of farming amongst the Scythian tribes in the Dnieper basin in the sixth to second centuries B.C.]. Moscow, 1952. (Collection *Materialy po istorii zemledelija SSSR* [Notes on the history of farming in the USSR].)
33. Malyugin, E. A. *Metody rastenievodčeskovo osvoenija pesčanyh polupustyn' Zapadnovo Kazakhstana* [Reclaiming the semi-deserts of Western Kazakhstan by means of plant-growing]. Moscow, USSR Academy of Sciences, 1954. (*Collection Pustyni SSSR* [Deserts of the USSR].)
34. Maryshchenko, A. A. *Arhitekturnye pamjatniki Turkmenii* [Architectural monuments of Turkmenia]. Anau.
35. Nechaeva, N. P. *Vlijanie vypasa na pastibišča Kara-Kumov* [Effect of pasturing on the pastureland of Kara-Kum]. 1954.
36. Passek, T. S. Periodizacija tripol'skih poselenij [Establishment of the different periods of the Tripolye settements]. *Izvestija Arheologii* [Archaeological news], no. 10, 1949.
37. Pelt, N. N.; Chervinsky, V. F. *Puti sel'skohozjaist vennovo osvoenija Ust'jurta* [Methods for agricultural cultivation of the Ust Urt plateau]. Moscow, USSR Academy of Sciences, 1956.
38. Pokrass, E. P.; Bazilevich, N. I. *Osnovnye černy geomorfologii . . . Barabinskoj nizmennosti; issledovanija Barabanskoj nizmennosti, kak obekta sel'skohozjaistvennovo ispol'zobanija* [Main features of the geomorphology of the Barabin depression; investigation of the Barabin depression with a view to the possibility of using it for farming]. Moscow, USSR Academy of Sciences, 1954.
39. Razumova, L. A. *Vlagoobespeččennost' jarovoj pšenicy v rajonah osvoenija celinnyh i zaležnyh zemel'* [Supply of moisture for spring wheat in virgin and fallow lands recently brought under cultivation]. Moscow, USSR Academy of Sciences, 1956. (Collection *Osvoenie celinnyh i zaležnyh zemel'v 1954 g.* [Virgin and fallow lands brought under cultivation in 1954].)
40. Rybakov, B. A. *Anty i Kievskaja Rus'* [The Antis and Kiev Rūs]. Moscow, 1945. (Collection *Itogi i perspektivy razvitija sovetskoj arheologii* [Achievements and future prospects for the development of Soviet archaeology].)
41. Samohvalov, N. F. *Klimatičeskaja harakteristika suhoveev Kazakhastana* [Climatical characteristics of the dry winds of Kazakhstan]. Moscow, USSR Academy of Sciences, 1957. (Collection *Suhovei.*)
42. Sapozhnikova, S. A. *Agroklimatičeskoe raionirovanie territorri osvoenija celinnyh i zaležnyh zemel'* [Agroclimatic divisions of the newly cultivated virgin and fallow lands]. Moscow, USSR Academy of Sciences, 1956. (Collection *Osvoenie celinnyh i zaležnyh zemel' v 1954 g.* [Virgin and fallow lands brought under cultivation in 1954].)
43. Selyaninov, G. T. *Agronomičeskoe ponimanie zasuhi i suhoveja i ih raspredelenie na evropeiskoj territorii SSSR; suhovei, ih proishoždenie i bor'ba s nimi* [Agronomical study of drought and dry winds and their distribution throughout the European territory of the USSR; dry winds, their origin and measures for dealing with them]. Moscow, USSR Academy of Sciences, 1957.
44. Slobodin, V. M. *K voprosu o razvitii i smene sistem zemledelija (ot vremeni evo vozniknovenija na territorii SSSR do I tysjaceletija n.e.)* (Development and change of the farming system, from the earliest beginnings of farming on the territory of the USSR down to the first millenium B.C.]. Moscow, 1952. (Collection *Materialy po istorii zemledelija SSSR* [Notes on the history of farming in the USSR].)
45. Sovkov, K. V. *Voprosy sel'skovo hozjaistva v russkih žurnalah poslednej tret XVIII v.* [Problems of agriculture discussed in Russian journals in the last third of the eighteenth century]. Moscow, 1952. (Collection *Materialy po istorii zemledelija SSSR* [Notes on the history of farming in the USSR].)
46. Tanzybaev, M. Zemledelija Hakasii v prošlob [Farming in Khakass in ancient times]. *Sel'skoe hozjaistvo Sibiri* [Agriculture in Siberia], no. 6, 1958.
47. Tolstov, S. P. *Osnovnye itogi i očerednye zadači izučenija istorii i arheologii Kara-Kalpakii i Kara-Kalpakov* [Main findings and future tasks in the study of the history and archaeology of Kara-Kalpak and its inhabitants]. *Bulletin of the Academy of Sciences of the Uzbek SSR*, Tashkent, nos. 9-10, 1945.
48. ——. *Drevnij Khorezm. (Opyt istoriko-arheologičeskovo issledovanija)* [Ancient Khorezm. Findings of historical and archaeological research]. Moscow, State University, 1948.
49. ——. *Po sledam drevnehorezmiiskoj civilizacii* [On the track of the civilization of ancient Khorezm]. Moscow, Leningrad, 1948.
50. ——. *Arheologičeskie i etnografičeskie raboty Horezmskoj ekspedicii 1949-1953* [Archaeological and ethno-

graphical investigations of the Khorezm expedition 1949-1953]. Moscow, 1958, vol. II.
51. TRET'YAKOV, P. N. Podsečnoe zemledelie v Vostocnoj Evrope [Having farming in Eastern Europe] *Izvestija Instituto Material Kul'tury* [Bulletin of the Institute of Material Culture], Moscow, vol. XIV, no. 1, 1952.
52. ZAKIEV, H. Y. *Lesopolosy i režim vlažnosti i temperatury vozdušnovo potoka* [Forest strips and the moisture and temperature régime of the air currents]. Moscow, USSR Academy of Sciences, 1957. (Collection *Suhovei.*)
53. ZVONKOV, V. V. *Kompleksnoe uspol'zovanie vodnih resursov v rečnih basseinah SSSR* [Multi-purpose usage of water resources in the river basins of the USSR]. Moscow, USSR Academy of Sciences, 1957.

# DEVELOPMENT OF LAND USE IN NORTHERN AFRICA
## With references to Spain

*by*

J. Despois

*Professor of Geography at the Sorbonne, Paris*

## NATURAL CONDITIONS

North Africa, or the Maghrib, which includes Morocco, Algeria and Tunisia, is adjacent to the Sahara, which is the largest and driest of the world's hot deserts [21].[1] While it is not itself desert land, four-fifths of its area lie in the more or less arid zone, and it marks the transition to the countries with a definitely Mediterranean climate. It will be recalled that these countries have a temperate climate, characterized by the fact that the dry season coincides with the hot months (summer) and the rainy season with the comparatively cool months (autumn, winter and spring); but precipitation, which varies in quantity from region to region, also fluctuates from season to season and from year to year [12, 13].

In North Africa, there is only one humid and subhumid zone (roughly distinguished by having a mean annual rainfall of more than 600 mm.) which is completely free from aridity, with a number of isolated uplands surrounded by dry regions, like the High Atlas in Morocco, and the Aurès. It represents only one-fifth of the total area, and covers the north of Morocco, on the Atlantic coast with the slopes of the Middle Atlas facing the Atlantic, and the northern side of the Algerian and Tunisian Tell Atlas mountains from Algiers to Bizerta. For the most part, it is made up of mountainous regions covered with thick forests of holm-oak or cork-oak, and sometimes of sea pines or cedars, which have often degenerated into scrub; deciduous trees are also characteristic of the region. The best land is to be found where the wild olive and the mastic tree both grow. Soil scientists find that unsaturated soils predominate and there is a tendency to podsolization. This zone will not be dealt with in this study, except for occasional references to it.

Between this small zone, which is definitely Mediterranean, and the Sahara, an arid desert region which is dealt with in another chapter, lie four-fifths of the area of North Africa, regions with modified Mediterranean characteristics, which are already more or less dry; some may be called 'semi-arid', and others 'non-desert arid lands'.

The former, which cover a comparatively small area, have an annual rainfall averaging between 350-400 mm. and 550-600 mm. and are Mediterranean rather than arid [52]. The soil is yellowish brown, and usually calcareous or chalky. In the low-lying plains of Oran the river deposits become saline [2, 44, 94, 98]. The main forest vegetation is the holm-oak and the Aleppo pine, and sometimes the thuja. Where this deteriorates, it is succeeded by thin scrub. The distinctive vegetation of the plains is one of scattered jujube trees *(Zizyphus lotus)* rather than of mastic and wild olive trees [46, 67]. Saline depressions are marked by the halophilous plants of the *shotts* and the clay of the *sebkhas* (solonchak), which sparkles with salt. In general, this area covers the non-humid regions (and those which are not even subhumid) of the areas known as the 'Tell' in Algeria and Tunisia, and half of the plains on the Atlantic coast of Morocco. Included in it are some southern groups of mountains like the High Atlas and the Aurès.

It would be more correct to call the 'non-desert arid lands' sub-arid or sub-Saharan—the important point is to bring out the difference. They form a zone with a low and erratic rainfall—ranging from 150-200 mm. to 350-400 mm.—a light-coloured soil and scant, scattered vegetation. The soil is mainly chalky and, owing to the fact that the fall of the water has been only partly towards the sea since the middle of the Tertiary period, it is largely composed of continental sediments, often encrusted, and of recent alluvial deposits, which as they become saline result in the formation of *shotts* and *sebkhas*. The degree of aridity is such that the wind can affect the contour of the soil and bring about the formation of small dunes. Elsewhere than on the mountain ranges,

1. The figures in brackets refer to the bibliography at the end of the chapter.

which still carry sparse forests of holm-oaks, Aleppo pines and large numbers of junipers, the scanty vegetation consists of small, bushy plants like the artemisias or hardy Graminaceae, such as alfa grass *(Stipa tenacissima)* or esparto grass *(Lygeum spartum)*. The herbaceous annuals are to a very great extent dependent on the rainfall. On the analogy of the Russian steppes, the French have given the name of 'steppes' to these arid regions which most of the native inhabitants regard as part of the Sahara; they are actually intermediate between the Tell, which is still more or less Mediterranean, and the desert.

The truth is that, apart from the small number of trees, these steppes have almost nothing in common with the steppes in the Soviet Union, which include black earth zones and deep brown soil, and are covered with thick, herbaceous vegetation which does not dry up in summer, because the rainfall is considerably heavier and particularly because it occurs during the hot season—both factors of prime importance. Soviet geographers do not consider that these regions in North Africa have any of the features of steppeland; instead, they find similarities with the semi-desert regions in their own country, and suggest calling them 'semi-desert regions' [55].

In these semi-arid and arid regions, the dry conditions prevailing in summer make it essential to water most cultivated shrubs and all summer crops, as in Mediterranean countries. In the arid zone, however, irrigation is essential for all crops, owing to the low rainfall. Where the mean annual rainfall is between 200 mm. and 300 mm., 2,000-4,000 m.$^3$ of water per hectare are needed each year for wheat, 3,000-6,000 m.$^3$ for olive trees, 6,000-8,000 m.$^3$ for fruit trees if no crop is grown between the trees (e.g., as in the case of apricots), 10,000-15,000 m.$^3$ for fruit trees where market gardening is carried on between the trees, and 15,000-16,000 m.$^3$ for lucerne. These water requirements, which vary according to the soil, are considerably less than the amounts needed in the oases in the Sahara, which, with their palm trees and 'layered' crops, require 20,000-30,000 m.$^3$.

On one side of the Maghrib is the Spanish peninsula, and on the other, Libya. Although each has a long Mediterranean coastline, both of them—and particularly Libya—show African features, with very definite aridity. Only about one-fiftieth of Libya is not desert (and largely very arid desert) while the only humid region in the country is the centre of the Jebel Akhdar (Green Mountain) in Cyrenaica [12, 33]. About half of the Spanish peninsula is semi-arid, and the south-east is arid. Reference will be made to these two countries from time to time, particularly because, both in ancient times and in the Middle Ages, they have to a very large extent shared the history of the Maghrib [90]. (See also Fig. 1.)

## TRADITIONAL METHODS OF LAND USE

In the arid and semi-arid regions of North Africa it is possible to use the land, and has been possible throughout the centuries, only by the application of suitable techniques : special dry-farming methods for cereals as well as trees; various methods of irrigation, some of which make use of a regular, steady stream of water fed by springs, wells or permanent rivers,

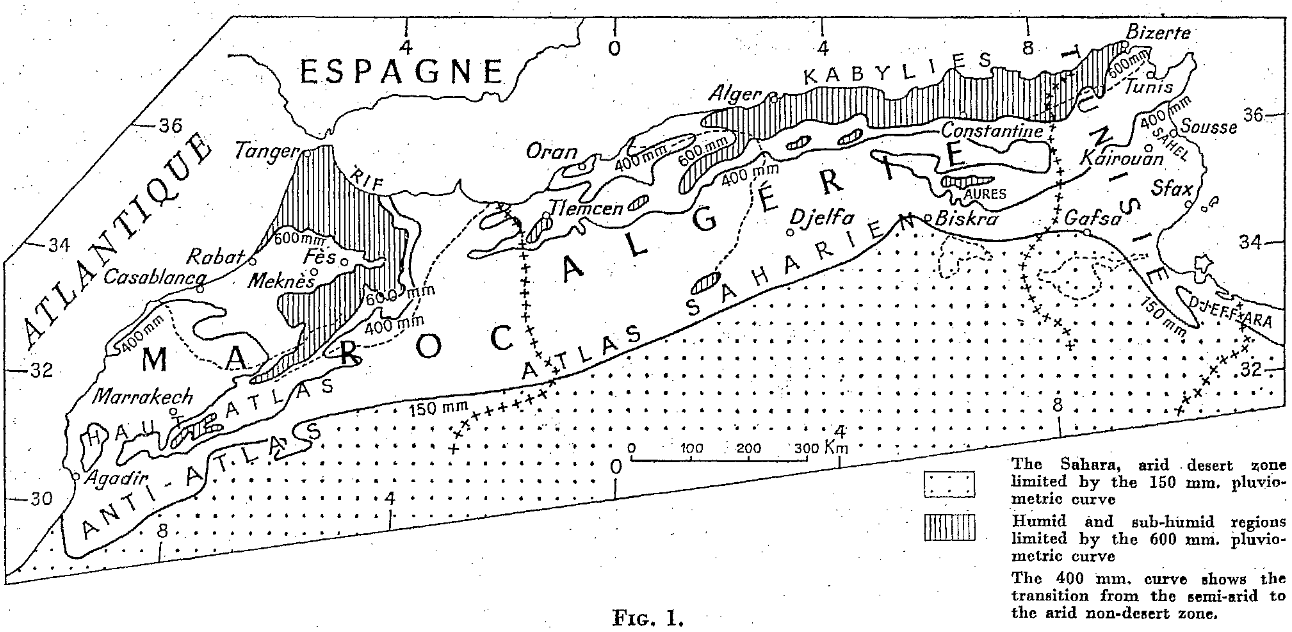



FIG. 1.

while the object of others is to harness the flood waters of torrents and local run-off and to spread them over the fields; and the preservation of the vegetation covering the slopes or the practice of terracing the fields. As the traditional agricultural techniques and procedures used by the inhabitants today appear to have changed very little over the centuries, and as it is difficult to say exactly what progress was made in each period, it seems advisable to begin by giving a fairly detailed description of these techniques and procedures.

## DRY FARMING

Dry farming naturally accounts for the greater part of the land under cultivation, mainly in regions defined as semi-arid. A variety of procedures are used of course and we have to consider not only annual crops like cereals (e.g., wheat and barley) and some leguminous crops (e.g. beans) but also tree growing. It must be remembered that trees—especially fig trees and olive trees—are much more important and are more valuable as a source of food in Mediterranean countries than in moderate or cold temperate regions.

Cereals are traditionally grown in two-year rotation, with a fallow period when the land is used for pasture. In an extensive economy which includes both the growing of cereals and the raising of flocks, this arrangement meets the need to let the ground rest, to manure it after a fashion, and to provide food—also after a fashion—for cows, oxen or a small herd of sheep and goats.

Preparatory spring ploughing is not unknown, especially where the soil is heavy. It has long been practised here and there, at least in Algeria and Tunisia [97]. Snatch crops—primarily beans, chick peas and lentils—do not yield any substantial results, because of the lack of adequate rain outside the humid zone, except, occasionally, in the area immediately adjacent to it.

The usual practice is to sow even before ploughing. The farmer waits until the first autumn rains have loosened the soil. Then he divides his fields up into a number of rectangular strips, which he marks out with the plough; he then sows them and immediately afterwards ploughs them [9, 35, 36, 70]. In many cases, however, the land is ploughed as a preparation for the sowing of the seed and before the seed is ploughed in. In any case, the ploughing is a mere scratching of the soil, a harrowing with a wooden swing plough which has an iron ploughshare. It is not strong enough for heavy land, but on hillsides which are liable to erosion it has the advantage of turning over only a thin layer of earth.

On the heavy soil in the Tell, the swing plough is harnessed to a pair of oxen, and sometimes, in these days, to horses or mules. On light soil, which is more common in arid regions, one animal is sufficient. The mountain dwellers use mules, and those who were once herdsmen use horses; camels are not used very often, except in Tunisia, to the south of the Dorsale and in Libya. The careless habit of going around obstacles such as trees, jujube bushes, or clumps of hardy grasses, has the advantage of leaving intact well-rooted plants which hold the soil in place on hillsides and provide shade for a variety of annual vegetation and a small amount of humus.

The drier the region, the less grain the farmers sow on the surface. In Tunisia, for example, they use 100 kg. of seed to the hectare north of the Upper Tell, in the Kef and Teboursouk regions, as is customary in the more northerly countries. Around Thala and Mahtar, they sow 80 kg. of wheat and 70 kg. of barley. On the other side of the Dorsale, the figures fall to 50 kg. and 40 kg. and in the sandy regions in the south of Eastern Tunisia only 30 kg. of wheat and 20-25 kg. of barley are sown per hectare. By sowing sparsely, even very sparsely, the farmers—who are usually herdsmen—have smaller losses to face when there is no harvest at all owing to drought, which frequently occurs. On the other hand, they count on the tendency of wheat and particularly barley to tiller with the help of rain, moisture borne on the wind or a slight trickle of run-off water; because of this, good harvests may be produced in certain areas, but they are exceptional [34]. Barley is the cereal favoured in the driest areas, since it is better suited to light soils than hard wheat, requires less water, and ripens about three weeks earlier, so that is is less likely to be shrivelled by the hot south wind (the sirocco). It is sometimes harvested in the second half of April or in May [36, 74].

In all regions, reaping is done with the sickle, and the ears are cut high up, so that the straw, which is left on the ground, may be used for the cattle. When the land is not farmed by the owner himself, the share-crop farming system—on the basis of either one-fifth *(khammès)* or one-quarter *(rebâa)* of the crop—is universally adopted [83].

Shrubs and trees, such as the olive, fig, vine and almond, do not usually produce a satisfactory harvest once the semi-arid zone is passed. Vines are not worth while if the mean annual rainfall is less than 400 mm. While olive trees do well in the region around Tunis, by dry-farming methods and with a rainfall of 400 to 450 mm., it is considered that, in slightly heavy soil, olive crops are reasonably reliable only near the humid zone, where the annual rainfall is at least 500 mm., and then providing the soil is ploughed several times [75, 92].

A remarkable dry-farming technique has been preserved, however, among the people of the town of Sfax, in the south-east of Tunisia, by the use of which extensive olive groves were recently planted in the 'steppes' of Tunisia and in Tripolitania, arid regions with a mean annual rainfall of only 170-250 mm. [36]. It is true that these areas have very light, sandy soils and a maritime climate. The direct fixation of water vapour in the atmosphere by the sand (occult condensation), together with dew, amount here to a few score millimetres of rainwater. The plants grown are spaced out, so that their roots do not interfere with each other. Olive trees are planted with intervals of 24 m. between them in all directions so that there are 17 or 18 to the hectare, and each tree has 576 $m.^2$ of ground. In the gardens, or rather in the orchards, which stretch out in a wide semicircle around the town of Sfax, the almond trees, which have taproots, and the few other trees (apricots, peaches, etc.) are planted about 12 m. apart, while vines are planted 5 m. or 6 m. apart. Even vegetables are grown in small quantities near the coast.

It is only by constantly working the ground that such results can be obtained. The land where vegetables are grown must be hoed frequently and sometimes needs to be well banked up. For trees, the land must be ploughed at least twice, and must have two surface dressings. For the first ploughing, ordinary wooden swing ploughs are used or, nowadays, light 'orchard' ploughs; for the second, growers in Sfax use a horizontal blade, known as a *mâacha*, which is harnessed like a plough and penetrates the ground to a depth of only 7-8 cm. The object of ploughing and hoeing is twofold : to keep the soil in a very loose condition, so that the rain and damp air may penetrate more readily, and to overcome the capillary attraction which leads to evaporation; and to keep the soil very clean, so as to prevent evaporation through the growth of weeds, especially couch-grass, which spreads very quickly in this region. This is one of the most outstanding examples of dry farming, for olive trees and almond trees in particular—and also apricot and peach trees—bear fruit and give a satisfactory return with an annual rainfall of less than 200 mm. Furthermore, in the Sfax area there is a system of a provisional partnership contract, the *mgharsa* contract, which has made it possible for French and Moslem capitalists to increase the extent of the olive groves very quickly. This is a planting lease, under which the *mgharsi*, who provides only his labour and the working tools, receives half of the plantation when, after a few years, the trees are producing—in the case of olive trees, after 12 or 15 years.

On the whole very poor results are obtained from the barley which people try to grow between the olive trees when they are young, for the roots of cereals do not go deep enough for them to profit by all the subsoil moisture. At the other end of the Maghrib, however, along the Atlantic coast—where, it is true, the rainfall is better—the Moroccans grow maize without irrigation [73]. It is clear that the proximity of the sea and 'occult condensation' are of the utmost importance, at least when people know how to take advantage of them.

## IRRIGATION

The area that can be irrigated is limited by the capacity of wells, the volume of water supplied by springs, the irregular flow of the wadis and the short duration of local run-off.

If wells are used for irrigation they must be fitted with devices for raising the water. The most common type, which is almost universally used, is animal driven and is also known as the *delou* well [26, 42]. The *delou* is a water-skin made of ox-hide or, much less frequently, of goat-skin, with a capacity of 15 to 35 litres. It is raised by an animal pulling a rope over a pulley fixed to a wooden or stone support. At the base, the water-skin has a leather spout, which is kept folded back by a cord while it is being raised but lets out when it reaches the top; the water is then discharged into a small pond which feeds the main canal. The animal which pulls the rope—an ox or an ass, sometimes a camel (in Tunisia), and occasionally a mule (near the Tunisian coast)—is accompanied and assisted in its progress over a sloping track by a man or a child, who also works the cord which holds the spout folded back or extended. In this way from one-quarter to one-half a hectare of orchard garden may be irrigated.

Another, but much less commonly used, system is the 'noria' (in Arabic, *nawra*, and sometimes *sanya*). This is an endless belt made of cord and wood, to which earthenware scoops are attached. It is driven by a capstan, worked by a horse, a mule, or sometimes a dromedary. It is most commonly found in the coastal plains of the Maghrib where humid conditions prevail. Still less frequently we find wells with a counterpoised sweep, which are often called 'stork-wells' and are practically unknown outside the Sahara, and scoop-wheels, which are used only in the immediate neighbourhood of Fez.

Irrigation is carried out almost entirely by submerging lands which have been ranged to form small basins. When the owner employs a farmer under the share-cropping system he remunerates him with a percentage, varying with the region and the type of crop, which may be olives, other fruit trees, vegetables, or winter or summer cereals.

The advantage of using spring water is that it flows of its own accord and does not have to be laboriously raised as well water must be. Once harnessed, more or less effectively, it is carried off by one or more main canals, which are dug out of the ground and branch out as they go downhill. There are two principles governing the relationship between water and earth [35, 64]. According to that known as the

'Tell' principle, in Algeria, earth and water are both private property, but are inseparable, and are entered on the same property title; they are sold, rented and mortgaged together. The amount of water to which each man is entitled is proportionate to the area he cultivates, and irrigation is carried out in sections, from the head waters downwards. The principle is subject to a number of minor violations : for example, a piece of land may be alienated without water, if water is comparatively scarce, or irrigation may be effected not for different sectors of land but for different groups of people, sections or subsections of a tribe, even if their holdings are intermingled; this causes waste of water, delays and complications [11].

The 'Saharan' principle is seldom applied outside the desert proper, though it is followed in the south of the Hodna [35]. According to this principle, the only valuable commodity is water; it is the most important of all possessions, and is not associated with the soil it irrigates. People trade in it and divide the supply independently of the gardens. It is possible therefore to have water and not to use it, or to let it to a farmer who has none, and who is thus able to establish a garden. Among some herdsmen, who grow hardly anything but winter cereals, the ownership of water is collective, and each man has the use of a certain amount of water and a plot of land, providing he has a team of draught animals and a plough. If the type of agriculture changes and wheat and barley are replaced by trees, the ground becomes *de facto* private property, while the water remains the property of the group; one man's share of water cannot be sold, and, if it is not used, it reverts to the group.

As in almost all areas, methods of division vary according to the volume of water supplied by the springs. If the springs are large ones, the water is divided by volume into a number of canals before it is allocated in units of time—hours or parts of days at regular intervals. The water from springs with a moderate flow is divided only by units of time. The water from springs with a small flow is allowed to accumulate in a small reservoir, or behind a small dam (in Arabic, a *madjen*, in Berber, an *ifri*). Each owner takes the water from the reservoir in his turn.

The Saharan system of the *foggara*, or underground galleries ventilated by shafts, which are driven through a slope to tap the phreatic water and bring it to the level of the crops by gravity alone, has made some headway in North Africa proper, in some of the driest regions. It is found especially in the Haouz of Marrakesh, where pipes, called *rhettara*, convey to the lower parts of the plain the water which has filtered into the foothills of the Atlas mountains [30, 80]. The same system is also found in the *chegga*, which are often mere trenches in the neighbourhood of Bou Sâada, in the south-west of the Hodna and in the Sahrez Chergui to the north-east of Djelfa. The principle adopted is that the water should be divided into a number of shares equal to the number of men who have worked on the construction and maintenance of the collection galleries [35].

The major rivers, especially those which rise in the well-watered regions of the north, and the main mountain wadis, which have water all the year round, can provide enough to keep trees and gardens alive and flourishing, provided that the growers know how to divert at least some of their water when the level is at its lowest. In the more or less arid regions of the Maghrib, especially in the main mountain massifs and in the foothills, it is quite common to find small dams, or rather diversion dikes, which are designed to direct a flow of water when the level is low, and even sometimes when it is high, into gardens or fields [11, 35, 36, 43]. Although they are constructed to be under water, they are readily swept away by floods, but can often be almost as easily reconstructed. In mountainous regions, these simple dams, which are called *rabta* or *sedd* in Arabic and *ouggoug* in Chleuh Berber, consist of dikes made of stones and branches of trees, sometimes held in place by strong stakes; in the plains, they are made of very wide superimposed layers of earth and branches. These dikes are build across the current or at an oblique angle to it; sometimes, when it is intended to divert the water on to both banks, they are curved. The channel *(seguia, targa)* or the two channels often become silted up or worn into gullies, and have to be carefully maintained. If they are small, they take the water straight to the crops; otherwise the flow of water is divided, after passing through a sluice into secondary channels which provide water for the gardens in their turn. In mountainous districts, like the western High Atlas, where irrigation is carried out only in summer, the dams which have been swept away by the floodwaters have to be remade every spring, and the canals along the mountain sides strengthened or repaired.

Naturally, only those who farm on the banks of the stream and who have taken part in the building and maintenance of the system have the right to use the water. In the mountainous regions, each takes as much as he needs, as only a small proportion of the land is cultivable. The dams are built at intervals, proceeding downstream, and are not placed too close together. They work simultaneously as long as there is enough water; if there is not, and providing that the riverside growers have managed to come to an agreement, or that those whose land is downstream have succeeded in imposing their will on those whose land lies upstream, they are used in succession, the inlets to the diversion canals being kept closed for varying periods.

When the wadis reach the foot of the mountains or the plain, they receive scarcely any further replenishment, and their flow decreases, largely as a result of seepage. Consequently, the inhabitants of the banks in the downstream section of the wadi often have only one dam, though it may be a fairly large one. Since, unlike their mountain neighbours, they have a lot of land and comparatively little water, there are—or often were in the past—disputes between plain and mountain dwellers. This applies equally to the Hodna and the southern foothills of the Aurès and to the *dir* of the High Atlas in Morocco.

As in the case of springs, the water available is generally in proportion to the area cultivated, and cannot be divorced from it, at least among the sedentary population and when it is to be used in gardens. Those who were formerly herdsmen, and the semi-nomads who at the outset grow only cereals, often treat water as communal property, like the land itself; the two elements, however, may be dissociated, and land may become private property before water does.

The permanent watercourses are always fuller between autumn and spring, and their spates come between September and May. This means that there is surplus water available for the use of the people in the cool seasons when less irrigation is required in the gardens. Downstream, therefore, there are often tracts of land of various sizes, beyond the orchards, where annual crops of wheat or barley are grown. The wheat and barley, however, may also be watered simply by the floodwaters of wadis which are normally dry; in that case, the word 'wadi' designates the 'thalweg'.

In the latter case, however, the word 'irrigation' is not quite appropriate, for the water is supplied not through the efforts of human beings but by the floods on the wadis; in other words, it depends on the rainfall. Furthermore, in this case the water is not a stream which can easily be diverted and shared—it is a destructive torrent, part of which must be directed somehow over the land under cultivation, at the risk of causing either shifting of alluvial deposits or erosion. Efforts are made to keep the bed of the wadi on the higher parts of the alluvial fans, so that the canals have only to assist the spreading of the floodwaters, while preventing the washing away of the soil, and the distribution of the newly deposited silt, which restores the fertility of the fields. Only cereal crops and pastureland can benefit by these floods, which rarely occur in summer; in any case trees would be buried too deeply in some places through the shifting of the alluvium and in others their roots would be exposed through the erosion of the soil.

The dams used for diverting the water are of the same type as those used for diverting permanent streams. They are still more liable to be swept away, and are therefore arranged one after the other, proceeding downstream, so that they do not interfere with each other to any extent. The first dams get most water from medium spates but are swept away by heavier ones, whereas when the floodwaters reach the plain they are less tumultuous, and are easier to distribute. The dams nearly always work simultaneously, although sometimes, when the floods are small, it is arranged that everybody shall have the advantage of them in turn. This 'canalized flooding' is most valuable and most widely distributed in the dry plains at the foot of the mountains which receive more rain—the foot of the Atlas mountains in Morocco, the Hodna plains in Algeria, the plains around the mountains of the Sahara and the Kairouan plains in Tunisia [35, 36]. In the latter region, the Wadi Marguellil and the Wadi Zeroud rise in the Tell. The two main dams *(rebta)*, which prevent the floodwater from running into the lower regions, are extended by dikes *(djenah)*, which are designed to carry the water across the upper part of the alluvial deposits to dividing sluices, or secondary diversion dikes *(mgoud)*, from which it is distributed over the plain by small earth banks. Over 300 owners in two syndicates enjoy the advantages of the floodwater from the wadis, and take part in the upkeep of the dams.

This very special system of using the water does not necessarily involve ownership of the land. Especially in the Saharan foothills the herdsmen generally have only the use of their land and common ownership of the water—always, however, on condition that they have worked on the building and maintenance of the dam and the canals. Land and water are fairly generally treated quite separately there.

Some regions have so few hills and are so dry that the wadis are nothing but short streams which flow for a while—a few score minutes or a few hours at most—after rain has fallen. Some of these are to be found on the indented edge of the plateau which overlooks the Tunisian-Tripolitanian plain of the Jeffara. [32, 82]. Small stone and earthen walls are built across the gullies, to hold back the water and the silt, and small diversion dikes are built of water-rounded stones to turn the water of the larger wadis towards the terraced banks. Lastly, in the hill country behind Susa as well as in the Matmata hills in Tunisia and in the Djebel Yéfren, Gharian and Msellata in Tripolitania, the olive trees which are planted in the little valleys are watered by the run-off from the hills between them after a fall of rain [36, 49]. These hills, arranged to serve as rain troughs with trenches *(meska)* to convey the water to particular olive plantations, are part of the property just as the trees are.

It will thus be seen that there are a number of gradations between irrigation proper, 'canalized flooding' and the process of merely diverting local run-off water.

## TERRACING

The mere fact that land is to be irrigated or run-off water diverted means that the fields must be at least roughly levelled. Therefore, as soon as the incline becomes steep they must be graded into tiered terraces. Terracing, which is very widespread in the Mediterranean countries, is usually used there as a way of making hillsides suitable for dry farming, generally of vines or fruit trees.

From the various ways of using water which have just been described, it is possible to deduce the different types of terracing to which they give rise—terraces descending in tiers below springs, terraces along hillsides or at the bottom of valleys, gullies across which small stone walls or banks of earth are built, and depressions formed in valleys to catch water which flows down over the ridges between them.

Strangely enough, however, dry-farming terraces, although so common in some Mediterranean countries, are the exception here, and where they do occur they are of recent origin [40]. For the most part only remains of them are found, as in the central Moroccan mountains and in some mountains in the Dorsale in Tunisia; in the Jebel Ousselet, north-west of Kairouan, it is known that the system was discontinued only two and a half centuries ago. Lastly, on moderate inclines such as a slope worn down by erosion, the removal of stones leads to the strengthening of the boundaries of the fields and, as a result of contour ploughing, to the formation of shelves, low, semi-spontaneous terraces or 'screens'. It may be that some of these screens were once arranged systematically so as to hold back the run-off and help it to penetrate—for example, in the region of the Roman *limes* of Numidia, which has been studied by Colonel Baradèz [6].

The absence of terracing in the humid and semi-arid regions of the Tell might be explained by the custom—more common in the past than nowadays—of using swing ploughs drawn by two oxen harnessed together to a very wide yoke which rested on the animals' withers, and would be difficult to turn in narrow fields. This explanation is worth bearing in mind, but there are other circumstances which offer more convincing evidence, as will be seen later on.

Whatever the reason may be, it is a matter for regret that terracing is not carried out on any of the uplands apart from the pre-Saharan mountains. Although the Kabyles plough and sow the steep slopes of their mountains only where the land is partly held in place by the roots of olive or fig trees planted here and there in the fields, although they make a few trenches in an attempt to drain away the run-off, and keep the footpaths in order by making little walls or hedges, their fields are often full of gullies and the soil is impoverished. And it must be remembered that the Kabyles are in the humid zone. Elsewhere, however, as a result of the clearing of forest-land, scrub or uncultivated moorland, in the drier regions, all the destructive forms of slope erosion can be observed, from mere 'scratches' to the stage where the rocky subsoil is exposed, from small gullies to 'bad lands' and landslides [81].

## STOCKBREEDING METHODS

Stockbreeding has always been able to adjust to varying degrees of aridity in climate by keeping to an extensive economy and having recourse to various forms of seasonal movement of stock [37]. Some systems are like those used in the Mediterranean countries [12]; in winter, flocks of sheep with a greater or less admixture of goats are brought down from the Moroccan Atlas and the Saharan Atlas in Algeria to the nearby plains, while they spend the summer in pasture-lands on the highest mountains, sometimes along with cattle. All the systems are explained by the differences in altitude, the need to escape from cold and snow and the necessity for cool pastures and springs in summer. But stock is also moved from one latitude to another, over greater distances, because there are zones of varying aridity to be found—low-lying desert, which is very hot in summer but comparatively mild in winter, steppes or pseudo-steppes which are usually fairly high, and Mediterranean regions which are not bare of pasture in summer and which have plenty of water points [11, 22, 23, 39, 43, 64]. On the other hand, for reasons that are both historical and geographical in origin, the practice of moving flocks seasonally to different pastures has brought about the development of various forms of nomadism, when families who own flocks move about, taking with them, on the backs of their camels and donkeys, their tents, their possessions and some of their food.

Two main types of nomads may therefore be distinguished: nomads proper, most of whom spend the cold season with their flocks in the Saharan foothills and in summer go with them to the drier regions of the Tell or only as far as the mountains of the Eastern High Atlas or the Saharan Atlas (except the Aurès) [39, 89]; and semi-nomads, who also grow cereals. The latter move about with their smaller livestock for only part of the year and over fairly short distances, they live in arid but non-desert regions, they only draw near to the Tell in summer, and sometimes if necessary even go a short distance into it. They are often in contact with stockbreeders in the semi-arid regions who have not enough pasture-land as a result of the extension of agriculture, and they work for them as herdsmen. The practice of moving the flocks from the mountains in winter and spending the summer on the heights also means that people move from one place to another, but this is less common.

Thus, by moving their flocks from one pasture to another and spending their lives in the open air, the stockbreeders have adapted their trade to arid conditions. This is not a necessary consequence of the geographical conditions. In many cases other forms of stockbreeding might have been undertaken, with irrigation for growing fodder plants, provision for flooding pasture-lands, reserves of food, and stalling of the cattle in certain seasons. Nomadism, however, is not due only to pastoralism; it is—and was to a still greater extent in the past—connected with the system of transport and trade between regions which had different natural resources; and, a few centuries ago, it was reinforced by the migration of nomads from the Middle East.

## USE OF LAND IN THE PAST : CONTRIBUTION OF THE DIFFERENT PERIODS

Fairly large numbers of people have always lived in the more or less arid regions of North Africa. This has been due to several factors : the use of often very careful dry-farming methods; various systems of irrigating the land and diverting the waters of rivers; the terracing of fields—admittedly over a very small area; and the adoption of certain forms of stockbreeding accompanied by nomadism.

It would have been an advantage if the account that has been given could have shown the historical development, with some indication of the different practices introduced in each period. But because of the gaps in our material (both written and archaeological), our ignorance regarding the origin of many processes and techniques, and the impression—possibly a false one—that they have changed very little through the centuries, we have thought it better to describe them first. We may, however, make an attempt to outline the development of land use in North Africa, a region which made its appearance in history some 3,000 years ago and which has apparently had no major changes of climate since that time, apart from brief fluctuations [63, 91].

### ANCIENT TIMES

To a considerable degree, the history of North Africa has been moulded by foreign influences and conquests. However, the oldest of the peoples inhabiting it, the Berbers, who, despite peaceful or violent immigrations, have always constituted the great majority, have not been inactive. Since Neolithic times, when more humid conditions at first prevailed, the Berbers have cultivated wheat and barley and bred the domestic animals known in our own day [5].

A number of peoples knowing nothing of the use of bronze and iron were brought into the history of the Mediterranean by the Phoenicians, whose influence was felt perhaps as early as the end of the second millennium B.C., although they did not greatly increase the number of their trading posts on the African coast until after the founding of Carthage (814 B.C.), and later by the Carthaginians, who occupied the north-eastern third of Tunisia [19, 58]. If they did not actually introduce arboriculture, they at least taught its principles to the Berbers—how to fertilize fig trees, for example. All the crops that are grown in Africa today were already known in Carthaginian times, with the exception of maize and tobacco. Almost the only plants introduced in later centuries were those requiring irrigation. The Carthaginian agronomist Mago, who had a great reputation in ancient times but is known to us only through a few quotations in the works of Latin writers, recommended that olive trees be planted, as a rule, 75 ft. (22.2 m.) apart in all directions, and at least 45 ft. (13.3 m.) apart in poor soil—advice which is entirely in line with the principles of dry farming although the latter had not yet been thought of [58].

He has very little to say about cereals. We know, however, that the types of swing plough still in use today were already employed and were generally drawn by two oxen [58]. Unless we presume that the methods of diverting floodwaters still used in the area were already known and practised, it is impossible to explain the reputation for fertility in grain enjoyed, at the end of the Carthaginian period and the beginning of the Roman era, by Byzacium (the centre of which corresponds to the Sahel in Tunisia and the plains of Kairouan) and the regions around the 'emporia' or trading posts along the Gulf of Qabes and the coast of Tripolitania [34]. Irrigation of crops was practised in the fields around certain villages, and was especially widespread in Megara, on the outskirts of Carthage, and in the Cape Bon peninsula.

All that we know of stockbreeding in this period is through occasional references. The inhabitants were still essentially pastoral peoples. It is said that Massinissa, the ruler of Numidia, made great efforts, in the last century B.C., to develop agriculture in his kingdom [58].

In Spain, the influence of the Phoenicians and later the Carthaginians was restricted to a certain number of trading centres on the southern coast. In Cyrenaica, however, Greek colonization was far more agricultural in character. Wheat, fruit and vegetables were grown on a large scale, and as the practice of agriculture spread towards the interior it produced reactions on the part of the Libyan herdsmen and was to continue to do so in the Roman period [24, 28, 84].

It was in the Roman period (from the second century B.C. to the fifth century A.D.), that agriculture developed most widely in North Africa, within the shelter of the *limes*—fortifications erected as a defence against the chief nomadic tribes, mountain dwellers and herdsmen, who were only partly subdued and Romanized [6]. How profound was the influence of Rome can be seen not only from the many archaeological remains, which are of great value to our argument, but also from the fact that the Latin names of the months in the Julian calendar have survived and were not ousted by the Moslem calendar with its lunar cycle. This influence can also be seen in the retention of an agricultural vocabulary of Latin origin in the Berber and Arab dialects.

The most surprising archaeological remains are the traces of the Roman land divisions, said to date from between the end of the second century B.C. and the first century A.D., which are laid out in a perfectly regular chequer-board pattern. Stretching over vast tracts of land, which are not always cultivable, there can still be seen traces of these divisions, which form squares measuring 710 m. along each side and divided into sections of from 2 to 20 ha.; they are wery clearly discernible in aerial photographs. Within these sections the crops were grown, at least in Tunisia—the only country in North Africa to provide evidence so far of definitely Roman agricultural organization on such a scale [17, 18, 41, 76, 85, 86].

The two-course rotation of crops, well known to Latin agronomists, seems to have been followed fairly regularly. Preparatory ploughing was not unknown; various graphic representations, such as the famous mosaic at Cherchel, show that the wooden swing plough drawn by two oxen was still used [8].

From the second century A.D., the cultivation of bushes and trees, especially olives, was extended to dry regions where they had to adapt themselves. In eastern Tunisia, especially in the regions which were on the Roman land registers, the position of the stumps shows that the distance between the trees might be 15 × 15 m., 12 × 15 m., 18 × 15 m., 18 × 18 m., 18 × 20 m. or 18 × 24 m. Similar facts have been established in the north of Tripolitania. These distances vary with soil conditions and show that attempts were being made to adapt arboriculture by dry-farming methods to regions which were already definitely arid. Between the second and the fourth centuries, the greater part of the light soil areas between the Tunisian Dorsale and the Gafsa chains and some of the coastal regions on the Gulf of Qabes and in Tripolitania were covered with olive trees, as evidenced by the many remains of oil presses. Olive groves were also planted in some regions of eastern Numidia and northern Morocco, which are less dry [20, 36, 55].

Archaeological studies reveal that the expansion of agriculture and the adoption of a more stettled existence were accompanied by a number of hydraulic engineering works [51, 59, 71, 76, 95]. For our purposes, however, no account can be taken of those which were intended only to provide water for the many cities or agricultural settlements scattered over the countryside. Most are of this type—harnessing of springs, piping of water, reservoirs, public and private cisterns, and wells.

There is, however, much evidence of the existence of an agricultural water system designed for irrigation proper or for diverting floodwater or run-off. There is no way of knowing whether the various types of lifting apparatus for raising the water from wells or rivers, which Vitruvius describes, were used in Roman Africa [62]. But in some parts of the Maghrib, remains of Roman wells are to be found here and there over the countryside, some of which still function. The main springs were tapped, in part, for the irrigation of fields used for cultivation. From the division into plots, which can be seen on the ground and from aerial photographs, it is evident that the land was mainly used for orchard gardens, just as it is today. Irrigation regulations dating from the time of Elagabal (218-222) have been preserved; they lay down the days, times and duration of each grower's turn to use the water for his orchard [63]. Some wadis, such as the Wadi Mina and the Wadi Rouina in Oran [97] or the Wadi Barika in the Hodna [35], had full-scale irrigation systems or systems for spreading floodwaters by the use of a number of dams. In some regions, almost every wadi of any importance has had some such system. The fine aerial photographs taken by Colonel Baradèz show that in the south-east of the Hodna, in the region of the southern *limes* of Numidia, the diversion dams and the network of channels are constructed in accordance with ideas which are still those of the inhabitants today [6]. They are always diversion dams which can stand submersion and made of fine masonry or pebbles set in solid concrete. They are at least 3-5 m. wide at the base; one of them, on the Mina, was about 20 m. wide. The downstream side was sometimes stepped so as to break the fall of the water and prevent undermining. The remains of stone-faced channels show the outline of old irrigation networks.

In Tripolitania, according to C. Vita-Finzi, fragments of masonry were found from dams which diverted the floodwater of the pre-desert wadis. In the Jebel, dams were built across deeply embanked wadis and, where the wadis widened, the floodwaters were sometimes held by long earth dikes protected by concrete spillways.

There are many remains of simpler and cruder systems, but earth-built dams, etc., which must have existed in great numbers, have disappeared without trace. In the sixth century, the poet Corippus speaks of African farmers who, seeing that a storm is coming up, make earthen embankments around their fields to keep the water in [27].

It is of interest that the system of tapping underground water by means of foggaras (tunnels with wells at intervals), which is thought to be of Iranian origin [30], was in use in the Roman period in the immediate neighbourhood of Carthage. Water from the dunes to the south of the Sebkha-er-Riana, in the plain of the Soukra, was conveyed by two foggaras, 2 km. and 2.5 km. long respectively, which tapped the water in the mountains, to another foggara which brought it to the aqueduct built by Hadrian to supply Carthage with water [87]. Simple supply foggaras were also to be found at Dougga (Thugga) and El Djem (Thysdrus), also in Tunisia.

Little is known about stockbreeding in Roman Africa, apart from the fact that the spread of agriculture drove back pastoral and nomadic life beyond the southern *limes*. From the remains of many watering places it is clear, however, that stockbreeding was carried out, on a sedentary or seasonal movement basis, in addition to the raising of animals for work. Horses had been bred from the second century A.D. onwards; 'Barbary' horses were highly esteemed in Italy for their staying power and were exported to Rome, as also were mules. There has been much discussion among historians about the importance of the camel, or, more accurately, the dromedary. It has long been acknowledged, since the work done by St. Gsell and E. F. Gautier [53] that the camel, which was little used in the Sahara when the Roman Empire was at its height, later became much more widespread, especially from the third century onwards. A recent, careful examination of historical sources gives reason to believe that there have probably always been camels in the Sahara and on its North African fringes, at least in historical times. The use of the camel in the Sahara, however, seems to have spread from the third century onwards, which would explain the marked increase in the importance of the Tripolitanian ports, especially Leptis Magna, under the Serveris [29, 31].

It may also be noted that the pig was not introduced into North Africa until Roman times. It was unknown to the ancient Berbers except in the form of the wild boar, and could not have been imported by the Phoenicians, who, being Semites, regarded the animal as unclean.

The expansion of agriculture also led to widespread clearing of the land, although this must also have been largely due to the fact that the population, which was probably growing in numbers, needed fuel. Wood and charcoal were at that time the only fuels known, and large amounts must have been required for the many, and very large, public baths in the towns. It is also known that Africa exported timber to Italy, and wood for heating to the baths in Rome; but most of this must have been drawn from the coastal forests in the humid zone [63].

The growing of cereals and hardy trees like the olive by dry-farming methods, and the cultivation of crops under irrigation and by flooding over smaller areas, were carried on as the herdsmen were driven back and the forests receded. In the Roman period, because farmers adapted their methods to suit the dry conditions and because extra water was available, farming was being carried on as far as the edge of the High Steppes in Algeria, and the fringe of the desert in Tripolitania, the south of Tunisia and the south of Constantine. Just as in our day, however, once the Sahara was reached there was no possibility of farming without extensive irrigation, and agriculture was doomed to take on the 'insular' character that we find in the oases of the present day. Unfortunately, we know almost nothing about the cultivation of date palms, except that in Rome African dates were considered to be inferior to dates from the East, at least in the first century of our era.

The question of terracing has still to be considered. Many archaeologists give credit to the Romans for all the remains of terraced fields to be seen on the ground or shown by aerial photographs. Let us consider the distribution of terraces at present [40]. There are none in the Algero-Tunisian Tell or in northern Morocco, except in irrigated gardens and where dry farming is practised around the villages in north-east Tunisia, where they are of quite recent construction. It is surprising that in these Mediterranean countries, including the Kabyle regions where the growing of trees is a characteristic feature, terracing is unknown. It is common only in the pre-Saharan mountains, nearly every part of which has an arid climate—the Tunisia-Tripolitania semi-circle, the Gafsa chains, the Aurès, the Atlas and the Anti-Atlas mountains in Morocco. It should be noticed that there was little or no Roman influence in these regions. It is in the south-west of Morocco, indeed, the area farthest from the Mediterranean, and especially in some valleys in the western High Atlas mountains, that the most remarkable examples of climbing terraced fields are to be found.

I mentioned earlier the possibility of a connexion between the absence of terracing and the use of a plough drawn by two oxen. But there is a still more interesting coincidence—terraced fields are found in the pre-Saharan mountains with a dense population of mountaineers living in villages, a non-Arabized population whose speech and customs are Berber, in regions with a mixed economy, where cereals and trees are grown and flocks are raised, where the people keep, or used to keep, their provisions in fortified storehouses [38], and where society is more or less cohesive and equalitarian. In short, the terracing of fields is closely associated with regions which would produce practically nothing if men had not contrived to keep the earth in place and make it productive by irrigation, and also with a type of rural Berber civilization which is found only on the borders of the Sahara, precisely where there was little or no Roman influence. This does not mean that the Pax Romana was not favourable to the extension of terracing, for instance in the vicinity of the *limes* in Numidia. Except locally, however, terracing was probably never practised in the Tell regions, which were the most subject to Roman influence. Certainly, the Berbers did not wait till the arrival of the Romans to make their arid mountainous land productive by terracing the fields. It is, moreover, of interest to note that there is no Latin of Greek word for this method of laying out land on a hillside; classical agronomists make no mention of it, whereas it has been pointed out by J. Berque that in the Moroccan Great Atlas there is a very rich Berber vocabulary of words dealing with terracing and irrigation [10, 11]. The North African irrigators appear to have had quite a reputation, to judge by an early sixth century text which shows how warmly Theodoric welcomed an *aquilex* from Africa [29].

## MIDDLE AGES

The Arab conquests of the seventh and eighth centuries annexed to the Oriental and Moslem world, a largely Latinized and Christianized North Africa, which had nevertheless remained fundamentally Berber, and, for a period of only a few centuries, part of Iberia.

The Arabs, who came originally from arid regions in the Middle East, converted the Maghrib fairly quickly to Islam and introduced Arab culture, the latter not so rapidly and with only partial success. At the same time they brought about substantial changes in the economy of the conquered countries, and had a marked influence on methods of using the land, especially irrigated land.

In the first place, they brought with them hard-grain semolina wheat, which was so successful that it gradually ousted the soft-grain flour wheat, which was the only type grown in ancient Africa [13]. Above all, they introduced a number of new irrigated crops of Eastern or tropical origin, which profoundly changed the nature of agriculture, adding variety and broadening its scope—crops such as rice and sugarcane, apricot trees and citrus fruits, cotton, indigo, henna and saffron. We are aware of the economic importance that was to be assumed, sooner or later, by rice, citrus fruits and apricots in the western Mediterranean countries. It may be that the palm-groves of the Sahara, which are hardly mentioned in ancient writings, were developed to some extent under the Arabs.

It is a curious fact that the influence exercised on irrigation by the Arabs, and the Orientals who came with them (Syrians, Egyptians, etc.), has left more signs and is more marked in the Iberian peninsula than in North Africa. The explanation may be that irrigation was more important in North Africa, and that the Berbers, together with their conquerors from the East, helped to introduce it into Spain. It is also noteworthy that the spread of Islam and its prohibition of fermented drinks had no serious effect on vine growing [60]. The inevitable set-back was very much mitigated by the fact that wine has always been drunk, even by Moslems, that there was a good home and export market for raisins, and that grapes were made into syrup, jam and 'honey'. The vines were first distributed over the gardens in many villages, which remained in being until the Bedouin invasions in the eleventh and twelfth centuries. Vines and other shrubs were then grown only in some of the mountain massifs such as Kabylia in the west and the Rif, where the vine was treated as a creeper growing on trees, and also in the oases and around the towns, especially in Tunisia, in the west of Algeria and in Morocco; they were grown to form arbours and planted together in small vineyards in the vicinity of Mostaganem and Mascara.

It is hard to say whether the superstructure of the wells used for irrigation was brought from the East by the Arabs; this is probably true, however, of the water-wheels which are said to have been used in the thirteenth century at Fez.

Stone-built diversion dams—the only ones which leave any trace of their existence—can still be seen here and there, on the Mina, for example, where the old diversion system has been brought back into use, a new dike constructed, an old dam restored, and an aqueduct built, with three arches spanning the river [97]. Other dams of which remains can be seen are of doubtful origin, or are mentioned by authors as being found in various regions, for example the Hodna, the borders of Tunisia and Tripolitania, or the Ziban, where not all the dams, etc., shown on aerial photographs are Roman [6, 16, 35]. Kairouan owes its place as a great capital city to the wadis which have always been diverted so as to flow over their alluvial fans, and to the numerous hydraulic engineering works to be found here and there near it and in the plain [36]. Mr. Solignac has surveyed and carefully studied the remains of pools and pipes which used to be thought Roman in origin, but which are in fact constructed by Oriental methods and may be assigned to a period between the eighth and eleventh centuries. Most, it is true, were used for supplying Kairouan and its stately residences, and to maintaining the pleasure gardens. But some were set aside for agriculture, for example : a dam fed by the waters of the Wadi Krioua near Bir Chaouch Ali ben Khalifa, north of Kairouan; a large reservoir at Tobna (Eastern Hodna), where the floodwaters of the Wadi Bitha were collected to provide water for the gardens and fields on the outskirts of the town; and a collecting basin built later, in the fourteenth century, near Tlemcen, to provide water for its gardens [68]. These ponds filled with water—*aguedal*, as they are still called in Morocco—have been, and still are, the charm of the great gardens of Islam [69]; they were also adopted in Spain. Many poets writing in Arabic, both in the West and in the East, have found inspiration in their mirror-like surface, their coolness, the green plants, flowers and fruit for which they provide water, and the birds which chirp in the trees.

Many pools, however, at least in the steppe-lands of Tunisia, seem to have been constructed to provide water for cattle. This is one of the conclusions reached by Mr. Solignac, who writes, 'Palaces and cities, which were built of sun-dried bricks and clay, have vanished; stone and mortar ponds still defy the ravages of time' [88].

However, not all the innovations of the Middle Ages relating to irrigation are to be attributed to the Arabs and Orientals. Berbers from the Sahara were responsible for the *rhettara* (underground galleries for tapping water which are elsewhere called foggara) that were introduced in the eleventh and twelfth centuries, after the foundation of Marrakesh by the Almoravides, and for the establishment of the strange palm grove around it [80, 91]. Today there are more than 600 of them in the Haouz, and the workmen who know how to build and maintain them are always from the desert, especially from the Drâa and the Todrha. At the other end of the Maghrib, in the fifteenth century, foggaras were built to the north of Tunis to reach the underground alluvial water surrounding the Jebel Ahmar, probably in order to provide water for the gardens of the palace at Le Bardo. There are few foggaras in the south of Tunisia (they are found only in the region of Kébili and at El Guettar), but there were some near Carthage in Roman times [87].

The most important change in the use of land in North Africa during the first part of the Middle Ages is perhaps therefore the introduction of many shrubs or annuals which require watering, rather than the extension of agricultural irrigation. Dry-farming processes seem to have remained unchanged, except that soft grain was replaced by hard, and new Eastern or Spanish varieties of vines and olive trees were introduced.

Very little is known of the way in which the inhabitants of the Maghrib in the Middle Ages treated the natural vegetation and the soil. Owing to the partial retreat of city life towards the interior and the foundation of new towns in arid regions, the major markets for wood—timber and especially fire-wood—shifted, in particular to Kairouan and its stately residences, Fez, to which Fez Djedid was to be added in the thirteenth century, and to the towns built in succession on the sites of Tlemcen and Marrakesh. Wood for use in Kairouan, Marrakesh and even Tlemcen was brought from forests which were dry in any case, far from the humid zone of the northern slopes of the eastern Tell Atlas and Northern Morocco [66].

Because both Islam and the Semites forbade the consumption of pork, the inhabitants of the Maghrib were unable, except in the Roman period, to engage in a lucrative form of stockfarming which could be carried on in the oak forests without any outlay. Moreover, this prohibition helped to encourage the people to keep goats, which, in all Mediterranean countries are most destructive of forests [77], instead of pigs, which, in other countries—Yugoslavia, for example—provide an incentive for preserving them.

The Arab conquest made practically no headway in the humid zone of the Iberian peninsula—which has so many African features, e.g., even productive date palms can be grown. It is thought, however, to have done much towards the development of irrigation in the relatively arid zones. In Roman and Visigoth times, Iberia had been a country mainly engaged in extensive stockbreeding, with some seasonal moving of herds, and in growing cereals. Trees, however, appear to have been fairly widely cultivated in olive and vine-growing districts and in the more humid apple-growing areas. Irrigation was by no means unknown in many regions, including lower Andalusia and the Mediterranean shores, where the Arab and Berber conquerors found beautiful *vegas*. The conquerors however introduced the Spaniards and Portuguese to the same crops as they had brought the Africans, and probably to new methods as well. 'Everything leads to the belief', writes E. Levi-Provençal, 'that the agricultural technique inherited from Roman and Visigoth Spain improved rapidly and then won general acceptance' [65]. It attained 'undeniable mastery', particularly with regard to irrigated agriculture; furthermore, the present-day technical vocabulary relating to irrigation engineering and methods preserves many words of Arabic origin, both in the *vegas* of Andalusia and in the *huertas* of Murcia and Valencia. It is difficult, however, to say definitely how far the Arabs were responsible for water regulations, the various types of water-raising machinery and the methods of diverting or damming rivers [15]. With regard to dry farming, the period of Moslem domination corresponds to a fresh expansion of olive growing and especially fig growing; for the same reasons as in North Africa, vine growing does not appear to have declined to any great extent.

The Arab conquests in the seventh and eighth centuries may have had the effect of encouraging a return to pastoral life and the expansion of stockbreeding for a certain time and in certain regions. Fairly soon, however, in Ifrikya (Tunisia, Constantine and Tripolitania), in Morocco and in Spain, there was a revival of agricultural and village life which lasted for some three centuries.

On the other hand, the invasions from the middle of the eleventh century onwards, followed by more or less violent incursions by groups of eastern nomads into North Africa, had consequences which were as disastrous for land under cultivation as they were favourable to the extension of a pastoral life and nomadism; this was one of the most decisive events in the history of the Maghrib, the effects of which have been felt for centuries.

The consequences, however, were most serious of all in Cyrenaica. The agricultural potentialities of this country, at least in the extreme north, had been shown by the Greek settlers, but for various historical reasons it had had great difficulty in maintaining its prosperity in Roman times. It was now threatened by the nomads from the steppes and the deserts, who isolated it immediately after the seventh century conquest. Sedentary life became less and less common there throughout the early Middle Ages—at the very time when it was gaining ground in the Maghrib—and gradually, as a result of the eleventh century invasions, practically died out, so that Cyrenaica became an almost entirely Bedouin region with no villages. It has remained so to this day; cereals are grown in only a few places, the people camping in tents beside their crops for part of the year, both in the forest clearings in the Green Mountain (Jebel Akhdar), where the Italian colonists had scarcely time to appraise the agricultural potential of the land, and in the vast dry areas in the south [3].

To the west of the Gulf of Sidra, in Tripolitania—which had the same fate as Ifrikya—village life and farming flourished and continued to exist along the Jebel and the coast till the eleventh century. The growing ascendancy of the herdsmen was resisted more successfully than in Cyrenaica. The herdsmen gained ground in several parts of the Jebel, establishing themselves, in particular, in the Jebel Tarhouna, where not one village remained; small dams which had been neglected were carried away and the silt terraces which had formed behind the barrages were gullied, erosion going so far that sometimes even the calcareous crust supporting the dams was breached [96]; they reduced the strip of palm groves and gardens on the coast to a few isolated patches [3, 32, 33].

In the Maghrib, historical studies and certain detailed surveys of the geography of the region [35, 36, 97] have shown how the increase in pastoral and nomadic life resulting from the eleventh and twelfth century immigrations brought about an expansion of stockbreeding and a decline in agriculture. As a result of this, villages sometimes completely disappeared and the cultivation of tree crops was gradually restricted to certain mountains, the Sahel in Tunisia and the outskirts of towns. Gradually an extensive economy, based on stockbreeding and cereal growing, took the place of a more varied and productive use of the soil, whilst in many cases encampments or villages of huts took the place of the centres of population of the early Middle Ages. In certain places villages survived because they had an elevated position or because there was a spring of some size nearby. Terracing, however, was practised less, especially on either side of the Dorsale in Tunisia [40].

The events which brought about these gradual changes seem to have led to a rather serious decline in the population. It is therefore likely, at least as regards the regions which we have called semi-arid, that many tracts of ground which had previously been under cultivation regained their fertility as a result of the revival of the natural vegetation and the droppings of the flocks. The forests no doubt suffered less from the depredations of the herdsmen and from the goats and even camels that grazed among them than from the clearing of land during the preceding centuries. Neither flocks nor men are really harmful to vegetation or to the soil unless there are too many of them, and this, because of the frequency of wars and epidemics and the latent insecurity of life, does not appear to have been the case.

To the north of the Straits of Gibraltar also, agriculture gave way before the advance of stockbreeding, but for rather different reasons. The wars of 'reconquest' gradually drove the Moslems back towards the south, whereafter the cattle-farmers, from the fourteenth century onwards, were granted privileges by the Christian kings for their flocks and for moving them at different seasons to other pastures; the last of such privileges were not abolished until as late as 1837 [50].

## MODERN TIMES

In the centuries between the Middle Ages and the nineteenth century there were scarcely any innovations in the techniques or processes adopted in the use of the more or less arid regions of North Africa. Moreover, techniques and processes were so long-lasting that it is difficult to decide whether they were of Berber, Carthaginian, Roman, Arabic or Oriental origin. Whatever changes occurred were changes in historical circumstances, such as the Bedouin invasions, the consequences of which have just been described. The chief object of the kingdoms into which the Maghrib was divided from the thirteenth century onwards, and of the Turks, who governed Algeria and Tunisia from the sixteenth century onwards, was to restore a seriously compromised political authority and to hold the nomads in check. From the sixteenth century onwards, they preserved a state of comparative peace, which made it possible for the nomads and the settled farmers to come to terms and enabled a certain balance to be established between the mediocre economy and nature, which was also mediocre.

A number of new crops, mostly of American origin, were introduced into North Africa, as well as into Europe. First a cereal was introduced—maize, which, like tobacco, needs no irrigation either in the humid zone or on the Atlantic coast—and then vegetables such as the different varieties of beans, and summer crops like tomatoes, peppers, pimento and pumpkins. Other plants have become acclimatized to such an extent that they are now an integral part of the Maghrib landscape—agaves, aloes and prickly pears *(Opuntia ficus indica)*. When planted in thickets or hedges, the last-named, with their joints full of water and their fruit, provide valuable summer food supplies for cattle and for men.

In the Maghrib, however, there was not, as in modern Spain [15], a revival of irrigation or any considerable extension of the irrigated zones except in very small areas adjacent to or near the towns, and in some country districts, often, though not always, under the influence of immigrants, such as the Moslems from Andalusia who were driven out of Spain by the 'reconquest' and the Catholic rulers from the fourteenth to the beginning of the seventeenth century.

## RECENT CHANGES

The capture of Algiers in 1830, the conquest of Algeria by the French and the establishment of the protectorates in Tunisia in 1881 and in Morocco in 1912 brought the whole of the Maghrib under French influence, notwithstanding the differences in political status. The result was that after some years of war or pacification a fairly long period of peace and orderly government ensued. Brought under the dominion of a nation whose material civilization was superior to their own, and provided with increasing financial and technical resources, the various countries of the Maghrib started to develop quickly—the more recent France's influence was, the more rapid was their development. While most of the European colonists came from non-arid regions and were inexperienced, there were a few capable, enterprising people who were able to follow the public authorities in their agricultural experiments. The result has been an improvement in the economy that has at times been spectacular. The native population however has increased to such an extent that demographic problems are now extremely grave.

What changes did the colonists make in the use of land in non-humid regions, and how far have they been followed by the indigenous population?

### DRY FARMING

With regard to dry farming and the cultivation of cereals, the colonists, who introduced—or rather re-introduced—soft grain, gradually abandoned the Mediterranean system of two-course rotation in favour of the most up-to-date dry-farming methods. In Algeria, in the last quarter of the nineteenth century, preparatory spring ploughing was started by some of the colonists, e.g., the Spaniards at Sidi bel Abbès, the Genevoise Company in the Sétif area, and already in 1876, two French colonists at Wadi Fodda in the Chélif valley tried out and adopted the method of preparatory spring ploughing [97]. However, this method was not altogether unknown to the indigenes. The ploughing was at first very shallow; later it was taken to a greater depth, but it was only after a considerable time that the system of leaving fields fallow after autumn ploughing was adopted. As long as animals were used for the work in the fields, farmers were reluctant to give up entirely the practice of using fallow land as pasture. Then again, ploughing was a slow affair and there would not have been enough time for it. Mechanization did not really develop till motor traction was introduced, between 1920 and 1930. Only then, since cattle were no longer used and the work could be done more quickly, was it possible to develop the system fully—that is, to work the fallow land for at least a year before sowing. Remarkable results have often been obtained and it is possible to grow wheat, which is preferred to barley, right to the edge of the steppes. In the plains country—Tunisia, Western Algeria and the Atlantic coast of Morocco—some varieties of soft grain, obtained by selection and hybridization, have been found to ripen very nearly as early as barley [13, 72].

Many Moslems who had sufficient means followed the example of the colonists. The disadvantages of the system gradually became apparent, however, especially in light soils in those areas under cultivation which received the least rain. The lack of farmyard manure and the complete destruction of vegetation deprived the ground of humus. Superphosphates were almost the only fertilizer used for any length of time, and they proved inadequate. It was found that the use of nitrates was very difficult in dry conditions and leguminous plants grown as a snatch crop—for artificial fodder and dried vegetables—need a rainfall found only in humid zones and regions very close to them. Wind and run-off over the sloping ground, which for months had no protection, combined to exhaust the soil and indeed often resulted in actual erosion. The number of Moslem farmers with small holdings grew steadily, while every day the amount of land available became less adequate; they were also too inclined to exhaust their fields by sowing annually and only the great droughts could force them to let them lie fallow.

Between the two world wars, some Italian colonists in Tripolitania tried in vain to grow cereals profitably by dry-farming methods. They failed, whereas their fellow-countrymen succeeded on the good ground with adequate rainfall in the Green Mountain region in Cyrenaica [33].

The greatest progress in the growing of trees in dry land has been made in Tunisia, especially in the country behind Sfax. A number of French capitalists entered into *mgharsa* agreements with the people of Sfax and were able to take advantage of the fact that the region is State property and that these people are masters of agricultural technique—in a sandy area that receives very little rain but with a humid atmosphere—to increase the area of the plantations, which, in 1881, contained only 350,000 olive trees [36]. It is due to their initiative and capital, and especially, in an ever-increasing degree, to the work and capital of the people of Sfax and the surrounding districts, that the olive groves, which cover almost all the country to a distance of more than 60 km. from the city, today contain six million trees. The technique and example of the people of Sfax have been followed by some of the colonists, and particularly by a large number of Tunisians in certain very dry regions in the interior as far as the foot of the Dorsale mountains and the southern shores of the Gulf of Qabes (in the Zarzis region). Not only have olives been grown, but also almond trees and some fruit trees—figs, apricots and peaches. The Italian colonists too, by adopting the Tunisian methods, succeeded in increasing the number of olive groves and fruit tree plantations, including vines, along the coast of Tripolitania—another area where the soil is sandy and atmospheric condensation is of value [33].

However, everything has another side to it. The success achieved has often led to only one type of farming being carried on, and this has disadvantages from both the economic and the human standpoints. In addition the trees appear to age rather quickly; the soil, which is very light and must be kept very clean, is apt to be carried away by the winds and begins to show signs of impoverishment in places.

## IRRIGATION

The French first set out to improve the Algerian systems of diverting water from the wadis in the semi-arid region by constructing stone dikes instead of the rough, insecure structures of the Moslem communities. Between 1860 and 1883 they built seven retention dams large enough to hold back the surplus winter rains for use in summer. Three of them, however, were carried away by severe floods and had to be rebuilt. In any case, they were not large enough. It was not till reinforced concrete was introduced and plans were made in 1920, that nine large reservoir dams were built in Algeria, seven of them in comparatively arid zones. They were completed and filled by 1939; two others have been built since then [54]. They have a total capacity of approximately 900 million m.$^3$ and could provide water for irrigating 170,000 ha. Actually, however, only about half of this area is at present supplied with adequate irrigation.

In the arid zone the object has been to improve the systems for diverting floodwaters. The best results have been obtained, especially in the Hodna, when the dams are fitted with sluice gates, and can be submerged [35]. Reservoir dams (of which there are two) are less suitable, owing to the amount of alluvial matter deposited and the low precipitation.

In most areas, improvements have been made in the system of tapping the main springs. It was not practicable to sink artesian wells outside the Sahara, except in some low-lying areas such as the Hodna. On the coast around Oran and especially near Algiers thousand of wells have been sunk because of the market gardening carried on there. These wells were equipped with norias [61]; almost all are now mechanized or have been replaced by pumps.

It is estimated that in Algeria irrigation could be extended to cover 300,000-350,000 ha. In Tunisia the figure would be little more than 100,000 for the only river system suitable for irrigation on any considerable scale is that of the Medjerda, work on which is already in progress [79].

It will be difficult to make use of the wadis from the steppes, especially those which flow towards Kairouan. Morocco, on the other hand, is in a much better position, being surrounded by high mountains which receive both rain and snow. There are five large dams, including one on the Moulouya which is not yet finished, with a combined capacity of 3,000 million m.$^3$—three times as great as that of the Algerian dams. It is expected that it will one day be possible to irrigate a million hectares [47].

Many of these dams silt up quickly, and the expenditure entailed is very heavy; in fact, their use involves costly work on the land to be irrigated, the solution of difficult problems relating to agricultural methods, the ownership of land, and human problems, and sound technical and commercial staff. To take full advantage of these dams is a long and difficult task; although there have been noteworthy achievements and spectacular successes, it cannot be said that the results obtained so far have always been entirely satisfactory from the economic and social points of view.

The fact remains, however, that over large areas water alone makes and can make it possible to increase production and to obtain larger crops, as must be done in areas where population is rising so rapidly. The Italians in Tripolitania were also conscious of this fact. As they could not construct diversion dams, except on a very small scale and sometimes on ancient sites, they concentrated on making regional use of a rising water level fairly close to the surface and, in certain places, of artesian wells proper.

## STOCKBREEDING

The amount of land under cultivation, especially by dry-farming methods but also by irrigation, has greatly increased at the expense of pasture-lands, and therefore at the expense of any extensive system of breeding light beasts, sheep and goats. In the Tell, stockbreeding has been abandoned in all the areas where any specialized crop is grown. The traditional economy was based on growing cereals and raising stock, but the latter has been sacrificed to the former. This has been largely due to lack of space as a result of the growth of colonization, the supervision of forests, the rapid rise in population and the failure of many farmers to let land lie fallow. Herdsmen found the seasonal movement of their cattle to different pastures difficult as larger areas were brought under cultivation, both in the steppes and in the Tell, and as forestry regulations imposed various restrictions. At the same time the herdsmen lost what were often their main sources of income—the monopoly of transport, the profits they made from raids, and the tribute paid by some of the sedentary peoples. Everywhere, mechanized farming and modern means of communication are challenging the use of draught, saddle and pack animals [37].

Generally speaking, the colonists showed little interest in stockbreeding [45, 93], although they gave some attention to heavier cattle, especially draught animals. They tried, by cross-breeding, to increase the size of their horned cattle and horses which, though sturdy animals, were not heavy enough to draw their ploughs and carts as the animals imported direct from France proved too unadaptable and too delicate. Their somewhat desultory efforts were abandoned however as the use of motor traction was developed. On the other hand, the military, who have always valued Barbary horses for use as light cavalry mounts, increased the number of remount depots, and encouraged the breeding and improvement of these horses in various ways. The demand for them has fallen considerably since the motorization of the army.

Except in the humid zone, the problem of fattening beasts, such as those for milk production, could be solved only by irrigation. But the local animals are bad milkers and are often difficult to fatten. Imported animals, on the other hand, are unadaptable and suffer from the summer heat; in addition, irrigated fodder crops are expensive. Moreover, because of the heat, it is difficult to transport milk products, so that condensed milk and farm produce are largely imported.

Sheep farming is the main livestock industry in the country, but the Europeans have taken little interest in it, except in association with the indigenous population, and have made few changes in the traditional methods, except as regards more selective breeding of the animals.

In the steppes, indeed, the decline of stockbreeding has scarcely been offset at all by improvement of the stock. Notwithstanding the studies that have been undertaken, crossing has not produced such good results as selection; the traditional methods of stockbreeding by moving the stock to different pastures at different seasons have been hampered without showing appreciable improvement. However, the provision of better supplies of water and watering places has made it possible to use the pasturelands more evenly, and epizootic diseases are now rare and are soon brought under control. The important problems of shelter, the protection of impoverished pasturelands and the building up of reserve supplies for dry years have for the most part been dealt with by public authorities—though they have been studied rather than actually solved. Similarly, consideration has been given to the possibility of fattening sheep from the steppes in the irrigated regions of the Tell before they are exported to France or sold on the city markets, but the scheme has not been put into practice.

## VEGETATION AND SOILS

It appears to be established that, throughout the history of North Africa, there has never been such an expansion of agriculture or such a rise in population as at the present time, and that the natural vegetation and soil, especially in the non-humid regions, have never before been in such danger.

The proportion of woodland in the three countries of North Africa is 14.8 per cent in Morocco, 12.5-13.6 per cent in Algeria and 9.4 per cent in Tunisia (including the humid regions but not the desert). This is only one-third of the area that the various woodland plant communities could cover without the intervention of man—a very small proportion [14]. And the figures are falling steadily. The State forests have held out fairly well, thanks to the work of the forestry officers, but most privately owned forests and those under group ownership have disappeared or are doing so. The main reasons are: the clearing of the ground by a rapidly growing population; the fuel needs of societies which use no coal and, as yet, very little mineral oil products, even in the towns; frequent fires; and grazing by small livestock, especially goats, of which there are often too many. The deterioration of the vegetation is evident everywhere and in every possible form—from sparse forests to scrub, from poor scrub to moorland, and from barren moorland to bare earth with only a few scattered clumps of plants, such as diss *(Ampelodesmos tenax)*, clinging to the ground until it is completely eroded.

On the steppes, the pastures have been ruined because too many flocks are grazed on them when there is a good year, and there is no system of rotation; the best plants are eaten first, so that they hardly reproduce at all, whilst thorny, poisonous or useless plants multiply. The esparto-grass steppe is also impoverished, especially in Tunisia and in Tripolitania, by over-gathering for export to foreign paper mills.

Sometimes the quality of the soil deteriorates as the vegetation declines [7, 78]. As we have seen, the soil tends to become exhausted by agriculture if nourishment is not put back into it, and the problem of fertilizers in dry regions has not been solved. Erosion and utter impoverishment are still more disastrous when very poor land, suitable for use as pasture, is cleared and brought under cultivation, when hillsides are ploughed across the contours, or when slopes that are too steep are ploughed deeply, even if they are planted with trees or vines. Every form of erosion described by the Americans in the western half of the United States is to be found here [81]. In many regions the consequences of failure to terrace the fields are only too evident. The system of terraces intersected by ditches and embankments parallel to the contour lines, which has been tried out and widely used in the United States of America, gives good results but not good enough : it is used on steep slopes which should be replanted with trees but which are too closely populated to allow of this; some clayey soils are not suitable for it; and lastly the reasons for the system are often not understood by both Europeans and Moslems, and it requires care in maintenance. In some areas, however, noteworthy results have been obtained locally.

To sum up the situation, it would seem that in the countries of North Africa we are witnessing the early stages of the destruction of the balance, so far as land use is concerned, between the needs of the population, which has grown too large, and the resources of nature, which is here arid and inhospitable. A number of remarkable advances in the technique and methods of cultivation have been made, particularly in the last fifty years, but these advances have not always proved to be very suitable for the country. I have stressed their shortcomings and the imbalance which is resulting. There is a saying that the cure must be looked for in the disease and, in fact, solutions are being found for most of the problems, but they are often more theoretical than practical and are always very difficult to apply because of the human factor, i.e., the nature and the number of the population. New methods of stockbreeding, the protection of forests, the conservation and reclamation of soil by the system of embanked terraces, the extension of irrigation, the careful use of dry-farming methods, the provision of assistance and advice for small farmers and for stockbreeders by the public authorities, and the reform of the system of land holding—all these are solutions which must now be applied not only in small districts but over ever wider areas.

Yet, whatever financial, technical and social assistance may be given to North Africa for the use of its land—and such assistance is absolutely essential—it must be remembered that, apart from desert lands, four-fifths of the area of the countries concerned are in the semi-arid or arid zone; that their resources are and always will be limited; and that they cannot support an indefinitely growing population. Other resources must be and are being sought elsewhere, especially in the industrial field. But it seems clear that there will be no satisfactory economic solution until the people themselves help in solving the demographic problem. [1]

1. In addition to the bibliography which follows I have taken into account a short note on land use in Tripolitania by C. Vita-Finzi of the University of Cambridge. Although it was only communicated to me at a late date, I have been able to incorporate in my text several of his relevant remarks.

# BIBLIOGRAPHY

1. ABDUL WAHAB, H. H. Coup d'œil général sur les apports ethniques en Tunisie. *Revue tunisienne*, 1917. p. 305-316 and p. 371-379.
2. AGAFONOFF, V. Sols, types de Tunise. *Annales du Service botanique*, Tunis, 1935-1936, p. 43-413.
3. AHLMANN, H. W. La Libye septentrionale. *Geografiska Annaler*, Stockholm, 1928, p. 1-118.
4. *Atlas des centuriations romaines de Tunisie.* Paris, Institut géographique national, 1954. 44 sheets. (Introduction by A. Piganiol.)
5. BALOUT, L. *Préhistoire de l'Afrique du Nord.* Paris, Arts et métiers graphiques, 1955.
6. BARADEZ, J. *Fossatum Africae.* Paris, Arts et métiers graphiques, 1949.
7. BENCHETRITT, M. Le problème de l'érosion des sols de montagne et le cas du Tell algérien. *Revue de géographie alpine*, Grenoble, 1955. p. 605-640.
8. BERARD, J. Mosaïques inédites de Cherchel. *Mélanges d'archéologie et d'histoire*, Rome, 1935. p. 113-142.
9. BERQUE, J. *Études d'histoire maghrébine.* Tanger, Fès, 1938.
10. ——. Un glossaire notarial arabo-chleuh du Deren. *Revue africaine*, Alger, 1950. p. 357-398.
11. ——. *Structures sociales du Haut Atlas.* Paris, Presses universitaires, 1955.
12. BIROT, P.; DRESCH, J. *La Méditerranée et le Moyen-Orient.* Paris, Presses universitaires, 1953, 1956. 2 vols.
13. BOEUF, F. *Le blé de Tunisie.* Tunis, Annales du Service botanique, 1931.

14. BOUDY, P. *Économie forestière nord-africaine.* Paris, Larose, 1948-1958. 4 vols.
15. BRUNHES, J. *L'irrigation dans la péninsule ibérique et dans l'Afrique du Nord.* Paris, Naud, 1902.
16. BRUNSCHVIG, R. *La Berbérie orientale sous les Hafsides.* Paris, Maisonneuve, 1940, 1947. 2 vols.
17. CAILLEMER, A.; CHEVALIER, R. Les centuriations romaines de *l'Africa vetus, Annales, E.S.C.*, Paris, 1954. p. 433-460.
18. ——; ——. Les centuriations romaines de Tunisie. *Annales, E.S.C.*, Paris, 1957. p. 275-286.
19. CAMPS, G. Les traces d'un âge du bronze en Afrique du Nord. *Revue africaine*, Alger, 1960. p. 31-56.
20. CAMPS-FABRER, H. *L'olivier et l'huile dans l'Afrique romaine.* Alger, Service des antiquités, 1953.
21. CAPOT-REY, R. *L'Afrique blanche française, II. Le Sahara.* Paris, Presses universitaires, 1953.
22. CELERIER, J. La transhumance dans le Moyen Atlas. *Hesperis*, Rabat, 1927. p. 53-68.
23. ——. L'économie montagnarde dans le Moyen Atlas. *Revue de géographie marocaine*, Rabat, 1939. p. 57-67.
24. CHAMOUX. *Cyrène sous la monarchie des Battiades.* Paris, de Boccard, 1953.
25. CHEVALIER, A. *Ressources végétales du Sahara.* Paris, Museum, 1932.
26. COLIN, G. S. La noria marocaine et les machines hydrauliques dans le monde arabe. *Hesperis*, Rabat, 1932. p. 22-60.
27. CORIPPUS. *La Johannide.* Tunis, Revue tunisienne, 1902. (Translation by J. Alix.)
28. COSTER, Ch. H. The economic position of Cyrenaica in classical times. In: *Studies economic and social history in honor of A. C. Johnson.* Princeton, 1951. p. 3-26.
29. COURTOIS, C. *Les Vandales et l'Afrique.* Paris, Arts et métiers graphiques, 1955.
30. CRESSEY, G. B. Qanats, karez and foggaras. *Geogr. Rev.*, New York, 1958.
31. DEMOUGEOT, E. Le chameau et l'Afrique du Nord romaine. *Annales E.S.C.*, Paris, 1960. p. 210-247.
32. DESPOIS, J. *Le Djebel Nefousa.* Paris, Larose, 1935.
33. ——. *La colonisation italienne en Libye.* Paris, Larose, 1935.
34. ——. Rendements en grains du Byzacium il y a 2 000 ans et aujourd'hui. In: *Mélanges de géographie et d'orientalisme offerts à E. F. Gautier.* Tours, Arrault, 1937. p. 186-193.
35. ——. *Le Hodna.* Paris, Presses universitaires, 1953.
36. ——. *La Tunisie orientale. Sahel et Basse Steppe* (2nd ed.). Paris, Presses universitaires, 1955.
37. ——. *L'Afrique blanche française. I: L'Afrique du Nord.* Paris, Presses universitaires, 1958.
38. ——. Les greniers fortifiés de l'Afrique du Nord. *Les Cahiers de Tunisie*, Tunis, 1953. p. 36-60.
39. ——. *Le Djebel Amour.* Paris, Presses universitaires, 1957.
40. ——. La culture en terrasses en Afrique du Nord. *Annales E.S.C.*, Paris, 1956. p. 42-50.
41. ——. L'Atlas des centuriations romaines en Tunisie. *Annales E.S.C.*, Paris, 1957. p. 460-466.
42. ——. B'ir. *Encyclopédie de l'Islam* (2nd ed.). 1954.
43. DRESCH, J. *Commentaires des cartes sur les genres de vie de montagne dans le Massif central du Grand Atlas.* Tours, Arrault, 1941.
44. DURAND, J. H. *Les sols d'Algérie*, Alger, 1954.
45. Élevage (L') en Tunisie. *Terre de Tunisie*, 1957, 1959. Nos. 4, 5.
46. EMBERGER, L.; MAIRE, R. *Tableau phytogéographique du Maroc.* Rabat, Société des sciences naturelles du Maroc, 1934.
47. *Équipement (L') hydraulique du Maroc.* Rabat, Société d'études économiques, 1954.
48. FISHER, W. B. Problems of modern Libya. *Geogr. J.*, London, vol. 49, 1953. p. 183-199.
49. (FRANCHETTI). *La missione Franchetti in Tripolitania. Il Gebel.* Firenze, Milano, 1914.
50. FRIBOURG, A. La transhumance en Espagne. *Annales de géographie*, Paris, 1910. p. 231-244.
51. GAUCKLER, P. *Enquête sur les installations hydrauliques romaines en Tunisie.* Tunis, Direction des antiquités, 1901, 1902. 2 vols.
52. GAUSSEN, H. *Carte des précipitations à 1:500 000. Tunisie, Algérie, Maroc.*
53. GAUTIER, E. F. *Le passé de l'Afrique du Nord.* Paris, Payot, 1937.
54. *Géologie (La) et les problèmes de l'eau en Algérie.* Alger, 1952. (Brochures of the nineteenth International Geological Congress.)
55. GOODCHILD, R. G. Farming in Roman Libya. *Geogr. Mag.*, vol. 25, 1952. p. 70-80.
56. ——. The decline of Libyan agriculture. *Geogr. Mag.*, vol. 25, 1952. p. 147-156.
57. GORNOUNG, M. B. A propos de ce qu'il est convenu d'appeler steppes nord-africaines. *Questions de géographie, Recueil 40 : Géographie physique de l'Afrique et de l'Asie.* p. 103-118. (Translated from Russian.)
58. GSELL, St. *Histoire ancienne de l'Afrique du Nord.* Paris, Hachette, 1913-1928. 8 vols.
59. ——. *Enquête administrative sur les installations hydrauliques des Anciens en Algérie.* Paris, 1902.
60. ISNARD, H. *La vigne en Algérie.* Gap, Ophrys, 1951, 1954. 2 vols.
61. ——. *La culture des primeurs sur le littoral algérois.* Alger, Faculté des lettres, 1935.
62. JARDE, A. Puteus. In: Daremberg and Salio, *Dictionnaire des antiquités.* Vol. IV, 1. p. 779-781.
63. JULIEN, Ch. A. *Histoire de l'Afrique du Nord* (2nd ed.). Paris, Payot, 1951, 1952. 2 vols.
64. LARTIGUE DE. *Monographie de l'Aurès.* Constantine, 1904.
65. LEVI-PROVENCAL, E. *Histoire de l'Espagne musulmane. III: Le siècle du califat de Cordoue.* Paris, Maisonneuve, 1953.
66. LOMBARD, M. Le bois dans la Méditerranée musulmane. *Annales E.S.C.*, Paris, 1959. p. 234-254.
67. MAIRE, R. *Carte phytogéographique de l'Algérie et de la Tunisie, Notice.* Alger, Baconnier.
68. MARCAIS, G. *L'architecture musulmane d'Occident.* Paris, Arts et métiers graphiques, 1954.
69. ——. Les jardins de l'Islam. *Mélanges d'histoire et d'archéologie de l'Occident musulman, I. Alger.* p. 238-244.
70. MARCAIS, W.; GUIGA, A. *Textes arabes de Takrouna.* Vol. I. Paris, Imprimerie nationale, 1925.
71. MERIGHI, A. *La Tripolitania antica.* Verbiana, 1940. 2 vols.
72. MIEGE, E. Les principales espèces et variétés de blé cultivées en Afrique du Nord. *Revue de botanique appliquée*, Paris, 1950. p. 16-38 and p. 203-215.
73. ——. Les céréales secondaires en Afrique du Nord. *Revue de botanique appliquée*, Paris, 1950. p. 555-578.
74. MONCHICOURT, Ch. *La région du Haut Tell en Tunisie.* Paris, Colin, 1913.

75. *Olivier (L') au Maroc.* Rabat, Mission horticole, 1949.
76. Picard, G. C. *La civilisation de l'Afrique romaine.* Paris, Plon, 1959.
77. Planhol, X. de. *Le monde islamique. Essai de géographie religieuse.* Paris, Presses universitaires, 1957.
78. Poncet, J. Problèmes actuels des campagnes tunisiennes. *Annales de géographie,* Paris, 1951. p. 255-269.
79. ——. La mise en valeur de la basse vallée de la Medjerda. *Annales de géographie,* Paris, 1956. p. 199-222.
80. Poupart, J. M. Les problèmes de l'eau à Marrakech. *Les Cahiers d'Outremer,* Bordeaux, 1949. p. 38-53.
81. Pouquet, J. *Les Monts du Tessala.* Paris, S.E.D.E.S., 1952.
82. Prost, G. Utilisation de la terre et production dans le Sud tunisien. *Les Cahiers de Tunisie,* Tunis, 1954. p. 28-66.
83. Rectenwald, J. *Le contrat de khammessat dans l'Afrique du Nord.* Paris, Pedone, 1912.
84. Romanelli. *La Cirenaïca romana.* Rome, 1943.
85. Saumagne, Ch. Les centuriations romaines de l'Africa vetus. *C. R. de l'Académie des inscriptions et belles lettres,* 1929. p. 307-313.
86. ——. La photographie aérienne au service de l'archéologie. *C. R. de l'Académie des inscriptions et belles lettres,* 1952. p. 289-301.
87. Solignac, M. Travaux hydrauliques hafsides de Tunisie. *Revue africaine,* Alger, II, 1936. p. 517-580.
88. ——. *Recherches sur les installations hydrauliques de Kairouan et des steppes tunisiennes.* Alger, Institut d'études orientales, 1953.
89. Spillmann, P. *Les Aït Atta du Sahara.* Rabat, Moncho, 1936.
90. Teran, M. de. *Geografia de Espana y Portugal. I: Geografia fisica.* Barcelone, Montaner y Simon, 1952, 1954. 2 vols.
91. Terrasse, H. *Histoire du Maroc.* Casablanca, Éditions Atlantides, 1949, 1950. 2 vols.
92. Tournieroux, J. A. *L'oléiculture en Tunisie* (2nd ed.). Tunis, Direction de l'agriculture, 1929.
93. Vaysse, J. *L'élevage au Maroc.* Rabat, Direction de l'agriculture, 1952.
94. Villar, E. Huguet del. *Types de sols de l'Afrique du Nord.* Rabat, 1947-1948.
95. Vita-Finzi, C. Some Roman dams of Tripolitania. *Antiquity,* Dec. 1960.
96. ——. Post-Roman changes in the Wadi Lebda. In: *Field studies in Libya.* Durham University, 1960.
97. Yacono, X. *La colonisation des plaines du Chelif.* Alger, Imbert, 1955, 1956. 2 vols.
98. Yankovitch, L. Étude pédo-agrologique de la Tunisie. *Annales du Service botanique,* Tunis, 1935-1936, p. 417-559.

# LAND USE IN THE SAHARA-SAHEL REGION

*by*

THÉODORE MONOD and CHARLES TOUPET
*Institut français d'Afrique noire, Dakar*

To deal with the history of land use in the Sahara and the Sahel—the intermediate zone between the desert and the Sudan—in the space of a few pages is an undertaking more than ordinarily difficult, and that for two quite opposite reasons.

First, the genuinely historical documents available are extremely few; they are in fact extant in any considerable numbers only from the time of the Arab geographers onwards, that is, from a fairly late date. And secondly, the very paucity of source material would necessitate careful and critical marshalling of even the minutest details—a requirement scarcely compatible with the limited number of pages at our disposal.

Hence the inevitably disappointing nature of this brief essay, which will be as apparent to the reader as it is to its authors.

## GEO-CLIMATIC SETTING

There can be no question here of dwelling on the general characteristics of the Saharan and Sahelian climates and their global meteorological causes, or on the various aspects of desert morphology and the main types of regions and their distribution, etc. All the necessary information on these matters will be found in general works (e.g., Capot-Rey [24];[1] Schiffers [72]) or in articles surveying the position (e.g., for the arid zones, Joly [47]; for Saharan climates, Dubief [41]; for Saharan morphology, Lelubre [49]; and for geology, Menchikoff [57]).

On the other hand, immediate mention must be made of a problem which is, at once, important for its bearing on the history of human settlement and vexatious because the many attempts to solve it have had to rely far too much on hypotheses. We refer to the problem of climatic variations in the Quaternary Era.

No one doubts the fact that in the Sahara and the Sahel as in many other parts of Africa there has been a series of alternating comparatively wet ('pluvial') and dry ('interpluvial') periods, the incidence, characteristics (deposits, fauna, industries) and distribution of which geologists and prehistorians are still trying to elucidate.

Let us admit at the start that it is impossible, in the present state of knowledge, to suggest an acceptable chronology for the Saharan Quaternary Era as a whole or to define the correlations between its various divisions and the classic divisions of the Pleistocene in Europe or East Africa. A mass of local or small-scale regional stratigraphic studies would have to be made before even the remotest comparison could be reasonably attempted.

In the north-west Sahara (Saoura region), recent works [1, 2, 3, 4, 5], have established the existence of three pluvial periods—$Q_{1a}$ and $Q_{1b}$ (pebble-tools, Acheulean) and $Q^1$ (Aterian)—and one humid phase, $Q^2$ (Neolithic). Generally speaking, it is agreed that there were two major phases of settlement in the Sahara in conjunction with humid conditions: Lower Palaeolithic (advanced Acheulean, in particular) and Neolithic, with Middle and Upper Palaeolithic less frequently or less widely in evidence.

At this juncture comes a clash between two main hypotheses: that of an 'ebb-and-flow' alternation of climates from side to side of the Sahara, whose northern and southern sectors are presumed to have had different histories [7], and that of a desert about which we are told that the belief in a 'wandering' Sahara should be discarded in favour of the thesis of the simultaneity of climatic rhythms on all sides [20, p. 110; 21, p. 39].

One thing that is certain—and that which matters in this context—is that the humid Neolithic phase, from about 5000 to 2400 B.C.,[2] constituted the last

1. The figures in brackets refer to the bibliography at the end of the chapter.
2. This relates to the eastern Sahara [21, p. 39]; we have no reason to believe that these dates can have been very different for the rest of the Sahara.

Saharan biological and human optimum, and that thereafter a probably irregular but cumulative deterioration gradually produced climatic conditions which in the main can hardly have changed since [21, p. 6].

There may well have been fluctuations : Butzer [21] notes for example that in the present period there has been a local fall in the water table in the eastern Sahara, together with a certain reduction in precipitation since 1900 (for the entire Mediterranean area, Saharan as well as Sudanese) and a slight rise in temperature.

But the essential fact, as far as we are concerned, is the almost complete absence of change over the past 4,000 years or so in a Saharan climate which, with the end of the final Neolithic humid period and the passing from the Sahara of the elephant herds, assumed the arid features with which we are familiar today.

It is essentially to those 4,000 years (for there is very little we can say about the Palaeolithic stages) that we must look in trying to trace the history of the use of natural resources.

It would be wrong to lose sight of the possibly important part played by human activities in the actual creation, maintenance and often extension of the desert. This point has been repeatedly stressed, and there is no doubt that there is a disturbing amount of truth in what Stebbing has said about 'man-made arid zones', as well as in Reifenberg's dictum, 'the nomad is not so much the "son of the desert" as its father' [69, p. 379]. Dubief [39] and Quezel [68] have also very rightly stressed the role of man in the deterioration of the plant cover in desert regions; and in 1958, Monod [59] collected a certain amount of material on this subject. The current experiments (IFAN-Unesco) have not taken long to demonstrate, in the case of protected plots in the Adrar area of Mauritania, how serious and how decisive is the pressure exerted upon plants by man and beast.

## ETHNIC GROUPS AND THEIR ESTABLISHMENT

Who are these men of the Sahara and the Sahel, whence did they come, and how did they establish themselves in their present domain? While it is still impossible to give a definite reply to these questions, we may venture to sum up what is now thought to be the likely answer—a task made easier by the fact that Cabot Briggs' recent publication *The Living Races of the Sahara Desert* [17] makes a major contribution towards solving these problems.

Despite the—in some cases prodigious—abundance of industries, human palaeontology supplies little information concerning the Sahara and its southern extensions : nothing for the Palaeolithic, nothing for the Mesolithic and practically nothing for the Neolithic. All in all a poor showing, which will need to be supplemented by extra-Saharan data extrapolated to a greater or lesser degree.

Cabot Briggs concludes that there has been a double inflow of population : some elements having entered the desert from the north (and north-east) and some from the south (and south-east), while others may perhaps have come from both directions at the same time, the whole movement probably amounting, in essence, to a twofold east-west penetration at different latitudes—one 'north Saharan' and the other 'south Saharan', one 'Mediterranean' and the other 'Sudanese'.

The 'Mediterranean' contingent would include :

1. *Palaeo-Mediterraneans* (industry : Ibero-maurusian; in the Sahara : Aterian (?)—date, 10,000 B.C. or earlier).
2. *Afro-Mediterraneans* (industry : Capsian—date, 8000 B.C. or earlier).

2A. *Afro-Alpines* (minor element).

3. Result of a mixture of the above contingents : the *Mechta-Afalou*, who are followed by :
4. *Neolithics*, whose 'north Saharan' heritage has added to it a 'south Saharan' element which, if not negro, is at any rate negroid.

The 'Sudanese' element, in fact, includes a 'negroid' or 'semi-Hamitic negro' element (identifiable only from the Neolithic onwards, incidentally) to which Asselar Man probably belongs. Cabot Briggs [17, p. 13] has defined this Sudanese element as a 'strongly negroid population with a visibly substantial Hamitic component'. Whatever its origin may have been (and we know nothing about it), it seems to have introduced Neolithic culture or, perhaps it would be more correct to say, *a* Neolithic culture (characterized by querns, grinders, incised pottery, polished axes, etc.) into the Sahara from the South probably some 5,000 years or more ago.

The peopling of the Sahara would thus be the result of a convergent occupation from the north (Capsian Mesolithics, followed by Neolithics, of 'Mediterranean' stock) and from the south (Neolithics of negroid, if not negro, stock).

The North African Mediterraneans are the parent stock of the Proto-Berbers and Berbers who, until the arrival of the Arabs, were to form a fairly homogeneous group (Teda, Tuareg, Proto-Moors), subjected to more or less intensive cross-breeding on coming into contact with the Saharan negroids, with the cross-bred element sometimes dominant (Haratin) but always marked.[1]

It is not surprising, therefore, to find existing Saharan groups composed of various elements derived from the main stocks which came in contact: Berber,

1. Sometimes more strongly marked in morphology than blood (as with the Teda) or vice versa (as with the Moors).

in the broad sense (B); negroid (and negro, by slave additions) (N); Arab (A)—e.g., Haratin (N + B), Teda (B + N), Tuareg (B [+ N]), Moors (B + N), Mozabites (B [+N+ A]), Chaamba (A [+ N]), etc.

The history of the Saharan populations, very roughly summarized, consists of a series of major stages.

First of all, the pre-historic northern and southern stocks, once in contact with each other, interbreed to a greater or lesser extent in a Sahara with a savanna vegetation, and large Sudanese animals traversed by small clans of hunters and food-gatherers. A grain-growing (millets) and settled farming community may already have been becoming established in the southern part, while pastoral stockbreeding seems to have extended throughout the desert.

After the Neolithic humid phase, with the deterioration of the climate and the vegetation (to which man and beast effectively contributed), segregation of an insular type gradually supervened : cultivation became confined to ever smaller areas and then to 'points', ending in the oases, peopled by garden-tending Haratins, which formed 'islands' of sedentary life in the midst of a vast ocean of no-man's land, where both nomadic pastoralism and trade contacts necessitated new modes of transport—first the horse and cart and then, probably about 2,000 years ago, the dromedary. The camel, pack-animal and mount in one, as a supreme stroke of luck for the herdsman and the warrior, was to enable human life to go on in the heart of a desert now closing in for good and all on pin-point palm groves—in a Sahara which had now become 'the finest desert in the world'. Saharans of all kinds—the various types of Berbers, the ancestors of the Teda, Tuareg, Moors, etc.—settled into the type of economy which was to characterize them up to modern times, based judiciously on the herd, the caravan and the *ghazw* (armed raid).

After several thousand years of relative stability, both ethnic and climatic (since the major groups were now established in the Sahara), and desiccation having reached its limit could scarcely get worse, the irruption of the Arabs at the height of the Middle Ages came to modify the language and religion of the area more than the racial admixture or way of life. At the same time however it was to produce that tremendous development of trans-Saharan trade, with the transport across the desert of the gold essential for an active Mediterranean economy importing Asian luxuries and black slaves—not all of which found a final destination in the Maghrib.

The scenes represented on rocks in the Sahara alone, incidentally, provide a kind of epitome of local history, beginning with the Neolithic. Proof of this can be seen in the summary table recently proposed by Butzer for the eastern Sahara [21, p. 43] and broadly confirming the categories long since defined elsewhere (bubaline, bovine, equine, cameline and pre-cameline/cameline groups; groups of hunters (Sudanese fauna), cattlemen, horsemen, camel nomads, etc.).

1. Neolithic hunters (about 4500-3600 B.C.). Big game : hippopotamus, crocodile, rhinoceros, elephant, ancient buffalo (*Bubalis)*, giraffe, ostrich, antelopes.
2. Nomadic Neolithic herdsmen and hunters (from about 4000 B.C.), bovine herds and game; withdrawal of the most significant species (hippopotamus, rhinoceros, elephant), which disappear from the eastern areas after 2750 B.C. and from the central area towards 2000 B.C. at the latest.
3. Warriors and war chariots (after 1500 B.C. in the east, and towards 1200 B.C. in the central area). Horse, giraffe, ostrich, antelopes.
4. Camel nomads (from the beginning of the Christian era). Camel, ostrich, moufflon.

In 1956, Mauny [55] distinguished the following separate groups among Saharan rock sites :

1. Naturalist group, with large Ethiopian fauna (5000-2000 B.C.).
2. Neolithic group, herdsmen and bovines (2500-1000 B.C.).
3. Equine group (1200 B.C.-present era).
4. Libyco-Berber group (200 B.C.-A.D. 300).
5. Arabo-Berber and modern group (from A.D. 700).

The growing scarcity and then disappearance of the large fauna can also be traced from the petroglyphs (see the charts prepared by Mauny [55, 56] and Butzer [21]). An attempt has been made, on the basis of these data on the distribution of the elephant, giraffe, rhinoceros and hippopotamus in the Neolithic, and in the light of the ecological requirements of these species, to reconstruct the isohyets for the period for the eastern Sahara.

It will be noted that, for the most part, the petroglyphs show animals (whether game or livestock). There is nothing to prove, however, that stockbreeding, especially of bovines, did not originate in an already agricultural environment if the following sequence proposed by von Wissmann and Kussmaul [80], which has sound arguments in its favour, is accepted : Stage A (hunting and food-gathering, succeeded by dogs, pigs, poultry and proto-arboriculture; stage B (millets, sorghums); stage C (millets and sorghums, barleys (?), first appearance of goats and sheep); stage D (barleys and wheats, cattle).

## TECHNIQUES OF EXPLOITATION

The difficulty of keeping, as desired, to established facts of history in an essay dealing with these regions has already been mentioned, but may well be stressed again. We shall therefore try in this context to dwell on those points—few in number, indeed—which allow reference to the past, albeit indirectly, in each of the three following connexions : wild products, cultivated plants and domestic animals.

## WILD PRODUCTS

It is quite certain—and archaeology bears this out for at least two of the three [1] activities—that hunting, fishing and food-gathering have played an important part in Saharan economy since prehistoric times.

For the Palaeolithic we are reduced to conjecture,[2] but with the Neolithic the material becomes more abundant, being based simultaneously on the subject matter of the petroglyphs, on industry (stone and bone) and on kitchen midden material.

This last, in the Sudanese Sahara and the Sudan, has yielded abundant remains of mammals (elephant, hippopotamus, rhinoceros—as at Esh Shaheinab and Tiouririne—buffalo, antelopes, gazelles, wart hogs, carnivores, rodents, etc.); birds; reptiles (especially a fresh-water turtle, *Tzion*); fish (especially the Nile perch (*Lates*) and various types of catfish); and molluscs.

As to industry, mention should be made, first, of the abundance (at least in the regional sense) of arrowheads, javelin heads and spearheads, and secondly, of the increasing number of discoveries of bone harpoons and fishhooks in the southern Sahara [60]. The finds may include other hunting or fishing equipment, the purpose of which has not yet been determined.

As to the rock carvings and paintings, they constitute as everyone knows, a regular gallery of animal art in which the wild fauna—represented on their own at the outset—continue to feature throughout, even in the singularly impoverished form of the Libyco-Berber graffiti, many of which depict ostrich, oryx or moufflon hunts. The ancient Neolithic representations show huntsmen armed with bows and what may be wooden missiles; the shield, the javelin and the spear seem to have come on the scene later, with the advent of iron. Lhote's *La chasse au Sahara d'après des gravures et les peintures rupestres* (See [50, p. 201]) may be profitably consulted in this connexion.

While there may have been Neolithic groups of hunters in the Sahara who were unacquainted with domestic animals—and the petroglyphs go to show that such was the case—it is probable that some of the hunting methods still practised were already current at that time, such as the use of snares of various types (including the sharp-spoke trap), whereas the bow had disappeared from the Sahara. The hunters at the bovine stage—for game-hunting and stockbreeding were to go hand in hand, as they do today—at first remained essentially bowmen, but other hunter-herdsmen were later to adopt the metal-tipped javelin and the shield. The horse appears soon after, and the only touches that need to be added to the picture to bring us to the Sahara as we know it today are the camel and the rifle. The present-day hunting practices of the Tuareg [19, 50], the Teda [29] and the Nemadi [18], for example undoubtedly give an idea of what prehistoric hunts—even Neolithic ones, in many respects—were like : snaring, coursing, hunting with dogs and nets, meat drying, etc. are all features which most certainly have a very long tradition behind them. Striking cases have been observed here and there of individual or group survivals of an extremely archaic way of life : the skin-clad hunter encountered in the Aïr region, as a living example of the men of ancient times, and himself on a par with the animals of the bush [19, p. 447], is symbolic in this respect.

Except for a small number of 'professionals' who went in for 'commercial' hunting (Nemadi, Azza, Haddad, Cherreck, Nichab, etc.), hunting provided the nomads with no more than an addition to their food supply—an addition, none the less, which was eagerly sought for and which included, in the case of children and slave groups as well as in times of scarcity, all sorts of small animals, down to rats, lizards, locusts and even the larva of an insect parasite of the Euphorbiae. But to be reduced to eating powdered bone was real famine.

Side by side with hunting, the population engaged more or less intensively—depending on locality and season—in gathering plants either as a source of titbits or condiments, or as a useful adjunct to an inadequate diet, or, if scarcity threatened, as a means of survival, even if it meant eating crushed wood, palm fibres or date stones.

The number of Saharan plants capable of providing wild food is fairly large, and the main ones might be tentatively grouped as follows:[3]

Fungi : *Terfezia* spp.

Rhizomes and fleshy stems : *Cistanche phelyphaea*, *Cynomorium coccineum*, *Typha elephantina*.

Amaranths : *Gynandropsis pentaphylla*, *Portulaca oleracea*, *Rumex* spp., *Eruca sativa*, *Schouwia purpurea*, *Solanum nigrum*, etc.

Seeds of Herbaceae : *Boerhavia* sp., *Chenopodium* spp., *Aizoon canariense*, *Cassia italica*, *Colocynthis vulgaris*, *Limeum* sp., *Glinus lotoïdes*, *Glossonema boveanum*, *Rogeria adenophylla* (S), *Blepharis* spp., etc.

Caryopses of Graminaceae : *Panicum turgidum*, *Panicum* spp., *Aristida pungens*, *Cenchrus prieurii* (S), *C. biflorus* (S), *C. ciliaris* (S), *Sporobolus spicatus*, *Sorghum* sp., *Echinochloa* spp. (S), *Latipes senegalensis* (S), etc.

1. For three out of three, if the Neolithic querns were used to mill wild seeds and not cereals.
2. Lhote has referred [50, p. 189] to Acheulean 'encampments' at Tihodaine and Admer, with bones of big game (prehistoric elephant, giraffe, hippopotamus, zebra); Arambourg [6, p. 283] mentions *Elephas* cf. *recki*, the white rhinoceros, a zebra, *(Equeus mauritanicus)*, the hippopotamus, *Bos primigenius*, a gnu, an elk, a strepticeros, a bubal etc., but without referring to the direct link between fauna and industry.
3. (S) denotes a species which is more particularly Sahelian.

Fruits : *Salvadera persica*, *Zizyphus* spp., *Balanites aegyptiaca*, *Cordia gharaf*, *Cocculus pendulus*, *Boscia senegalensis*, *Maerua crassifolia*, *Capparis aphylla*, *Rhus oxyacantha*, *Grewia tenax*, *Grewia* spp. (S), *Sclerocarya birrea* (S), *Hyphaene thebaica* (exocarp and corozo), etc.

Aromatic plants for infusion (often used more or less medicinally) : *Solenostemma argel*, *Artemisia* spp., *Brocchia cinerca*, *Paronychia* spp., *Cympopogon schoenanthus*, *Myrtus nivellei*, *Menta* spp., *Salvia chudaei*, etc.

Edible gums and mannas : Gum of *Acacia* spp., manna of *Tamarix*.

A very interesting chapter with lists of species,[1] is to be found in an unfortunately little known book by Creac'h [35] on plant food-substitutes among the Chad Arabs. Also worth consulting is the relevant chapter in A. Chevalier's *Plantes spontanêes du Sahara et de ses confins utilisées dans l'alimentation* [31, p. 803].

Generally speaking, the plant foods collected are an important item mainly in the mountain massifs (especially Tibesti) [2] and in the Sahel, with its 'kreb' graminaceae, usually gathered in baskets. This food, whatever its local or seasonal usefulness, however, never amounts to anything more than a supplementary supply.

## CULTIVATED PLANTS

### *The origins*

The excavations of the Neolithic site at Esh Shaheinab have yielded no clear indications of agriculture, but emmer (*Triticum dicoccum*) and barley are, of course, known from various Neolithic sites in Egypt (Fayum, Merimde, etc.) from about 4000 B.C. onwards [75, p. 242 and p. 288].

Was agriculture practised in the Sahara in Neolithic times, or not? It is generally agreed—at least implicitly—that it was, so obvious does that development appear; and the heavy equipment found (querns, crushers, pestles, etc.) is considered to have been used for 'agricultural' purposes.

According to A. Chevalier [32, 33], the Sahara saw the emergence of protoculture at the end of the Palaeolithic period, and (in the extreme south) must have been a veritable 'breeding ground for cultivated plants'—such as, date palms, certain jujube trees, sorghums, penicillariae, digitarise, rice (*Oryza glaberrima*), and various vegetables—'old' crops (sorghums and penicillariae) being supplemented by new ones of Eastern origin (wheat, barley, leguminous plants, etc.). Schnell states firmly [73, p. 91, see also p. 105 and p. 130] that 'Neolithic sites, many of them abounding in querns, occur in large numbers in the savannas right up to the Sahara, where this form of grain growing must have been very widespread'.

It is equally certain, however, that a quern may perfectly well serve for grinding wild seeds [67, p. 80] and even many other substances (condiments, dyes, perfumes, etc.).

Only recently, Balachowsky, in a paper on insects harmful to Saharan crops, felt justified in stating that there appeared to be no indication of agriculture having been practised in the Sahara [3] in Neolithic times; he obviously considered (although he does not say so in as many words) that it was for crushing wild seeds that the grinding equipment was used.

It is true that for the Saharan Neolithic we have no material evidence of the existence of agriculture (as we do for the lake-dwellings or for Egypt) in the form of cultivated grain. In the case of the Kharga 'peasants' of the Neolithic, however, G. Caton-Thompson unhesitatingly concludes that 'although, unlike Fayum, no concrete evidence for agriculture was forthcoming, the artefacts and grinding stones proclaim it . . .';[4] while at Armant, Huzayyin says that 'as to the grinders and the quern there can be no mistake about their use', they are objects 'connected primarily with agricultural food'.[5]

Significant points, in respect of the Neolithic Saharan populations (Waran, Aklé, Awker, Azawad, etc.) who had heavy grinding material, are : (a) the existence of identical material associated with a highly developed agriculture (Fayum, etc.); (b) the presence of settlements, and sometimes of regular villages; (c) the association, with the querns, etc., of a vast quantity of pottery; [6] (d) the possibility that many of the 'polished axes', especially those with dissymmetrical bevels, are really hoes; (e) the difficulty of imagining a large sedentary settlement, or even a large group of semi-nomadic cattle breeders, relying on plant-gathering for a large part of their food supply and the whole of their plant food; (f) the invariable association of the quern in West Africa (in places where it exists!) with agriculture (cf. Schnell [73, *passim*], Prost [67] and Pales [64]; (g) the probable use, among the Tuareg of the Central Sahara, of the wooden mortar, especially for millet, dates, cheese and locusts, whereas it is the guern that they use for grinding wheat [63, figure 12].

However that may be, the present-day Sahara is characterized by a fairly large number of cultivated plants : Corti (1942) gives a list of 93 for the Fezzan alone; and A. Chevalier should also be referred to for his list of cultivated, cultivable or spontaneous

1. But the botannical names are not always reliable.
2. Where the colocynth seed industry is particularly extensive.
3. Mission Scient. Tassili des Ajjez, III, *Zool. pure et appliquée*, Inst. Rech. Sahar. Univ. Alger, 1958. p. 9.
4. *Kharga Oasis in Prehistory*. London, 1952. p. 38.
5. In : Sir R. Mond and Oliver H. Myers, *Cemeteries of Armant*. Vol. 1, London, 1937. p. 225.
6. Practically absent from the culture of the steppe hunters (e.g. bushmen).

plants used by the peoples of the Sahara and on its northern and southern fringes [31, p. 825].

In the absence of archaeological material, the history of ancient Saharan agriculture remains conjectural. Nor should it be forgotten that the origins of agriculture reach back, without clearly defined limits, to protoculture and plant-gathering : it can be seen, for instance, how the digging stick of the food-collectors, weighted with a stone *kwé*, becomes an agricultural implement among the Galla [73, p. 121].[1]

Many of the plants which were used for various purposes (food, magic, etc.) must have gone through a stage of protoculture or 'semi-domestication' such as that which is still being traversed today by the Karité, the Néré (*Parkia biglobosa*), the baobab, the tamarind, certain palm trees (including the *Elacis*), cola trees, etc. Kronenberg [48] sees Nachtigal's report that the colocynth (with edible pips) had been sown in the wadis of north-western Ennedi [2] as an interesting example of the transition between the stage at which a wild plant is gathered and that at which it is cultivated.

As a first approximation, the introduction of cultivated plants in the Sahara and Sahel might be divided into the following stages : (a) Ancient elements from Mediterranean (Near Eastern or Abyssinian) centres; (b) ancient indigenous elements (Afro-steppe centres); (c) various contributions ('Eastern')—Arab period (eighth to fourteenth centuries); (d) various contributions (mainly America, Asia)—Portuguese period (fifteenth to seventeenth centuries); (e) various contributions—Modern period (eighteenth to twentieth centuries).

While it can be taken that the Saharan Neolithic time (or part of it, at any rate) was acquainted with agriculture, it is not possible to determine which of the two contributions, the Near-Eastern (Egypt, Abyssinia : Emmer (*Triticum dicoccum*) and barley) or the Sahelo-Sudanese (sorghums, penicillariae, etc.), is the older. It emerges, on the other hand, that there are—and have probably been for a very long time—*two* Saharas, one growing wheat and the other millet, the boundary between them very roughly coinciding with that between the 'Mediterranean' and 'African' Saharas.

Even if the Sahara proper had not been the real home of cultivated plants that Chevalier imagined it to be [31, 32, 33], it would, with progressive desiccation and hence 'encystation' and isolation of the oases, have become a 'secondary centre for the neoformation of wheats' [65, p. 315] whose forms would have assumed, by parallel variation, a 'Saharan aspect' corresponding with Ducellier's *oasicola* type (cf. Erroux, [43]).

Whereas the modern contributions to traditional Saharan agriculture are negligible, and the American species (tomato, pimento, tobacco, ground-nuts, etc.) are easily discernible, it is extremely difficult to differentiate between the 'Arab' contributions (a better name would be 'Moslem') and those of the old Berber Mediterranean, as also between the latter and those of a Neolithic 'Near East' already perhaps acquainted with wheat, barley, beans, peas, the onion, the fig tree, the apricot tree, the vine, henna, etc.

Even where the date palm is concerned, we know nothing definite about its origin, nor about the history of its introduction throughout the desert. Chevalier [31, p. 10] considers it 'certainly of Saharan origin' and hence more or less locally 'domesticated' at a stage of protoculture comparable to that of the Dum (*Hyphaene*) among the Teda—a theory which would not, of course, preclude the possibility of many of the palm groves being of recent origin, dating from the Middle Ages.

### *Types of cultivation*

The peoples of the Sahara and the Sahel very soon learned to exploit their meagre water and soil resources by developing a *linear* pattern of farming along the Sahelian wadis and a *punctiform* one in the Saharan oases. The sedentary groups were reduced, in fact, to using only the clayey, sandy soils of the alluvial valleys, the floodwater debris areas or the hollows between the dunes.

'Of an area of 350,000 square kilometres, equivalent to sixty French Departments, the Hoggar extension has a population estimated in 1949 at slightly over 10,000 but to feed them this enormous tract contains only 1,420 hectares of useable land, representing a ratio of 0.00004 to 1, as between useable and total area. And even so this poor and particularly disfavoured area, with its very marginal agriculture, exploits only 460 hectares of the cultivable land at its disposal.' [53, p. 338.]

Water control has assumed many different forms, involving a coherent and developed social organization from the very start. It would be wrong to assert that the simplest techniques are the oldest. In the Tagant oases, for example, the sedentary population has for centuries been using wells with counterpoised sweeps whereas the nomads who have lately been converted to the profitable cultivation of the date palm make do with the simple type of well—the only one they know how to build.

The limited spread of what are considered to be more efficient techniques is not exclusively due to human causes; the fact is that natural conditions are so varied that the settled population has been able demonstrate its inventiveness in a variety of solutions adapted to every set of natural circumstances. Figure 1 illustrates this regional development of water control techniques. Since the small volume

1. See also G. Mortelmans, A propos de quelques pierres percées remarquables du Katanga central. *Bull. Soc. Roy. Belge Anthrop. Préhist.*, LVIII, 1947, p. 151-171.
2. *Sahara und Sûdân*, 11, 1881. p. 179.

and unequal distribution of precipitation preclude farming based on year-round rainfall,[1] two main systems of cultivation are possible : those based either on *floodwater* or on *irrigation.*

*Floodwater cultivation* makes use of the sheet of water which covers the main bed of a wadi at flood-time, moistens the dried earth and leaves behind small alluvial deposits, brought down from upstream; the saturated soil can be cultivated as the water recedes. Hence the size of the flood governs the acreage to be sown : one year there may be too much water, and the fields are transformed into marshland because of the very slow run-off, while in another year the flood may be insufficient and the marginal fields will stay dry. This form of natural floodwater cultivation becomes precarious when practised along the wadis in the Sahele-Saharan zone, where the floods are very rare as well as being too short-lived —often lasting only from 36 to 72 hours—to wet the dried-out soils sufficiently. The sedentary population builds dams (as in Adrar, Tagant, Hodh, Assaba, Brakna) to retain the water and increase the flooded area, but these earth and stone embankments—leaky, unstable and often without overfalls —are usually incapable of withstanding peak floods.

1. In the Sahelian zone, between the 500- and 300-mm. isohyets, and especially in the Trarza area, rainfall cultivation can be practised in the hollows between the dunes when the summer rains are sufficiently abundant; but this form of cultivation is an uncertain one.

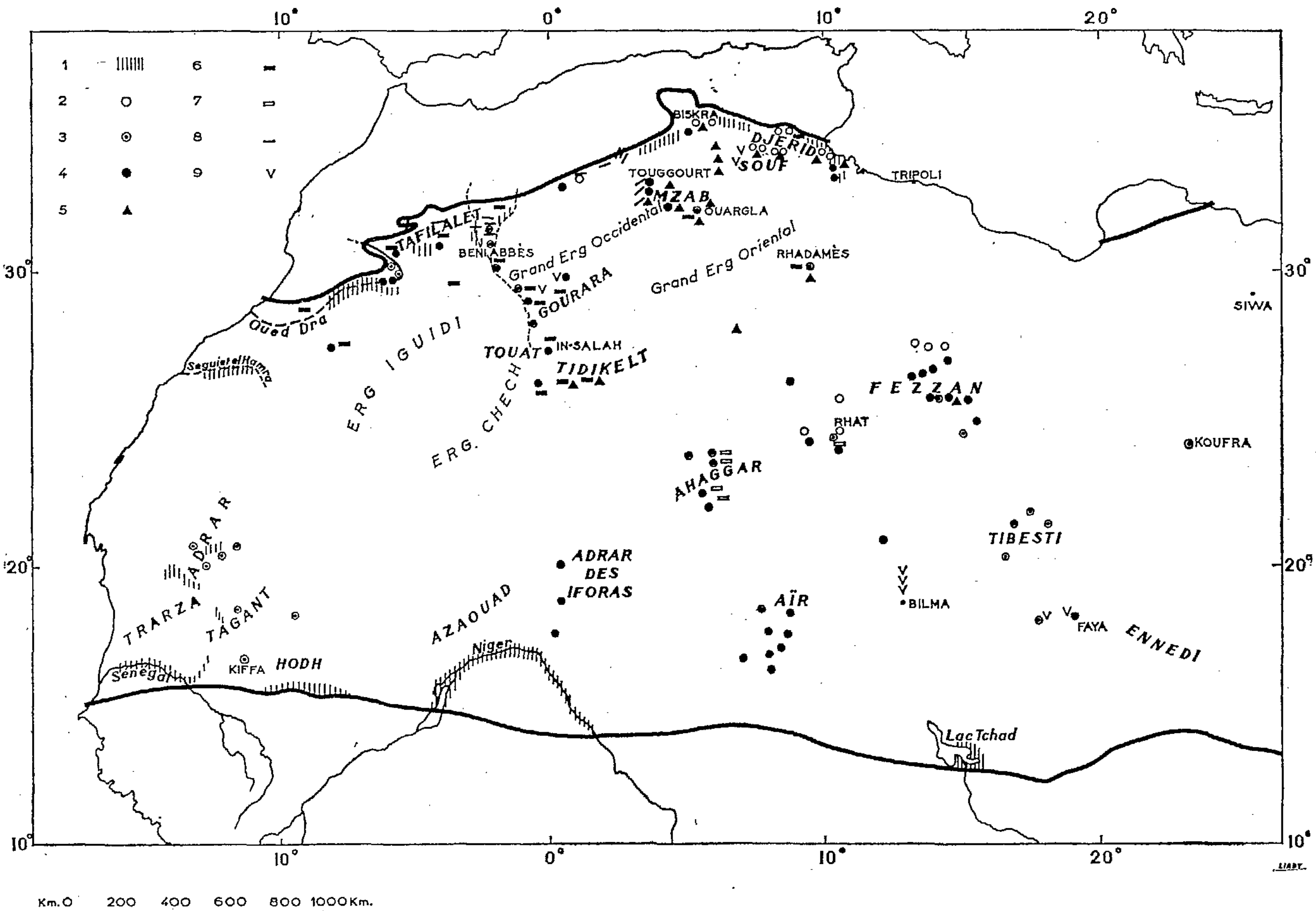



FIG. 1. Types of land use in the Saharo-Sahelian zone. (Irrigation systems as described by R. Capot-Rey [24].)

The heavy lines represent the limit of palm plantations to the north and the 500-mm. isohyet to the south.

Key:
1. Floodwater cultivation
2. Spring-water irrigation
3. Irrigation by wells with counter-poised sweeps
4. Irrigation by wells worked by draught animals
5. Irrigation by artesian wells
6. Irrigation by *foggaras*
7. Irrigation by open culverts
8. Irrigation by dams
9. *Bour*-type cultivation

The wadis at the exit from the Mauritanian plateaux (Aïr, Tibesti or the Saharan Atlas) end up in areas covered with flood debris—known as *grara* or *maader*—representing the last outposts of floodwater cultivation in the desert zone. Some of the Sequiet el-Hamra hollows are likewise cultivated along *grara* lines although they receive not only run-off water but also autumn and winter rainfall, thus providing a transitional form between floodwater cultivation and rainfall cultivation. A striking fact about these particular lands, which are scattered throughout the *hamada* (stony plateaux), is that their nomad owners cultivate them with the aid of the swing plough, since they have enough camels to use them as draught animals. Everywhere else (except at Biskra), hand implements are the rule.

*Irrigation cultivation* takes a variety of forms: 'bour'-type cultivation; irrigation from the wadis, with run-off water or spring water; use of the water table with the aid of simple wells, wells with counterpoised sweeps, draw wells driven by animals, foggaras and artesian wells (see also Fig. 2). A classified list of these various methods, with an exhaustive analysis of them, will be found in Capot-Rey [24, p. 306]; while regional examples are examined in detail by Cl. Bataillon [8] and Jean Bisson [13], as well as by Jean Despois in *Mission scientifique du Fezzan, tome III, Géographie humaine.* These techniques definitely seem to have been in use for a very long time. For example, the Adjal foggaras were mentioned by Idrisi in the twelfth century; and there is a fourteenth century description of artesian wells by Ibn Khaldun. Hand-cultivation methods, too, have hardly changed. El Bekri gives valuable details concerning life in the oases as early as the eleventh century: 'Sidjilmessa [in Tafilalet] is situated in a plain whose soil is full of salt. . . . It has many gardens. . . . The water used for watering the seedbeds comes from the river and is collected in tanks, as is customary elsewhere for cultivating gardens. Dates, grapes and all manner of other fruits are found there in great abundance.' [12, p. 282.] El Bekri also visited Aoudaghost (the present Tegdaoust, in Rkiz Hodh) on the other

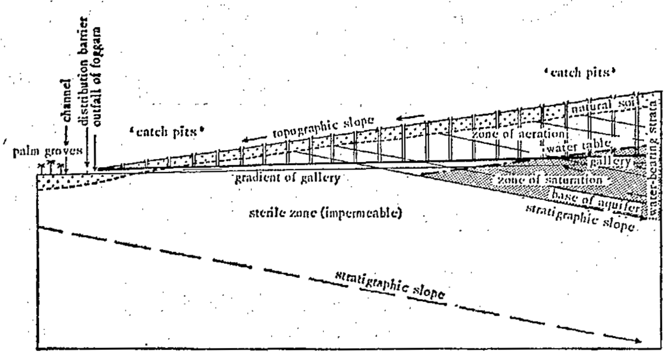



FIG. 2. Section through a foggara. (After J. Savornin, *Trav. Inst. Rech. sahar.*, 1957, p. 47.)

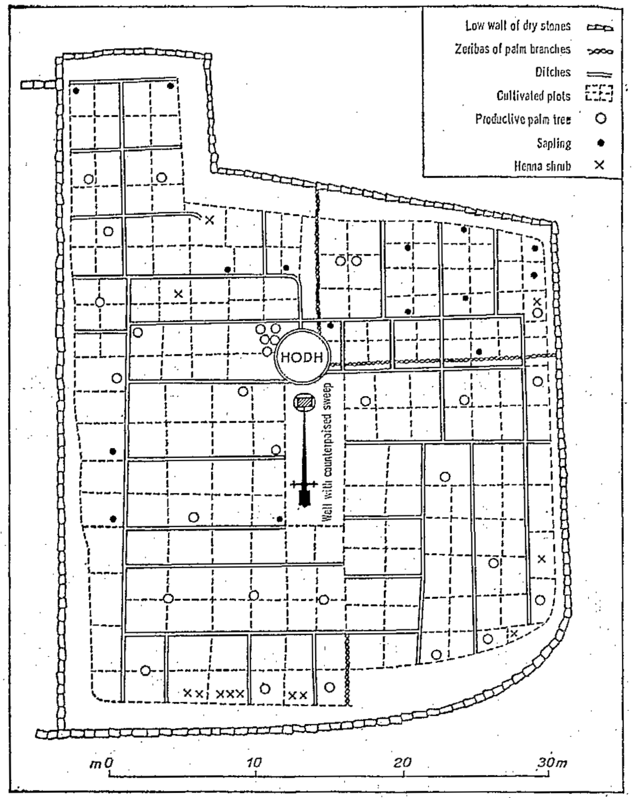



FIG. 3. Plan of a garden in the Tijigja palm-grove.

edge of the desert: '. . . We arrive at Aoudaghost, a large and populous town built in a sandy plain . . . all around spread gardens of date palms. Wheat is grown here with the spade [1] and is watered by hand. Only the princes and rich folk eat it; most of the population lives on *doro* (millet). Gourds flourish here. They also have some small fig trees and a few vine stocks. The henna gardens their owners much wealth. Aoudaghost has wells which provide fresh water.' [12, p. 299.] Thus an Aoudaghost garden grew the same crops as the oases do today: the date palm, millet (presumably the dwarf variety, or *mutri*), wheat, and henna; only the vine stocks seem to have disappeared from Mauritania.

Four centuries later, Valentim Fernandes [28, p. 79] gives us this lively description of life in the Adrar oases:

> The whole mountain is covered with date palms . . . every inhabitant of the region owns land in these wadis. By digging to the depth of one cubit into the dry wadi beds, they straightway come upon water which is the best in the world. On this mountain, named Baffon, grow wheat, barley and Guinea millet.
>
> They sow the seed in the sands, [notwithstanding] that God has never yet made a plant grow there, and build an enclosure of palm branches round each seed-plot. In the

1. He undoubtedly means the hoe.

middle of the sown area they dig a fountain to which a water-raising device is fitted for drawing off the water in a pail: with this water they irrigate the sown [field] in which the [plants] grow very tall and strong. They [proceed] in the same way for every other crop they wish to grow, for henna, for example, and for other plants which are strange to us. These fields are harvested in March.

Figure 3, representing a plot of land in the Tijigja oasis, gives an idea of the persistence of techniques and crops since the fifteenth century.

This persistence of such a variety of techniques is matched by the continuity of social structures and the land-tenure system. Land use in the Sahara and Sahel is conditioned, in fact, by the problem of the relations between the nomads and the sedentary population. The latter are usually Berbers of no great affluence or Haratin 'freedmen' of Negro origin. The Haratin seldom own the land they work, and the Berbers do not always do so: it usually belongs to nobles of Arab or Berber origin, leading a nomadic, or at least semi-nomadic life (Doui Menia, Kunta from Tagant). There are two separate types of ownership: collective (*arch*), in respect of flood-water farmland, and private (*melk*) in respect of oasis land, i.e., land 'vivified' by water, with the person responsible for 'vivification' becoming the owner.

But private ownership is limited within the general context of collective ownership. In Tagant, for example, the *sharia* recognizes the Idawali as supreme owners of all the lands on the upper reaches of the Wadi Tijigja. No stranger may acquire uncultivated land there for planting palm trees and digging wells—'vivifying' it; he is only allowed to buy land which has already been developed, and even that possibility is limited by the system of *habou* property. The object of this is to keep the family inheritance intact, the originator of the settlement retaining the ownership and his descendants having only a life-interest in the property. Joint ownership is also very common and is, of course, another obstacle to land transactions.

The inheritance protection measures also militate against those who work the land. According to a census conducted in El Goléa in 1942, 'less than one-third of the palm plantation belongs to those who cultivate it' [23, p. 25]. It is very rare that noblemen, who often suffer from malaria and, above all, despise any form of work on the land, will be prepared to wield the hoe or draw water. In the past they relied on their slaves; and it is the latter, now free, who work the estates of their former masters under a contractual system of sharecropping known as *khamessat* whereby they receive one-fifth of the crop. The *khammès* can also acquire ownership of newly developed land: the owner provides the land, the seed and the palm shoots, and the *khammès* undertakes to plant and tend it for a given period, at the end of which he becomes the owner of one-third or one-half of it; but the system of planting leases is not very widespread.

## DOMESTIC ANIMALS

### *The origins*

The Mesolithic site mentioned in *Early Khartoum* [9, p. 27] contained no trace of domestic animals, but the Neolithic one at Esh Shaheinab yielded a few slight remains of other than local animals (goats or sheep?) which must therefore have been introduced by man. Bates suggests [10, p. 13] that the dwarf Neolithic goat of Esh Shaheinab may have reached the Upper Nile from Barbary by way of the Hoggar and Tibesti.

The origins of domestic animals in the Sahara remain as conjectural as those of agriculture. Considering the extreme uncertainty and frequent confusion which continues to bedevil zoological identification even in the case of the Nile Valley,[1] the position as far as the Saharan problems are concerned can well be imagined.

One ingenious hypothesis [37, 38] is that the Sahara was an early centre of domestication, which had been more or less forced on man through the changes occurring in local conditions—in this case, desiccation. The hunter, attached to a particular herd, which becomes more clearly segregated geographically as water points become scarcer, ends up by husbanding, supervising and 'administering' the game which has now, for him become livestock, and from which he obtains milk instead of always having to kill it for its meat. This new civilization, with its Saharan domestic animals, is considered to have withdrawn to the Nile Valley, where the later representations of the oryx and the addax [2] are thought to be not examples of tamed menagerie animals but 'scenes relating to the ancient life of the Saharan peoples' and depicting animals 'kept in captivity for the purpose, in particular, of religious sacrifice' [38, p. 114].

Dechambre's hypothesis raises from a new standpoint the great problem already raised by Saharan Neolithic pottery [3] of the possible influence of the Sahara on Egypt. It will be noted that it applies only to species whose domestication would have been merely temporary, probably because of the intro-

1. Where petroglyph experts have been able to identify *Bos primegenius* (urus), *Syncerus caffer* (African buffalo) and *Bos indicus* (zebu) (cf. J. W. Jackson. In: R. Mond and O. H. Myers, *Cemeteries of Armant*. Vol. 1, London, 1937. p. 254).
2. Cf. L. Joleaud, *Bull. Soc. Géogr. Archeol. Oran*, vol. 38, fasc. 150, 1918, p. 105, notes 4-5; the representation would appear to be of the addax rather than of the *Kobo unctuosus* and the kudu. The author also lists, as animals domesticated in the Old Empire, the bubal, the *Beden ibex* and the moufflon. Incidentally, a number of rock carvings seem to depict giraffes secured by a halter, which may represent either captured beasts or domesticated ones.
3. R. Mond and O. H. Myers, op. cit., p. 267-276 (by O.H.M. and C.A.E.).

duction of more profitable species (whose domestication may not necessarily, however, invariably have preceded the practice of agriculture); if goats and sheep were among the first domestic animals, as has been reasonably conjectured, and if this association with man coincided in time and place with the beginnings of grain growing, the hunter-stockbreeder hypothesis would not apply to them [63, p. 105; 79; 80].

The question of the existence of African centres of domestication, especially in areas where progressive desiccation might have favoured such attempts, remains open [44, p. 554].

The Neolithic Sahara went in for breeding bovines, and its rock art provides a wealth of evidence of that fact, sometimes in the form of a series of regular frescoes (Mertoutek, Tassili des Ajjers, Awénat, etc.). For the most part, they probably represent various breeds, differently horned (cf. Rhotert's table [70, p. 102]), of the *Bos africanus* and *Bos ibericus* [44, 52]. The zebus are believed to have been introduced later.

The history of sheep, goats, asses, horses, dogs and pigs in the Sahara is no less obscure than that of the bovines [44] (for the horse, see also [51]). That of the camel remains perhaps even more debatable, for while the recent rise of a camel-based civilization following the equine and bovine periods is obviously beyond dispute, some quarters maintain that the appearance of the camel (or its reappearance, since Pleistocene camel fossils have been found in Barbary) dates back to the beginning of our era, whereas others consider that the camel, which was known in Egypt long before this,[1] has never ceased to be used in North Africa and the Sahara in historic times: 'It is completely pointless, I think, for the historian to try to determine the time at which the camel was reintroduced into North Africa, for the simple reason that there are no grounds for believing that it was ever absent from it in historical times' [35, p. 99].

Whatever may be the facts of a history which is not yet fully cleared up (cf., for example, [17, p. 31; 26; 51; 58; 61; 71; 74; 76-78]), it is quite certain that the part played by the camel in Saharan economy manifestly increased during the Libyco-Berber period, enabling man to continue to live and possibly to survive in a desert which had become singularly inhospitable.

The development in the Middle Ages of an extensive trans-Saharan caravan trade, which was to disappear only with the European occupation of both shores of the desert-ocean, is inconceivable without an animal which, in another sphere, was to provide the nomad with most reliable assistance for a less pacific industry—that of pillage.

### *Types of stockbreeding: nomadization*

Although, considering the level of traditional techniques, extensive stockbreeding is the most rational form of land use in the Saharo-steppe region, nomadization imposes such strict geobotanical and social imperatives and assumes such varied aspects that it is particularly difficult to grasp the process of its development.

*Nomadic life and its compulsions.* The herdsman, whether Saharan or Sahelian, is compelled to move about in search either of permanent but scattered pasturelands or else of *acheb*, the temporary fields that appear after the fall of the life-giving rains—*rahma*, 'the mercy of God', as the Regueibat Lgouacem call them [27, p. 96].

He has to plan his route according to the water points available, and to reconcile himself to abandoning good pastureland which is too remote from the wells. The extent to which he is tied in this way also varies according to the nature of his livestock.

The camel is able to do without drinking during the cool season if the pasture is green, but has to be watered every four days in summer; the ox, on the other hand, needs water every day; sheep and goats, which can make do with one watering every two days in summer, can scarcely be more than 15 miles from a water point.

Whereas the camel is fond of *had*, and of salty plants in general, it rejects straw, which the ox, on the other hand, finds acceptable. It cannot make its home in areas which are too well watered, like the southern Sahel, where there are swarms of a species of fly transmitting a type of sleeping sickness. Then again, camels, oxen, sheep and goats all need salt; and providing them with a salt-cure means still more treking, especially in the southern Sahara. For all these reasons, camels are essentially Saharan and oxen Sahelian, with sheep and goats proliferating in either zone. All in all, the task of leading herds, looking for strays, watering, milking, and if necessary shearing and providing veterinary treatment, absorb the whole of an encampment's energies and call for a large and hard-working labour force. Although stockbreeding ranks as a worthy occupation, most of these tasks are traditionally performed by 'servants' and Haratin, and the departure of this labour force, like the advent of drought, means the disappearance of the encampment. The herd, in fact, provides the community with its living, its food, shelter (and in former times its clothing), and represents its means of transport, its exchequer and its currency. The milk supply is the main source of food for the women and children, and even for the men after the rains or during some of the long camel treks. El Bekri, in the eleventh century, cites the example of the Beni Lemtouna: 'These people live a nomadic life and travel about the desert... They know nothing about tilling the land or sowing; they do not even know what bread is. Their herds are all their wealth, and

1. Alexander's expedition to the oasis of Ammon included camels.

their food consists of meat and milk.' [12, p. 310.] Actually, the contemporary herdsmen (and this was probably true of those of olden times) are reluctant to slaughter their beasts and therefore eat little meat. Valentim Fernandes (fifteenth century) makes special mention of milk : 'In the provinces of Lodéa and Brebish, which consist entirely of desert, the people eat neither bread—of which they have never even heard—nor fruit, but simply drink camel's milk, which is the food of all who travel. . . . Milk is the healthiest thing in the world, which is why the Moors regard she-camels as sacred.' [28, p. 99.]

The nomad's dwelling, his tent, is usually made of strips of woven goat and camel hair (western Sahara) or black sheep's wool (Mauritania), or of moufflon skins, gazelle skins and oxhide (Tuareg) stretched across poles or arches. Only the Peuls, on the Sudanese border of the Sahel, and the Teda of Tibesti use plant products (palm-leaf mats and fibres). The recent increase in the use of light tents made of strips of cotton material *(bênié)* should also be mentioned.

As far as clothing is concerned, vegetable products nowadays predominate : the descendants of the Azenègues, clad in their oryx skins, have turned, like most of the Saharans, to flowing garments made of blue Guinea cotton.

One of the main uses of livestock, even though reduced since the beginning of this century, is for transport. The encampment organizes its own moves : the camels carry food supplies and tent poles and the asses are laden with *tassoufras*, pots and pans and a gaggle of children, or disappear beneath the opulent curves of outsize women. The men have their saddle-camels and the chiefs their horses. And lastly, nomadism would be completely impossible without the goat-hide water-skins (*guerbas*). Sometimes a Saharan caravan consisting of a few camels will transfer its burden to pack-oxen in the south and thus provide for local trade in millet, salt, dates, tea, sugar and cotton goods. In the southern Sahara, the salt trade from Idjil to Kiffa or Nioro, and from Taoudeni to Timbuktu, barely survives : 'Trans-Saharan trade was destined to run up against the increasing attraction of the seaports, with their inland tentacles of railways and tracks' [24, p. 291]. The end of the *ghazw*, those protracted wars of plunder against rival tribes or fertile oases, has also reduced the use of camels and saddle-horses considerably. In Tagant, a camel was worth twenty milch cows in 1910 but is only worth one today.

The main function of livestock, however, is probably as capital and currency (although very sparingly used, in the latter case). The herd is the supreme form of capital even more than the date palm; the merchant who has netted a profit, or the official or labourer who has accumulated some savings, gets himself a herd. As for the stockbreeder, his aim is to increase his capital, and he is only willing to sell occasional beasts in order to buy millet, dates and cotton goods, or the tea and sugar that make tent life agreeable.

It can therefore be concluded that stockbreeding is still the main form of land use in the Sahara and the Sahel alike; but there are differences, as even this all too brief study indicates, in the way this land use is understood.

*Types of nomadism.* The most convenient approach, in this context, is to recall the now classic distinction made by Professor Capot-Rey between pure and semi-nomads : the former, who are perpetually on the move with their herds, may engage in seasonal migrations along the north-south axis when the regularity of rainfall permits. This is the case with the Arbaa, of the Saharan foothills, who spend the summer in the Tell and the winter (the rainy season) in the Sahara; and, following the same pattern, with the Ouled Biri, in the Mauritanian Sahel, who spend the dry season in the Sahel and the wet season (summer) in the Sahara. The pure Saharan nomads are obliged to undertake irregular migrations on account of the extreme irregularity of the rainfall.

The author makes a distinction, in this latter group, between the nomads of the *ergs* (who engage in nomadism all the time, like the Regueibat Lgouacem, or return to the oasis periodically, like the Chaamba), the valley nomads, like the Tuareg of the Hoggar, and the nomads of the Sahelian and Saharo-Sahelian savannas, of whom the Iullemmeden and the Kunta of the east are typical.

The semi-nomads who come back from time to time to the lands or palm groves they themselves have cultivated are represented by the Doui-Menia, who grow grain and own plantations, and the Teda, who also own plantations [22; 24, p. 250].

This diversity of types is due of course to the variety of natural conditions but also to historical factors making for social differentiation. There are very few nomads who depend solely on their herds for a living; even the Regueibat own a few *maader* alongside Seguiet el-Hamra. Unlike their Asian counterparts, the Saharo-Sahelian herdsmen are more or less attached to agriculture. But whereas the true nomads merely have the land tilled by their servants and their Haratin, camp beside the fields at harvest time in order to pocket their share, or stay in the oasis at *gatna* time in order to feast on fresh dates, the semi-nomads are both stockbreeders and farmers.

There is no doubt that the suppression of the slave trade, followed by the progressive impact of French law on this traditional life, is helping to accelerate the rate of change.

*The evolution of nomadism.* It appears, in fact, that an irreversible process of 'sedentarization' has set in since the time of pacification; true nomads are becoming semi-nomads, while the latter seem to be turning to a sedentary life and entrusting herdsmen with the task of moving their livestock to summer or winter pastures.

This phenomenon, common throughout the Sahara, is particularly observable in Mauritania. A camel-using tribe forced by drought to leave the Sahara settles in central Mauritania, whence it pushes other tribes back towards lower Mauritania; and this southerly migration means abandoning camels and acquiring oxen, with a resultant reduction in the site of the herding area, a new attraction in the form of farmlands, and especially the possibility of the servants escaping from tribal constraints [15]. But it should not be concluded that the stage of sedentarization has finally been reached. The nomadic life can still be lived to the full, as is evidenced by the case of the Regueibat Lgouacem. Only a small tribe a century ago, they have developed into a large confederation thanks to their demographic health and above all to the acquisition of a large body of 'followers' (in 1950, there were 1,354 'followers' tents as against 645 'nobles' tents, representing a total of about 15,000 men). Their demographic strength and their economic resources (40,000 camels of thereabouts) enable them to meet the requirements of full nomadism [27].

But most important of all, history provides many examples of temporary sedentarization and a subsequent return to nomadic life, thus proving that political and social circumstances can upset the postulates of nature. Only two cases need be cited. After Tinigui (Adrar), the Tadjakant were compelled, at the beginning of this century, to abandon Togba in the Hodh, which had been ravaged by the Ulad Naser, and revert to a nomadic life, although their town had been a big and populous trading centre with fine palm groves, and had been the counterpart, on the borders of the Sudan, of Tindouf, the other Djakani town on the southern borders of Morocco.

The Haiballah (a Kunta people, in the Tagant area), who had been settled for two centuries at Kasr el-Barka, did the same thing when their chief town was destroyed on two occasions, in 1890 and 1898, by the Idouwaich and the Ahel Sidi Mahmoud.

The consequences of pacification, too, are complex: on the one hand, security brings with it an increase in pastoral land; and on the other, the effect of French techniques and laws has been to depress the nomads and raise the social status of the settled element.

## MAN AND NATURE

What accounts for this evolution of nomadism seems to be the search for a precarious balance which is constantly being destroyed and re-established. Technical innovations do not appear to have reduced the imbalance to any great extent. It has become more than ever necessary, in fact, to devise and apply a programme of rational development.

### A PRECARIOUS BALANCE

The reasons for the lack of balance are both climatic and social.

The main threat, of course, is the scarcity of water; while the nomad can take steps to cope with a meagre or irregular rainfall he is powerless against drought. A year without rainfall in the Sahara means that an entire tribe will have its herds decimated and will either have to disappear or become sedentary. Even in the Sahelian area, the prolongation of the dry season may cause serious ravages among the livestock, especially the younger beasts. On the other hand, a series of rainy years brings about an increase in the size of the herds such as to produce the risk of overgrazing, especially around water points. In that case, again, the herdsman is powerless to check the beginnings of erosion; and nature will take it upon itself, by means of a new drought, to kill off the livestock and thus 'restore the balance'.

Does this succession of balance and imbalance necessarily imply a tendency towards irreversible desertification? The Saharan climate has remained unchanged since the end of Neolithic times, and the herds of goats and sheep have been traversing the Saharo-steppe expanses for thousands and thousands of years.

Excluding the areas surrounding the *ksoun* and, to some extent, the immediate vicinity of the water points, vegetation is holding out against human aggression: the alternation of series of wet and dry years enables the vegetation cover to reconstitute itself, and the pressure of man and his herds is in any case neither ubiquitous nor permanent.

The rigours of nature underline the inadequacies—still further heightened by social considerations—of the traditional techniques.

The French peace has put an end to the ruinous tribal wars but has not been able to improve relations between nomads and sedentary population to the required degree. Disregarding their own interests, the herdsmen allow their flocks to despoil the *grara* or *maader* millet fields; while the exercise of seigniorial rights and the traditional practice of pillaging, in particular, have had an inhibiting effect on the development of farming. Valentim Fernandes long ago noted that the Azenègues, living near the Alarves, never troubled to build up stocks, for their neighbours would only come and take them [27, p. 123]. René Chudeau [34, p. 411] takes the view that the limited extension of palm groves in the *arrem* is due to the fact that the whole of the date crop is reserved for the Tuareg.

Even now the sedentary population all too often suffers from the system of customary dues (*hormo* in Mauritania, *tioussé* among the Tuareg) and 'gifts'. Finally, the land-tenure system, with its safeguards for continued ownership by the nobles while keeping those who work the land in the position of share-croppers, is also a cause of serious imbalance.

### TECHNOLOGICAL INNOVATIONS

The administration's first task was to develop water resources. In southern Algeria, and especially in Wadi Righ and at Ouargla, the sinking of new artesian wells has given fresh impetus to life in the oases. In the same way, deep wells have attracted large numbers of Peuls to the Ferlo pasturelands which had previously been deserted, and have even induced them to settle there; while on the high Algerian plateaux, in the Awkar of Hodh and in the northern part of Trarza, similar deep wells are extending the areas where nomads can roam.

In the floodwater cultivation areas, technicians have replaced the unstable traditional embankments by concrete dykes equipped with draining outlets and overfalls, Lastly, to offset the exodus of servants, an attempt has been made to introduce machines for the use of the *ksour* folk, and motor pumps are now coming into service throughout the Mauritanian oases.

But it has to be recognized that the set objectives have not been achieved despite the substantial results obtained through the introduction of machine techniques : 'Let us not be too hasty in awarding ourselves good marks for having sunk a well here, or built a dam there; what is the point of these high flow figures when the indigenous peoples are left to carry on with their obsolete watering methods and nothing is done to teach them other techniques which avoid making the soil saline or leaching it?' [24, p. 433.]

New techniques (introduction of new plant species to restore pastureland, possibility of making fodder in silos in the Sahelian zone, or ley rotation in the Saharan zone) can only be brought to bear as part of a general development plan.

### NECESSITY FOR RATIONAL DEVELOPMENT

The fact is, however, that all innovations entail on the one hand climatological, soil and botanical research, and on the other legal and sociological research. They have no hope of success unless they are preceded by tests and experiments in the field. From this point of view, the experiment with protected plots, for example, which IFAN has undertaken at Atar under Unesco's auspices, should prove highly instructive.

In conclusion, a development programme is worth the name only if it is accepted by those for whom it is designed; it can only be implemented provided they co-operate; and traditional society will need to be educated before it is able to see the point of the changes proposed.[1]

1. Pastoral life has long been a serious obstacle to school education. While the establishment and spread of nomad schools seems to be reducing the proportions of that obstacle to a marked degree, much remains to be done as far as school textbooks are concerned. *Mutatis mutandis*, the draft of a teaching manual on the conservation of natural resources, prepared by R. Balleydier for the International Union for the Conservation of Nature and Natural Resources and the Arab States Fundamental Education Centre (Unesco), would be well worth adapting for use in the Saharan regions.

## BIBLIOGRAPHY


1. ALIMEN, H. *Préhistoire de l'Afrique.* Paris, Boubée, 1955.
2. ——. Présence d'Acheuléen dans les alluvions de l'Oued Saoura. Chronologie quaternaire du Sahara nord-occidental. *Bull. Soc. Préhist. franç.*, vol. 52, fasc. 8, 1955. p. 480-492.
3. ——. Chronologie du Paléolithique ancien au Sahara nord-occidental. *C.R. Acad. Sci., Paris*, vol. 242, no. 16, 1956. p. 2023-2025.
4. ——. Chronologie préhistorique du Sahara. *Proceedings Third Pan-African Congress on Prehistory, Livingstone, July 1955.* London, 1957, p. 80-85.
5. ——; CHAVAILLON, J. Industrie acheuléenne de l'Oued Farès dans les Monts d'Ougarta (Sahara occidental). *Bull. Soc. Préhist. franç.*, vol. 53, 1956. p. 202-214.
6. ARAMBOURG, C.; BALOUT, L. L'ancien lac de Tihodaïne et ses gisements préhistoriques. *Actes du Congrès pan-africain de préhistoire, Alger, 1952.* Algiers, 1955. p. 281-292.
7. BALOUT, L. Pluviaux interglaciaires et préhistoire saharienne. *Travaux de l'Institut de recherches sahariennes, Alger*, vol. VIII, 1952. p. 9-21. (Reproduced in : *Préhistoire de l'Afrique du Nord, Essai de Chronologie.* Paris, 1955.
8. BATAILLON, C. *Le Souf, étude de géographie humaine. (Université d'Alger, Institut de recherches sahariennes, Mémoir*, no. 2.)
9. BATE, D. M. A., The vertebrate fauna. In : A. J. Arkell. *Early Khartoum.* London, 1949. p. 16-18.
10. ——. The vertebrate fauna. In : A. J. Arkell *Shaheinab.* London, 1953. p. 11-19.
11. BATOUTAH, IBN. *Voyages d'Ibn Batoutah.* Paris, Imprimerie nationale, 1893. 5 vols. (Arabic text with a French translation by C. Defremery and R. Sanguinetti.)

12. BEKRI, EL. *Description de l'Afrique septentrionale.* Paris, Imprimerie impériale, 1859. (Translated by MacGuckin de Slane.) (Revised editions, Algiers, Jourdan, 1913.)
13. BISSON, J. *Le Gourara. Étude de géographie humaine. (Université d'Alger, Institut de recherches sahariennes, Mémoire* no. 3*).*
14. BONNET-DUPEYRON, F. Cartes de l'élevage en Mauritanie. Déplacement saisonniers des éleveurs en basse et moyenne Mauritanie.
15. BORRICAND, Lt.-Col. La nomadisation en Mauritanie. *Travaux de l'Institut de recherches sahariennes,* vol. V, 1948. p. 81-93.
16. BOU HACQ. Noirs et Blancs aux confins du désert. *Bull. Com. A.O.F.*, 1938. p. 480-488.
17. BRIGGS, Lloyd Cabot. *The living races of the Sahara Desert.* 1958. *(Pap. Peabody Mus., Archeol.-Ethnol., Harvard University,* vol. 28, no. 2).
18. BROSSET, Diego. Les Némadi. Monographie d'une tribu artificielle des confins sud du Sahara occidental. *Afri. franç., Bull. Com. Afr. franç. Rens. Col.*, vol. 42, no. 9, 1932. p. 337-346.
19. BROUIN, G. Notes sur les ongulés du Cercle d'Agadez et leur chasse. *Contribution à l'étude de l'Aïr.* 1950. *(Institut français d'Afrique noire, Mémoire* no. 10.*)*
20. BUTZER, K. W. The recent climatic fluctuation in lower latitudes and the general circulation of the Pleistocene, *Geografiska Annaler, Stockholm,* vol. 39, no. 2-3, 1957. p. 105-113.
21. ——. *Studien zum vor- und frühgeschichtlichen Landschaftswandel der Sahara.* 1958. *(Akad. Wissenschaft. Litteratur, Bonn,* no. 1.*)*
22. CAPOT-REY, R. Le nomadisme pastoral dans le Sahara français. *Travaux de l'Institut de recherches sahariennes,* vol. 1, 1942. p. 63-86.
23. ——. *Problèmes des oasis algériennes.* Alger, 1944.
24. ——. *Le Sahara français.* Paris, Presses universitaires, 1953.
25. ——; MARÇAIS, Ph. La Charrue au Sahara. *Travaux de l'Institut de recherches sahariennes,* vol. 9, 1953. p. 39-69.
26. CARNOT, Y. L'évolution des Camélidés. Apparition du dromadaire au Maroc. *Bull. Soc. Sci. nat., Maroc.*, vol. 33, 1953. p. 207-230.
27. CAUNEILLE, J. Les nomades Regueibat. *Travaux de l'Institut de recherches sahariennes,* vol. 6, 1950. p. 83-100.
28. CENIVAL, P. DE; MONOD, Th. *Description de la Côte d'Afrique de Ceuta au Sénégal par Valentin Fernandes : 1506-1507.* Paris, Larose, 1938.
29. CHAPELLE, J. *Nomades noires du Sahara.* Paris, Plon, 1957.
30. CHAVAILLON, J.; CHAVAILLON, N. Chronologie du quaternaire saharien depuis les derniers dépôts du Paléolithique ancien jusqu'au Néolitique. *C.R. Acad. Sci., Paris,* vol. 244, no. 12, 1957. p. 1663-1666.
31. CHEVALIER, A. Les productions végétales du Sahara et de ses confins nord et sud. Passé, présent, avenir. *Rev. Bot. appl.*, vol. 12, 1932, p. 669-924. (*Publication* no. 133-134.)
32. ——. L'origine des plantes cultivées dans l'Afrique du Nord et le Sahara. Ce que ces pays pourraient apporter au progrès de l'agriculture mondiale. *Travaux botaniques dédiés à René Maire,* Algiers, 1949. p. 51-56.
33. ——. A quelle époque a pris naissance la protoculture au Sahara? *Revue internationale de Botanique appliquée,* no. 321-322, 1949. p. 418-419.
34. CHUDEAU, R. D'In Ziz à In Azaoua. *Géographie,* vol. 15, no. 6, 1907. p. 401-420.
35. COURTOIS, C. Histoire du chameau nord africain. *Les Vandales et l'Afrique.* Paris, 1955.
36. CREAC'H, P. *Aliments et alimentation des indigènes du Moyen Tchad (Afrique Équatoriale Française).* Marseille, Marcel Leconte, 1941.
37. DECHAMBRE, E. Le Sahara, centre primitif de domestication. *C.R. Soc. Biogéogr.*, no. 238, 1950. p. 147-151.
38. ——. Discussion de l'interprétation de figurations animales anciennes. *Terre et la vie,* no. 2, 1951. p. 105-115.
39. DUBIEF, J. *Le climat saharien.* 1953. (Reprint from *Maroc médical,* no. 342, 1953.)
40. ——. Rapport sur l'évolution des régions arides dans le passé et à l'époque actuelle. Paris, Unesco. (Document Unesco/NS/AZ/112. Mimeographed.)
41. ——. Note sur l'évolution du climat saharien au cours des derniers millénaires. *Actes du IV' Congrès international Quaternaire, Rome-Pise, 1953.* Vol. 2, 1956. p. 848-851.
42. *Économie (L') pastorale saharienne. Notes et études documentaires no. 1730.* Paris, Édition de la Présidence du Conseil, La documentation française, 1953. *(Le Sahara des Nomades* no. 58.)
43. ERROUX, J. Notes sur les blés des oasis du Sahara algérien. *Bull. Soc. Hist. nat. Afr. N.*, vol. 49, no. 5-6, 1958. p. 180-195.
44. ESPERANDIEU, G. Domestication et élevage dans le nord de l'Afrique au Néolithique et dans la Protohistoire d'après les figurations rupestres. *Actes du Congrès panafricain de préhistoire, Alger 1952.* Algiers, 1955. p. 551-573.
45. HUZAYYIN, Soliman. Changes in climate, vegetation, and human adjustment in the Saharo-Arabian Belt with special reference to Africa. In: W. L. Thomas. (ed.) *Man's role in changing the face of the earth.* Chicago, University of Chicago Press, 1956. p. 304-323.
46. JOLEAUD, L. Les débuts de la domestication, d'après la chronologie des gravures rupestres. *Actes du 16e Congrès international d'Anthropologie, d'Archéologie et de Préhistoire, Bruxelles, 1935.* Brussels, 1936. p. 924-938.
47. JOLY, F. Les milieux arides, définition, extension. *Notes marocaines,* no. 8, 1957. p. 15-20.
48. KRONENBERG, A. *Die Tedas von Tibesti.* Vol. 12, Wiener Beitrage Kulturgesch. Ling, 1958.
49. LELUBRE, M. Conditions structurales et formes de relief dans le Sahara. *Travaux de l'Institut de recherches sahariennes,* vol. 8, 1952. p. 189-239.
50. LHOTE, H. *La chasse chez les Touaregs.* Paris, 1951.
51. ——. Le cheval et le chameau dans les peintures et les gravures rupestres du Sahara. *Bull. Inst. franç. Afr. noire,* vol. 15, no. 3, 1953. p. 1138-1228.
52. ——. Comparaison avec d'autres sites peints d'Afrique septentrionale. In: M. Breuil. Les roches peintes du Tassili-n-Ajjer. *Actes du Congrès panafricain de préhistoire, Alger, 1952.* Algiers, 1955, p. 125-146.
53. MALAURIE, J. Touareg et Noirs au Hoggar. Aspects de la situation actuelle. *Ann. Géogr.*, July-September 1953. p. 338-346.
54. MAUNY, R. Notes historiques autour des principales plantes cultivées d'Afrique occidentale. *Bull. Inst. franç. Afr. noire,* vol. 15, no. 2, 1953. p. 684-730.
55. ——. Préhistoire et zoologie: la grande 'faune éthiopienne' du Nord-ouest africain du Paléolithique à nos jours. *Bull. Inst. franç. Afr. noire,* série A, vol. 18, no. 1, 1956. p. 246-279.

56. ——. Répartition de la grande 'faune éthiopienne' du Nord-ouest africain du Paléolithique à nos jours. *Proceedings Third Pan-African Congress on Prehistory, Livingstone, July 1955.* London, 1957. p. 102-105.
57. Menchikoff, N. Les grandes lignes de la géologie saharienne. *Rev. Géogr. phys.*, 2e série, vol. 1, fasc. 1, 1957. p. 37-45.
58. Mikesell, Marvin W. Notes on the dispersal of the dromedary. *Sthwest. J. Anthrop.*, vol. 2, no. 3, 1955. p. 231-245; *Bull. Inst. franç. Afr. noire*, série A, vol. 18, no. 3, 1956. p. 895-913.
59. Monod, Th. Parts respectives de l'homme et des phénomènes naturels dans la dégradation du paysage et le déclin des civilisations à travers le monde méditerranéen *lato-sensu* avec les déserts ou semi-déserts adjacents, au cours des derniers millénaires. *Union internationale pour la conservation de la nature et de ses ressources, 7e réunion technique, Athènes, septembre 1958.* (In press.)
60. ——; Mauny R. Découverte des nouveaux instruments en os dans l'Ouest africain. *Proceedings Third Pan-African Congress on Prehistory, Livingstone, July 1955.* London, 1957. p. 242-247.
61. Murray, G. W. Early camels in Egypt. *Bull. Inst. Fouad I du désert*, vol. 2, no. 1, 1952. p. 105-106.
62. Myers, O. H. Note sur l'amélioration des pâturages dans les 'déserts semi-steppiques' et les 'semi-déserts'. Paris, Unesco. (Document Unesco/NS/AZ/137. Mimeographed.)
63. Nicolaisen, J. Some aspects of the problem of nomadic cattle breeding among the Tuareg of the Central Sahara. *Geogr. Tidsskr.*, no. 53, 1954. p. 62-105.
64. Pales, L.; Tassin de Saint-Pereuse, M. *L'alimentation en A.O.F.* Dakar, Orana, 1955.
65. Porteres, R. Géographie alimentaire, berceaux agricoles et migration des plantes cultivées en Afrique intertropicale. *C.R. Soc. Biogéogr.*, no. 239-240, 1951. p. 16-21.
66. ——. Les appellations des céréales en Afrique, II: Les blés et leurs dénominations. *J. Agric. trop. Bot. appl.*, vol. 5, no. 4-5, 1958. p. 311-364.
67. Prost, A. Pierres à moudre en pays songay. *Notes africaines*, no. 63, 1954. p. 80.
68. Quezel, P. Quelques aspects de la dégradation du paysage végétal au Sahara et en Afrique du Nord. *Union internationale pour la conservation de la nature et de ses ressources, 7e réunion technique, Athènes, septembre 1958.* (In press.)
69. Reifenberg, A. The struggle between the 'desert and the sown'. *Desert Research. Proceedings Symposium held in Jerusalem, May 1952.* Jerusalem, Research Council of Israel, 1953. p. 378-389. (*Special publication* no. 2.)
70. Rhotert, H. *Libysche Feldsbilder.* Darmstadt, Wittich, 1952.
71. Robinson, A. E. The camel in Antiquity. *Sudan Notes and Records*, vol. 19, no. 1, 1936. p. 47-69.
72. Schiffers, H. *Die Sahara.* Stuttgart, Franckh'sche Verlagshandlung, 1950.
73. Schnell, R. *Plantes alimentaires et vie agricole de l'Afrique noire. Essai de phytogéographie alimentaire.* Paris, Larose, 1957.
74. Staffe, A. Die Frage in Herkunft der Kamels in Afrika. *Z. Tierz. ZüchtBiol.*, no. 46, 1940, p. 135-141.
75. Täckholm, V.; Täckholm, G.; Drar, M. *Flora of Egypt, I.* Cairo, Fouad I University, 1941.
76. Walz, R. Zum Problem der Domestikation des altweltlichen Cameliden. *Z. dtsch. morgenländ. Ges.*, no. 101 (N.F. 26), 1951. p. 29-51.
77. ——. Neue Untersuchungen zum Domestikationsproblem der altweltlichen Cameliden. *Z. dtsch, morgenländ. Ges.*, no. 194 (N.F. 29), 1954. p. 45-87.
78. ——. Beiträge zur altesten Geschichte der altweltlichen Cameliden unter besonderer Berücksichtigung des Problems des Domestikations Zeitpunktes. *Actes IVe Congrès international des sciences anthropol. ethnol., Vienne 1952.* Vol. 3, Vienna, 1956. p. 190-204.
79. Wissmann, H. von. Ursprungsherde und Ausbreitungswege von Pflanzen- und Tierzucht und ihre Abhängigkeit von der Klimageschichte. *Erdkunde*, vol. 11, part 2, 1957. p. 81-94; part 3, p. 175-193.
80. ——; Kussmaul, F. Histoire des origines du nomadisme et ses aspects géographiques. *Encycl. Islam.* Vol. 2, 1958. p. 899-906.
81. Zohner, Ludwig G. A. La population du Sahara antérieure à l'apparition du chameau, *Bull. Soc. neuchâtel. Géogr.*, vol. 51, fasc. 4, 1952-1953. p. 3-133.

# LAND USE IN PRE-COLUMBIAN AMERICA

*by*

Pedro Armillas

*Museum of Anthropology, University of Michigan, Ann Arbor, USA*

> . . . '*natural resources' are in fact cultural appraisals.* Sauer

## EARLY STAGES

Human occupation of the Western Hemisphere is comparatively recent, but much older than was accepted a few decades ago. The spread of man over North America during the last (Wisconsin) glaciation is well attested, and the terminal Pleistocene age for remains found in southern South America is, likewise, beyond question. The gradient of the known carbon-14 dates and other considerations support the generally held view of an early drift migration from north to south, through the Central American funnel and along the Andes, fanning out into the Argentinian grasslands and Brazilian parklands, although well substantiated findings of corresponding antiquity have not been made in the intervening area so far, no doubt through want of systematic search. It is generally assumed that the early Americans avoided the jungle regions, which would have been penetrated by man only with the development of adaptative technologies.

The presence of man in America during the last glacial epoch, and in terms of absolute chronology since 12,000 years ago, is proven geologically and palaeontologically on the basis of numerous findings and dated by sufficient carbon-14 tests. On the basis of unquestionable archaeological evidence, some North American hunting cultures are certainly earlier than that date and an antiquity even greater is not improbable for some of the oldest known South American hunters, whose traces have been found in recent years in the Argentinian grasslands.

Furthermore, a few carbon-14 tests would make the minimal antiquity of man in this continent considerably older: possibly 37,000 years ago [91, p. 58][1] for fires burnt in basin-shaped hearths near Lewisville, Texas, with bones of the American camel and horse, mammoth, and bison of an extinct species, and tools; a similar assemblage of camp remains, albeit with different artifacts, yielded an antiquity 'older than 23,800' for a site, Tule Springs, near Las Vegas, Nevada. Whilst there are good reasons to view such very old datings with caution until corroborated by additional evidence, a minimum date of 25,000 years before current times for the first entry of man to the New World seems quite likely on various considerations.

The presence of man in the extreme southern part of the continent for at least 9,000 years is dated by the carbon-14 test for the surface of the layer containing the oldest remains of occupation in the Palli Aike cave, in the region of the Strait of Magellan. These remains, and others found in the same area, reveal a culture of hunters of the American horse, ground sloth, and guanaco. On the basis of typological correlations and geological dating estimates, the antiquity of the earliest traces—lithic industries—of man southward in Patagonia seems to be even greater.

There is no doubt that the first people to move into the New World through the Bering gateway were in the predatory-foraging stage of economy—as were, by the way, their followers of later times—and we may add, on the basis of what is known of the prehistory of north-eastern Asia, that they possessed the knowledge of generalized Old World Palaeolithic technologies for the exploitation of land resources, rather than specialized equipment [20] (but see also Tolstoy [79]). The diverse palaeo-Indian cultural traditions whose profiles were becoming quite distinct—certainly so in North America, and probably so in South America as well—even before 10,000 B.C., appear to represent indigenous developments out of that ancestral generalized background.

In North America, an antiquity of well over 11,000 years (later in the east) is indicated for the origins of the big-game hunting tradition, which extended mainly east of the Rocky Mountains, to the Atlantic seaboard and from Canada to central Mexico, at least. Also, in the south-west of the present United

1. The figures in brackets refer to the bibliography at the end of the chapter.

States and in the intermontane area, a few findings seem to indicate that big-game hunting might have been important there before the desiccation of the area. In the plains and the south-west, proboscidians, camel, and horse, were at first normal prey; later, they might have become scarce, for the economy of the Folsom hunters (at about 8000 B.C.) seems to have depended mostly on the pursuit of *Bison antiquus*. In the Atlantic region, mammoth and the other species mentioned were apparently rare, instead elk, deer, and bear were hunted. In central Mexico, the early hunters chased *Archidiskodon imperator*, roaming in large numbers by the shores of the lakes in about 9000 B.C. In the rest of North America the Columbian mammoth (*Parelephas columbi*) was more common.

A different tradition, which includes a large variety of cultures, is noticeable before 8000 B.C. in the Plateau-Great Basin area, and becomes more defined from 6000 B.C. onward. Its distribution reaches from the eastern foothills of the Rockies to the Pacific coast and from Oregon to Mexico. The common characterization of this pattern is very generalized, and best seen in contrast to the concentration on big-game hunting formerly described. This occidental tradition was based on diversified food-gathering, adaptable to the maximal utilization of available resources, plant as well as animal. Ecological adaptations to a great diversity of environments produced a variety of economies, including adjustments to arid country,[1] and to riverine, lacustrine, and littoral habitats.

The oriental Archaic tradition, similar in its approach to the natural resources, tending to broad diversification dependent upon local conditions, was also developing east of the plains, towards the Atlantic shores, during the 8000-6000 B.C. period, succeeding there the early hunting pattern.

During the period of Altithermal climate, the Great Plains became a zone of extreme aridity, indicated by the formation of loess deposits in Nebraska between 5500 and 2000 B.C. Much of the area might have been deserted and other parts very sparsely populated, for archaeological evidence of occupation is lacking or rather obscure. With the subsequent improvement of ecological conditions, when the modern type of climate became prevalent, camp remains indicate a re-orientation of the economy towards greater exploitation of plant resources and small game—reflecting, probably, a comparative scarcity of bison—although big-game hunting was always an important part of the subsistence basis, and a dominant one in some localities or at some periods [81, p. 85].

In central Mexico, the food-gathering culture upon which plant-domestication could have developed, is believed to be represented by the still ill-defined Chalco industry. A carbon-14 date places this complex of lithic tools at about 4500 B.C.; its beginnings, however, must be considerably older. In fact, at that comparatively late date indirect evidence—that will be reviewed in the next section—suggests that experiments in cultivation and the production of cultigens had already begun in highland Mexico and Guatemala. If so, the Chalco culture economy must have combined incipient farming and food-gathering.

In South America, the parallel cultural developments of early post-Pleistocene times are still little known. Nevertheless, a mixed hunting-food-gathering pattern seems to be represented by the Ayampitín culture. Its vestiges were first found in the sierras of Córdoba and San Luis, in north central Argentina; lately, it has been reported from the north-west of that country and around San Pedro de Atacama, in northern Chile. A putative date around 6000 B.C. is currently attributed to that culture.

Man has had a long time to adapt himself culturally to varied and changing environments, and to modify by his actions the American landscapes. However, although the activities of pre-agricultural human groups, living by hunting and food-gathering, may affect natural resources,[2] the adaptation of primitive populations to life on arid and semi-arid lands, which is our concern here, seems to be rather narrowly ecologically conditioned, specially in the case of pre-Columbian America, where the pastoral way of life never developed as such, for the distribution of tamed grazing animals was limited to the Andean area and was there subordinated to intensive agriculture.

It was with the growth of cultivation and the improvement of agricultural techniques that the American Indians became capable of mastering many of the arid and semi-arid zones of the continent, and in two independent cases to build, upon the foundations of intensive agriculture, civilizations comparable to those of the pre-Classic Old World : Mesopotamia, Egypt, the Indus, and north China.

## DEVELOPMENT OF CULTIVATION

The appearance of cultivation and particularly its logical, but not immediate, consequence, the achievement of established agriculture, signalled a profound change in the relationship of man to land. The conver-

1. Increasingly arid conditions, resulting in the desiccation of lakes, and stream and wind erosion, etc., became prevalent in the Great Basin, the south-west, and southern California about 5000 B.C. (Xerothermic or Altithermal phase, lasting in force to about 2000 B.C., when climate became somewhat cooler and moister, comparable to the present time); hence the generic name of 'Desert Culture', which is nowadays preferred for the tradition. However, since the extension of the pattern trespasses the limits of the arid zone, some less committing designation might be advisable. On the definition and extension of the 'Desert Culture' see [38, p. 69-72; 41, p. 276-280; 61]. For the latter-day survival of the desert food-gathering economy of the Great Basin, see Steward's [76] classic ecological study.
2. Namely, man's possible contribution to the extinction of large, roving, slow-breeding animals. Also, I think of the often debated question of the effects of fire on the extension of grass-lands; for some recent statements pro and con and supporting bibliographies on this subject, see [71, p. 12-18; 72, p. 54-56; 77, *passim*, specially p. 129; 82].

sion of man from a parasite on nature to an active partner with it, as the late Gordon Childe so well expressed,[1] affected all aspects of human life; it was a cultural revolution by which mankind was able to progress beyond the ecological limitations set by nature to the foraging primitive man, establishing the foundations for the eventual development of civilization. What is known at present on American prehistory, and the fact that the basic food plants of native agriculture were, beyond reasonable doubt, developed in this continent out of indigenous wild plants, plus the proven antiquity of some of them (I am thinking specifically of the most recent data on the origin of maize, see below), makes it highly probable that the American Indian agricultural tradition was the result of an independent development, analogous in its basis, effects, and consequences, to the Neolithic revolution of the Old World.

The question of the origins of agriculture requires a multiple attack : geographic, botanic, and archaeologic. The ethnological approach must be taken into consideration too, but it has proved repeatedly misleading and therefore should be used only with the greatest caution.

On geographical and botanical bases, two main zones of probable origin of the most significant New World cultigens are generally recognized, the Middle American region (mainly Mexico-Guatemala) to the north, and the Andean to the south [71, chapters III and IV; 25, p. 115]. The first is believed to be the focus of the seed culture, the second that of vegetative culture. Only a few American cultigens seem to have originated outside of these areas.

Archaeological evidence on the beginnings of native cultivation is still very scanty; the interest of the archaeologists on this subject has been aroused only recently. Difficulties for such studies are many, variable chances of preservation of plant remains and the hazards of localization of incipient farmers' dwelling places complicate the problem. However, it is to the credit of a few of my colleagues that notwithstanding these difficulties some significant, although as yet very fragmentary, data have been obtained through painstaking spade work.

Several campaigns conducted by MacNeish in the State of Tamaulipas, north-eastern Mexico, since 1945 have resulted in the discovery of a long sequence of human occupation in that region. The oldest vestiges found correspond to the stage of early American hunters of Late Pleistocene times; the earliest tool assemblage uncovered to date is still ill-defined, but the youngest one is well characterized and associated with indications of a climatic phase very wet and perhaps cooler than at present, correlated with the final phases—Valders advance and Cochrane—of the last North American glaciation [52, p. 152], and dated, by a single carbon-14 test, in the eighth millennium B.C. (M-499 : 9270 ± 500 B.P.) [24, p. 1103] which agrees with the geological and faunal evidence.

From the trash (including human coprolites, the detailed examination of which is still yielding remarkable information) found in many once inhabited caves explored by MacNeish and his associates in south central and south-western Tamaulipas, vegetal remains (both wild and cultivated plants) were recovered that throw revealing sidelights on the questions of origins of agriculture in the Western Hemisphere —especially as that region is generally accepted by the botanists as marginal with respect to the reputed centres of origin of the main American cultigens.

The earliest evidence of cultivated plants was found in the 1954-1955 field season at the Infiernillo Canyon, in the rugged country of the abutments of the Eastern Sierra Madre, in the south-western section of the state. The oldest known occupants of that tract ('Infiernillo Phase') were nomadic food-gatherers who depended also for their food on hunting; in addition, cultivated *Lagenaria*, *Cucurbita pepo*, peppers and some sort of runner bean, perhaps, wild, were found in the lowest strata of refuse. Two carbon-14 dates place these remains in the seventh millennium (M-498 and M-500, [24]).

In the following Ocampo Phase the importance of hunting as a supplement to vegetal food diminished. The diet depended mostly on wild plants, but to the cultivated species listed above common beans were added. Direct carbon-14 dates for Ocampo material range from 3700 to 2600 B.C., and cross-dating with the Sierra de Tamaulipas sequence of artifacts (see below) support the placing of this phase in the third and fourth millennia.

*Panicum*, *Amaranthus*, and a primitive type of maize related to that of Bat Cave (see below) increased the number of cultivated plants before 2000 B.C. (Flacco Phase, one carbon-14 date 3947 ± 334 B.P.), but these people were still primarily gatherers of wild plants, with very little hunting and snaring as supplementary economic activities. However, during the succeeding Guerra Phase[2] cotton and perhaps *C. moschata* were introduced,[3] and very soon, at about the middle of the second millennium, agriculture with a number of varieties of maize, teocentli (= teosinte, *Euchlaena mexicana*, probably as a weed, cf. Dressler [25, p. 150]), common, lima and runner beans, *C. pepo* and *C. moschata*, gourds, and cotton, became established as the basis of the local economy with the ensuing Mesa del Guaje Phase, at the same time that pottery appears for the first time in that archaeological sequence.

1. In his classic *What Happened in History* (chapter III: 'Neolithic barbarism').
2. Oddly dated by a single radiocarbon test over 2750 B.C., to be adjusted perhaps to about 1900-1600 B.C. (cf. Crane and Griffin [24, p. 1104] dating of samples M-504 with M-567, and comments on M-505; also MacNeish [52, p. 199].).
3. While, perhaps significantly, neither *Panicum* nor *Amaranthus* are mentioned in the published summary [52, p. 168]; improved maize may have replaced them [see 71, p. 72].

In the Sierra de Tamaulipas, a detached mountain range rising above the Gulf of Mexico coastal plain in the south central section of the State, the Nogales culture, still based upon a foraging economy, succeeded —with an apparent time gap which would correspond to the Infiernillo Canyon earliest phase—the Lerma primarily hunting culture mentioned above; however, it was wild plant life which constituted most of the Nogales people's food-supply, hunting being only a supplementary economic activity. It seems that there is no concrete evidence for cultivation during this phase, albeit—because of the continuity of cultural development with the following one and by parallelism with early Ocampo—MacNeish thinks that cultivated plants may have contributed a very small proportion of the people's diet in the last part of the period.

The ensuing La Perra Phase, seemingly cross-dating with late Ocampo of the Sierra Madre sequence, certainly represents a stage of incipient farming, with maize and *C. pepo* constituting maybe from 5 to 10 per cent of the food consumption, the remainder being supplied by wild plants (about 80 per cent) and the products of hunting and insect catching. The corn remains found belong to two now extinct varieties, classed by Dr. Mangelsdorf of the Botanical Museum of Harvard University as Primitive Nal-tel A and B types; these are pod-pop corn, with two-inch long eight-row cobs having each kernel of every row surrounded by pod-like leaves, and seem to be ancestral to lowland adapted Middle American maize of later times. A radiocarbon test dates La Perra Phase at about 2500 B.C.

The Almagre late sub-division of the La Perra Phase, may have lasted well into the second millennium. A blank follows in our knowledge of this sequence after which, the Laguna Phase, dated by correlation with the Huastec area to the south at about the middle of the first millennium B.C. [52, p. 172 and p. 198], represents a tradition of fully established agriculture, evidently introduced to this region from the south. Not only in the Sierra proper but also on the level land south and west of these mountains, villages of 200-400 circular huts and with ceremonial mounds arranged around plazas, reveal the new social pattern—which is known to be much older in central and southern Mexico and in Guatemala. Three new races of maize, *C. ficifolia*, and *Manihot dulcis*, appear for the first time in that area. The races of maize are 'modern' types showing evidence of *Euchlaena* introgression; they must have been developed outside the area and introduced to the Sierra with other innovations such as pottery.[1] *M. dulcis*, a cultigen of generally undoubted South American origin, appears here for the first recorded time reaching the northern limit of its pre-Columbian distribution (cf. [70, p. 508; 71, p. 62]).

In spite of the fact that there are still some blanks, uncertainties, and incongruities to be smoothed out in these sequences, together they constitute the most detailed case history to provide a firm foundation upon which to build the study of the origins of native American agriculture.

Evidence from caves in west central New Mexico indicates that the period from perhaps the fourth millennium to a few centuries before the beginning of the Christian era was one of slow shift from the food-gathering economy of the Cochise 'desert' culture to a sedentary way of life based on cultivation. Primitive maize and *C. pepo* were added to the subsistence basis by at least 2000 B.C.,[2] as an innovation derived seemingly from Mexico, and around 1000 B.C. 'modern' races of maize—hybridized with *Tripsacum* or *Euchlaena*—and the common bean appear. Established agriculture, however, did not replace the ancient food-gathering pattern until about 300 B.C., coinciding with the appearance of pottery [38, p. 74-78].

It is generally accepted that the introduction of cultivation in Tamaulipas and New Mexico indicates an even greater antiquity of its practice in the highlands of central and southern Mexico and Guatemala. The botanists agree that the last mentioned regions are the hearth where many of the most important American cultigens were developed. Of the plants mentioned in the previous paragraphs, the origins of *Phaseolus vulgaris*, *P. lunatus*, and *P. coccineus* (or *multiflorus*), and *C. moschata*, seem to be certainly traced to that area. Two species of *Amaranthus*, *A. leucocarpus* and *A. cruentus*, are tentatively assigned to central Mexico and the Guatemalan highlands respectively [25, p. 153]. The case for *C. pepo* is dubious; it is dominant in the cool highlands of Mexico, where it is a staple food, but it is more diversified in the eastern United States [71, p. 67]. Considering its very early occurrence in Tamaulipas, it seems that the possibility of an origin to the north has to be discarded, since, on the basis of our present knowledge, cultivation began much later there; the archaeological evidence, then, adds weight to Dressler's statement [25, p. 131] that the endemic forms found in Mexico and Central America should be considered with regard to the origin of this cultigen.

The case for *Zea mays* is now seen in a new light. The discovery of pollen, apparently of maize, at great depths in the subsoil of Mexico City, would indicate that a wild ancestor of the cultivated species grew in the highlands of Mexico (and probably Guatemala

1. The preceding summary is based on MacNeish [49, 50, 51, 52].
2. Incipient cultivation of these plants is represented by remains found at the Bat and Tularosa caves.

   At Bat Cave, the succession of corn samples starts with the tiny ears of a very primitive pod-pop type of maize. Mangelsdorf [53, p. 409] says 'although this earliest Bat Cave maize may have been cultivated, it was not far removed in its botanical characteristics from wild maize'. The hybrid corn mentioned in the text appeared in upper levels of the excavation. There is a series of carbon-14 dates 'presumably correlated with the development of maize culture' [47, p. 111], beginning c.4000 B.C. However, the validity of the oldest dates is not yet generally accepted. The specialists in the area do not commit themselves more than to mention the minimum age of 2000 B.C., or leave it vaguely between 4000 and 2000 B.C.

too) at the time when man might have begun experiments in cultivation [25, p. 150-152; 4]. This, and the late advent of the cultigen to the Peruvian coast (see below), which leads us to discard the hypothesis of a South American origin, make highly probable its domestication within the Middle American nucleus.

The mixed food-gathering/incipient-farming economies have not yet been identified with certainty in the hearth of seed culture (but see my remark above, on the Chalco food-gathering pattern). Dated remains from central Mexico to Guatemala indicate a minimum antiquity for sedentary farming communities between 1500 and 2000 B.C.; circumstantial evidence points to the third millennium for the beginnings of established agriculture, as distinct from incipient cultivation.

Along the arid Peruvian coast a good number of middens, some of them attesting by the accumulation of refuse to a prolonged period of abode, reveal an occupation by a people with a mixed economy based on fishing, gathering (shell-fish and wild plants) and an incipient cultivation (probably in moist areas at the valley mouths, [see 22, p. 19]; marine mammals formed an appreciable complement of the subsistence basis, but there is no evidence of hunting land animals in the northern sites [11, p. 24; 78, p. 41] and only a little elsewhere [26, p. 134]. In area, their presently known range extends from the neighbourhood of Pacasmayo (latitude S. 7°20′) to past the Ocoña River (latitude S. 16°30′) [8, p. 118; 26, p. 73-85]; in time, from about 2500 B.C. (based on carbon-14 dating) to the latter centuries of the second millennium when, after the introduction of maize,[1] archaeological evidence from the only well-studied oasis, the Virú Valley,[2] indicates a revolutionary change in food production, a shift of population away from the old fishing stations into sections of the lower valley more favourable for established agriculture (probably based on river floodplain farming) and an increase in numbers—a trend gaining momentum in the early centuries of the first millennium B.C. [86, *passim*, especially p. 390].

The record of cultivated and possibly cultivated or semi-cultivated plants during this period at Huaca Prieta, on the Chicama Valley shore line, includes : cotton, gourd, squash,[3] chile pepper, jackbean *(Canavalia ensiformis)*, two varieties of pacae or guaba (*Inga* sp.), achira *(Canna edulis)*. Truly wild eaten tubers, roots, and fruits were : 'papas de junco' *(Scirpus riparius* or *americanus)* cat-tail, a sedge (*Cyperus* sp.), lúcuma *(Lucuma obovata)*, 'ciruela de fraile' (*Bunchosia* sp.), and guayaba *(Psidium guajaba)*. A few of the plants found are not identified for certain but maize remains were conspicuously absent from this assemblage [11, p. 24].

While the techniques of cultivation—that allowed the pre-ceramic pattern of mixed subsistence economy to develop—must have come from the north [cf. 71, p. 44], from north-western South America and beyond, Engel makes an interesting suggestion to place the ancestral home of these coastal people on the 'lomas' ecological zone, between Chala and Arica [26, p. 142].

A striking conclusion stands out of the available factual information on the remote prehistory of native American agriculture, that the period of experimentation might have been a long one, with mixed food-gathering/incipient-farming subsistence economies persisting long after plant domestication began. A truly sedentary way of life based on farming, was only achieved when the development and diffusion of high-yield varieties of maize induced man to devote himself full-time to the pursuit of cultivation [12, p. 21].

## THE GREAT PLAINS

In the north-western Great Plains of North America, the hunting-gathering pattern mentioned in the introduction persisted, without important modifications of the ecological balance, until it was altered by the introduction of the Old World horse and the development of the highly mobile methods for equestrian hunting and warring (eighteenth century).

In the central plains and on the middle Missouri River basin, horticulture (the maize-beans-squash complex) was added to the hunting-gathering basis since about A.D. 500, as an intromission of the eastern 'woodland' agricultural pattern into the western fringes of the prairie zone. A shift of the agricultural frontier eastwards to the ninety-ninth meridian, evidenced by archaeology for late prehistoric times, might as well be due to climatic fluctuations as to other undetermined factors [81, p. 89] (see also [80]). However, it was the spreading of the mounted nomadic bison-hunting pattern, militarily oriented, that most profoundly affected land use in this region. The horticultural village communities dwindled in number,

1. The beginnings of maize cultivation on the north coast date from no later than 1200 B.C., on the basis of its association with Chavín horizon style ceramics [87, p. 355]; plain pottery appears first in the archaeological sequence in the former half of the second millennium, but corn is also to be found in deposits of this age. On the central coast maize might slightly antecede the appearance of ceramics (at Aspero, near Supe [see 88, p. 151; 26, p. 78]) or appear together with undecorated pottery (at Chira-Villa, near Lima [see 26, p. 80]); although neither its inception nor that of plain earthenware have been precisely dated there, sequential evidence makes the earliest maize anterior to the spread of the Chavín style. What is significant, however, is not just the introduction of the new plant but the conversion of the economy to established agriculture, allowed by its high yield; this momentous change definitely corresponds with the horizon of the Chavín ceramics (1200 to 700 B.C. according to carbon-14 dates).

   To judge from Engel's list of cultivated plants in 'pre-ceramic' times [26, p. 145] it seems that the common bean *(Phaseolus vulgaris)* may have been introduced at the same time as maize, although Collier [22, p. 23] places it later in the sequence.
2. Although our present knowledge is very sketchy, for want of exhaustive methodical studies such as those made in Virú Valley, it is manifest that similar changes took place at the same time elsewhere along the Peruvian coast.
3. For the pre-ceramic period Engel [26, p. 145] lists : *Cucurbita ficifolia* and *C. moschata; C. maxima* appearing with the oldest pottery and maize, *C. pepo* tardily (see also Sauer [70, p. 504]; Dressler [25, p. 130]).

   Remains of *C. ficifolia* have been uncovered in good quantity at Huaca Prieta, to judge from a remark by Sauer [71, p. 66], quoting Whitaker and Bird in *Amer. Museum Novitates*, No. 1426, a paper not available to me at the time of writing.

and the settlements were fortified. In the late eighteenth century, tribe after tribe were joining in the mounted carrousel.

After the horse, firearms (and indiscriminate buffalo hunting, ending with the almost complete extinction of the species), open range cattle-raising, barbed wire and the plough, the prairie schooner and the iron horse—with the white man behind all that—in rapid succession changed the face of this landscape in the course of the nineteenth century, as described by Professor Logan in a later chapter.

## THE COLORADO PLATEAU

The Anasazi (Basketmakers and prehistoric Pueblo) Indians lived in the Colorado Plateau physiographic province, and extended east into the Rio Grande Valley, as their contemporary descendants (the Hopi, Zuñi, and Rio Grande Indians) still do.

The climate of that area ranges from arid (with less than 250 mm. of mean annual precipitation and mean annual temperatures above 11° C.) below 1,800 m., to semi-arid between 1,800 m. and 2,200 m. (precipitation between 250 mm. and 450 mm., temperatures averaging between 11° C. and 7° C), and humid and cool at higher elevations. The vegetation changes with the altitude, from desert scrub in the lower climatic zone, to sage-brush, grass, and juniper and pinyon trees in the intermediate elevations, and to pine and Douglas fir, or spruce in the highest mountains.

Below about 2,100 m. rainfall is generally too scanty to mature crops, and in the moist zone at high altitudes the growing season is too short;[1] crops are grown most successfully in climates between the extremes [14, p. 445; 31, p. 8].

The climate does not seem to have changed materially during the period which concerns us here (see Brew [13, p. 5], for archaeological evidence), although occasional spells of prolonged drought, recorded by the tree-rings, have worsened temporarily the normally precarious situation throughout the semi-arid country.

In one period however the devastating effects of recurrent droughts seem to have produced lasting results. The succession of consecutive dry years which occurred over the plateau area from A.D. 1276 to 1299—and has been recorded, too, in the Rio Grande Valley, with dates 1269-1296—appears to have been merely the climax of a long period of defective precipitation. This abnormally prolonged dry period has been correlated with an epicycle of erosion, attested in diverse localities within the Anasazi country. Stream cutting would have been particularly destructive to the narrow flood plains of the San Juan drainage, thus destroying the ground basis of Anasazi agriculture and forcing the desertion of the settlements in that area [15]. Whatever the causes may be, the abandonment of the hearth of the Pueblo territory at the end of the thirteenth century is an archaeologically proven fact. Henceforth, the Pueblo Indians concentrated south and south-eastwards, in zones where different physiographic features made the farmland less destructible by gullying.

The erosion hypothesis has been contested by O'Bryan [60], who prefers to explain the desertion of the San Juan area as resulting from the harassment exerted by marauding Athapaskan invaders; however, there is little archaeological evidence of widespread violence by nomadic bands against the sedentary people.

The compounded effect of prolonged drought and loss of farmland through erosion, as the primary causes, raiding by the nomads (Ute or Navajo) on the outlying settlements, pillaging of crops, and so forth, as a force contributing to aggravate the unrest, and intervillage rivalry, intravillage feuding, and perhaps malnutrition and disease, as secondary or derivative factors, is the explanation favoured by Brew [13, p. 298] and Kelley [39, p. 384], and the one that the present writer, being an outsider, finds intellectually more satisfactory.

The hearth of the Anasazi tradition lies in the San Juan River drainage, in north-eastern Arizona, south-eastern Utah, south-western Colorado, and north-western New Mexico. There is no evidence of agriculture in that area until the beginnings of the Christian era (Basketmaker II phase), at first with maize and *Cucurbita moschata*, to which *Phaseolus vulgaris* were added in Basketmaker III times (*c.* A.D. 400-700), while *P. lunatus* and *P. acutifolius* var. *latifolius* seem to have entered still later [16, p. 66 and p. 72]; on archaeological evidence for beans in some sites of the San Juan area see Appendix C, by Volney H. Jones, in [13]. Although cotton was traded into the Anasazi country already in Pueblo I times (700-900), cotton growing seems to have begun in the north central Arizona section of the territory by about 1000, and spread from there to other parts in late Pueblo II and III phases [16, p. 80; 38, p. 76]. *Cucurbita pepo* was introduced to that area at about the same date, and also spread from there over the Pueblo country [16, p. 20].

With regard to farming systems, we shall turn to ethnographical information supplemented, when possible, by archaeological evidence, to see them in historical perspective.

In the zones of higher rainfall ordinary rain farming is practised, although contingent to the killing frosts, owing to the short growing season. Hack [31, p. 34] mentions dry farms in the zone of yellow-pine of the Defiance Plateau of north-eastern Arizona,

1. In present day Hopi country, the average length of the growing season is about 130 days, the bulk of the Hopi crops need over 120 days for maturation [31, p. 20; 16, p. 101].

where the mean annual precipitation is over 420 mm. On the mesa tops north of the San Juan River, in south-eastern Utah and south-western Colorado, planting depends mostly on the residual moisture left in the ground from the fall rains and the winter snows, since the spring rains are very slight and June is the dryest month of the year; the crops are brought to maturity by the July and August thundershowers [13, p. 11]. Brew considers probable that cultivation on the mesas might have been in the past dry farming, as it is today (but see Logan, page 277).

A remarkably specialized form of rain farming, taking advantage of local conditions prevalent in the Hopi country, is planting in sand dunes [36, p. 434; 23, p. 588; 31, p. 32]. This method utilizes the moisture stored in the dunes; the superficial sand acts as a dry mulch which facilitates the absorption of rain-water and prevents its evaporation. A shallow cover of sand (15-16 cm. deep) resting upon less pervious subsoil seems preferred for dune fields; however, planting in thick dunes—perhaps more than 3 m.—is also practised, the growth of the young plants during the dry spring probably depending on a sub-superficial moisture horizon. Maize and beans are grown in these fields, the latter being the most important as a sand-dune crop; an adapted variety of drought-resistant maize is planted widely spaced (about 1.80 m. apart) at a depth of 15-45 cm., allowing the seed to germinate in moist soil during the dry spring, protected from the late frosts [36, p. 437; 23, p. 588; 31, p. 19].

In some places seepage contributes to supply moisture. Sand-dune fields situated against the escarpments of the mesas utilize the water seeping from the porous sandstone cap rocks [31, p. 34; p. 32, fields watered by underground seepage]. Seeps in dune hollows are also utilized to farm on a small scale.

In order to protect the young plants from being damaged by blowing sand or swept away by the violent winds, large stones—or tin cans, nowadays—are placed close to each one of them, this being done in the less exposed fields. In places open to the prevailing winds, bush windbreaks, placed in parallel lines and held by rows of heavy stones, are built at 2-5 m. intervals. However, this protection for the plants does not suffice to anchor the dunes, and the fields have to move with the shifting sands. The moving field caused the failure of attempts to assign allotments of land individually to the Indians, the native land division being by clans.

Ancient sand dune fields are identified by the stone lines left after the windbreaks are gone. One of them, in the Jeddito Valley, seems to date from the thirteenth century (Pueblo III phase) [31, p. xx and p. 70]. Archaeological evidence for still greater antiquity of the practice derives from the eruption of Sunset Crater, on the eastern slopes of the San Francisco Peaks, in north central Arizona. The eruption of this volcano is certainly earlier, but not much older, than A.D. 875 [23, p. 584]; it covered a large area between the peaks and the small Colorado River with a mantle of basaltic cinder. The black ashes overlay Basketmaker III and Pueblo I sites, or very early Pueblo II. Colton plausibly relates to the practice of sand-dune agriculture the attested great increase of settlements in Pueblo II and Pueblo III times. Towards the year 1000, population seems to have been flowing into the area of the black dunes, by 1200 most of the people had departed, and after 1300 the country was deserted. The cinder blanket covering the region would, at first, have made an ideal place for the pursuit of sand-dune agriculture, but gradually the prevailing westerly winds may have removed the fine sand cover, piling it into dunes too deep for successful planting, and drifting sand into canyons where much of it was washed away; thus, in the short term of two or three centuries the country may have lost its attraction for sand-dune farmers. There too, lines of stones indicate the practice of setting up windbreaks [23, p. 589], older, apparently, that those of Jeddito Valley.

The dominant type of agriculture among the present day Hopi Indians is floodwater farming, and it is probable that it was the same in the past for the whole of the Anasazi country. The modern practice has been described by Gregory [30], Bryan [14, 15], Hoover [36] Forde [29], and Hack [31]. As defined by Bryan [14, p. 444], the term floodwater farming applies to the utilization of areas naturally flooded by run-off derived from higher ground, without maintaining a regular system of diversion or conveyance of water. Thus, the moisture supplied by the strictly local rainfall is reinforced by the overflow. Since the areas selected for planting are those likely to be flooded, special conditions are required. Thus, the washing out of the crop by the flooding water or a heavy deposition of silt that might bury the plants are to be avoided. The location of the fields relative to the physiographic features, which determine the characteristics of the flooding, serve as a basis for the classification of the different variants of this system [31, p. 26].

The preferred situation over the Hopi country is at the places where the stream gradient flattens at the foot of the slopes and the run-off of the high ground gathered in torrents spreads a sheet of water over the shallow fan built by the deposition of the load of debris discharged through their channels. Such localities have always been used for fields by the Zuñi Pueblo Indians [14, p. 449]. These places are called *ak-chin* (arroyo mouth) by the Papago Indians of southern Arizona, and this descriptive term has been used as a technical word since Bryan's days. The distribution of the water over the field is partially controlled by the farmer, by building earthen spreaders, by digging furrows to areas that are in danger of being left dry or even by diverting water to individual plants. In several instances, according to Hack, the ratio between the areas of cultivated *ak-chin* fields and those of the arroyo watersheds which supply them with water varied from 3 : 100 to 6 : 100; the variation between these limits is explained by the differences in the amount of run-off from one drainage basin to another, depending on the nature of the ground [31, p. 31].

The effects of the late epicycle of erosion (since 1880) have increased the importance of the *ak-chin* fields, by reducing the amount of farmland available in the floodplains of large streams [31].

A second class, with a few subdivisions, is that of fields located on the floodplains of the main valleys, the low flood terraces of large arroyos, or in the dry beds of small intermittent streams, in places where the water will spread over a wide area during a flood and yet will not be destructive to the crop. This practice is limited nowadays by the deepening and widening of the stream channels in recent times. An example of such valley-bottom fields cultivated by the Navajo—who, incidentally, learnt agriculture from the Pueblo Indians—is given by Bryan [14, p. 451]. The Hopi, and less frequently the Navajo, sometimes direct the floods by constructing temporary earthen diversion dams, up to 30 cm. or more in height [30, p. 104]; these are renewed every season.

A third class, fields watered by hillside wash, was described by Bryan [14, p. 445] as practised today by the Spanish-speaking inhabitants of small valleys in the Sandia Mountains of New Mexico. Since the settlement of that area dates only from 1815 and the procedure has not been reported for the Indian country [31, p. 30], is might be colonial rather than aboriginal. Anyway, the distinction between these fields and those of the second class does not seem to be clear-cut, to judge from Bryan's pictures.

Still another technique—which involves works of a more permanent nature—is the building of check dams in small wash bottoms to form terraces. The dams are made of loosely piled stones and brush, and serve to hold soil and moisture, by slowing the run-off, and to obstruct gully erosion. The crop planted in those terraces is nearly always early corn, which is associated with ceremonial celebration [31, p. 30]. According to Gregory [30, p. 104], remains of such check dams on the terraced floor of washes may be seen near many of the ancient ruins. In addition, prehistoric check dams across the run-off and on rock ledges are found at Mesa Verde (south-western Colorado), and it is likely that more would be found if the San Juan area were searched for them [13, p. 10].

Finally, canal irrigation was practised, at least in the San Juan area, during Pueblo III times (1100-1300) as evidenced by the ancient reservoirs and ditches found in the Mesa Verde region. The main ditch on Mesa Verde is about 6 km. long, over 9 m. wide, and 28 cm. deep, and falls more than 200 m. with a very regular gradient [13, p. 10]. Modern Hopi gardens irrigated by diversion are described by Hack [31, p. 34], and in the Navajo country by Gregory [30, p. 105] However, the amount of land watered in this way is very small, and it was apparently the same in the past [13, p. 11].

## IRRIGATION AGRICULTURE OF THE MEXICAN BORDER

At the close of the seventeenth century, when the first Christian missionaries entered the section of northernmost Sonora and southern Arizona, later known as the Pimería Alta, the agriculture of the Pima Indians depended upon canal irrigation [18, p. 4]. The climatic features of that area are a precipitation low in average and extremely unreliable owing to annual fluctuations, a very high rate of evaporation, and a long growing season. Of the rivers which supplied the water for irrigation, the Gila and the Santa Cruz are discontinuous streams, and the San Pedro flow, although perennial, fluctuates greatly [18 p. 13]. Piman settlements and irrigation were found along the stretches of continuous flow. South of the present international boundary they lived by the upper reaches of the Sonora and San Miguel rivers, and down the San Ignacio and Altar, where rich irrigated land was found as far west as Caborca [18, p. 5, quoting Mange's *Luz de tierra incógnita*, based on his visit in 1694].

As noted by eighteenth—and nineteenth—century observers of the Gila Pimas practice, temporary diversion dams were built of upright poles, driven into the river bed in zigzag lines, as a supporting frame for a barrage of branches and bundles of bush; rocks and tree trunks were also used sometimes to reinforce the construction. These barrages rarely stood longer than a year, being washed away by sudden floods. The networks of conveyance and distribution canals were very extensive; from the main canals many laterals branched out on both sides of them. The main ditches were as much as 3 m. deep at the intake and generally 1.20-1.80 m. in width. The irrigated fields were subdivided by earth ridges into rectangles of about 70 m. by 35 m. The main canals were communally owned, and they were cleaned and repaired every spring under the direction of elected officials, who also regulated the distribution of water. Often the men of several communities worked reciprocally for the maintenance of their irrigation systems [18, p. 156].

With regard to land ownership, elongated cobblestones set vertically in the ground, suggestive of boundary markers, have been found by modern farmers; some clue on the nature of the ancient field system might have been provided by the study of their pattern of arrangement, but it was obliterated by reclamation works before its significance was appreciated by archaeologists [35, p. 8].

In addition to canal irrigation, some floodwater farming was practised in a few favourable places. Also, it is noteworthy that food-gathering was an important activity, intricately interwoven with gardening in Piman economy. Even in normal years the products of wild plants, mainly mesquite beans (*Prosopis* sp.) and cactus fruits and seeds (*Carnegiea gigantea*, *Lemaireocereus thurberi*, *Opuntia fulgida*, *O. echinocarpa*), constituted an important part of the diet. When crops were washed out by overflows or they failed for other reasons, the relative importance of farming, food-gathering and hunting as the foundation of subsistence became reversed [18, p. 28 and p. 63]. It must be noted, however, that increased reliance on food-gathering and hunting as important complements of the subsistence basis was possibly a reversion which occurred at the time when the prehistoric irrigation systems dwindled—in the early fifteenth century.[1]

The prehistoric sedentary culture of southern Arizona is called Hohokam. Apparently it evolved out of the food-gathering Cochise Desert culture with the introduction of agriculture shortly before the beginning of the Christian era. Although there is a dark period in the development of this tradition, from the early fifteenth century to the late seventeenth, there is no reason to doubt that the Hohokam people were the ancestors of the Upper Pima Indians of later days.

Since no evidence of canal irrigation is yet known for most of the first thousand years, some form of floodwater farming is postulated for that period. River floodplain farming might have been feasible in the vicinity of the archaeological site of Snaketown, a settlement close to the Gila River whose origins are much earlier than the attested antiquity (*c.* A.D. 800) of the local canal system [33, p. 57]. Later, the development of the canal networks permitted settlement away from the rivers; an example of this was the town whose ruins are now called El Pueblo de los Muertos, that flourished in the fourteenth century as the centre of a large population cluster, 10 km. south of the Salt River [34, figures 1 and 24, and p. 14-43; 35, p. 9].

The remains of prehistoric networks of irrigation canals are very extensive in south central Arizona; in the Salt River valley the aggregate length of conveyance ditches has been calculated to be more than 300 km., of which 120 km. correspond to the Los Muertos system alone [35, p. 8; and 34, p. 41, quoting Turney's *Prehistoric Irrigation in Arizona*]. Some of the ridged depressions revealing the course of an ancient canal can be traced for more than 30 km.

An excavated section of one of the Los Muertos ditches, 10 km. from the intake, was found to be 9 m. in width at the top and over 2 m. in depth, with a large groove at the bottom, apparently designed to carry the small flow of water during periods of scarcity, a feature also found in other broad channels. In a section of the Snaketown canal, the actual water conduit is about 2 m. in width and 1 m. in depth, although from crest to crest of the side ridges it is about 10 m. in average. Haury [33, p. 56] pointedly notes that the widths given for the Hohokam canals on the basis of surface indications do not necessarily correspond to the actual size of the channels, which has to be ascertained through excavation of their cross-sections.

The study of the Snaketown canal [32, 33] revealed an interesting story of deposition of alkaline crusts, silting and re-excavation of channels, covering a time span of at least 500 years, beginning at about A.D. 800.

The Hohokam canal systems reached their maximum development from about 1200 to 1400 [32, p. 50]. Their planning, construction, and maintenance would have required a considerable degree of community control by a political organism; the fact that in some instances several villages evidently drew water from the same canal, indicates co-operation and co-ordination at the intervillage level [35, p. 8]. The layout of settlements and canals in the Los Muertos area, suggests some degree of political centralization of the kind that, in larger and more compact irrigation districts in other parts of the world, produced the rise of city-States. This phenomenon, in the Hohokam area, was apparently limited to a very incipient stage by the scattering of irrigable zones, at least under the resources-technology equation operative in the Hohokam culture.

## THE SONORAN DESERT

Further south, along the middle and upper Yaqui River and the mid-course of the Sonora River (in the zone of *BShw* climate), the agriculture of the Lower Pimas (Nebome and Ures groups) depended on well-developed canal irrigation, according to the reports of the early Spanish explorers.

The desert's Papago division of the Pima people, living in the very arid section west of the Santa Cruz River, forcibly depended more on gathering of wild plants and/or hunting than on agriculture. The average annual precipitation over that area is less than 125 mm. Residence was seasonal, near the scanty permanent water sources during the

1. The causes of this are still undetermined. In a personal communication dated 8 April 1959, Dr. Haury writes that lowering of the main-stream channels or alkalinization have been mentioned as possible explanations, but none is directly attested by archaeological evidence. Personally, he favours rather a break-down of the society—by effect of forces not yet surely recognized, which were operative over a large part of the North American south-west—as the main cause of the cultural recession.

winter months and in the places favourable for agriculture after the summer rains started. Crops were raised mostly by thunderstorm floodwater farming. *Ak-chin* fields are reported by the earliest chroniclers (end of the seventeenth century); low embankments, brush barriers, and shallow ditches were used to capture and spread the water. Also, in a few places they irrigated with water derived from springs or the stretches of permanent flow of the Sonoita River [18, p. 40 and p. 168].

The Yuman tribes of the lower Colorado River valley—in the western section of the Sonoran Desert province—depended on natural[1] river floodplain farming, planting as soon as the water receded in the ground moistened and fertilized by the annual summer overflow (see the thorough study by Castetter and Bell [19]). The erratic ways of the river—variability and even failure of seasonal floods and unseasonal destructive ones—precluded the maintenance of permanent fields [19, p. 38 and p. 69 *et seq.*] and made the Yuman economy unstable. In spite of the eventual possibility of a bounteous harvest of cultivated crops (maize, tepary beans, and pumpkins), subsistence depended to a large extent (50-70 per cent) upon the products of wild plants—mainly *Prosopis juliflora*, *P. odorata*—and fishing [19, p. 66 *et seq.* and p. 238].

River floodplain farming, based on natural inundation, was likewise the source of subsistence of the pre-Spanish nations of southern Sonora and the Sinaloa coastal plain, in north-western Mexico. There, dependable summer floods and less so, but still ordinary, winter ones—which originated in the upper drainage of the rivers in the high Western Sierra Madre—and the all-year-round growing season (climate *BWh'w* in the north, *BSh'w* in the south) allowed two and even three crops a year on the continuously re-fertilized fields. It is quite significant from the aspect of sociological theory that, although it sustained a dense and prosperous population, this natural irrigation did not produce any appreciable degree of urbanization nor a complex political structure.

## MESOAMERICA

The term 'Mesoamerica' is used nowadays to refer to the culture-area comprising the ancient 'Mexican' and 'Mayan' civilizations (in their many varieties as manifested in time and space), which in the past have been generally considered as rather distinct developments.[2] Its fundamental unity is now beyond question, and the differences in socio-economic structures and settlement pattern can well be explained as ecological adaptations to contrasting environments.

The climate of the eastern lowlands, facing the Gulf of Mexico and the Caribbean Sea, where the classic Mayan and other cultures of related type flourished, is for the most part of the tropical-rain forest (Köppen's *Af*) and monsoon forest *(Amw, Amw')* types, the main exception being the tropical savanna *(Aw)* area of the north-western part of the Peninsula of Yucatan—a limestone formation with no surface running water and where, noteworthily, a distinctive variety of Mayan culture existed since ancient times.

On the other hand, notwithstanding the great climatic contrasts effected by the relief, most of the highlands, the interior valleys, and the Pacific coast share a common characteristic—well-marked periods of seasonal drought lasting over half of the year (generally, seven to eight months). Over most of the plateau and range regions, aside from the high mountains, the dominant climate is the mesothermal savanna (*Cw*) type, and in the interior depressions and along most of the Pacific coast the tropical savanna (*Aw*) type is found. The temperate forest *(Cf)* only occurs in the mountains. In the zone of rain shadow west of the Eastern Sierra Madre high peaks, there are tracts of cold steppes *(BSk)*, and in the depths of the inland valleys tropical steppes *(BSh)* and even cactus desert *(BWh)*.

In the light of the extreme environmental diversity within Mesoamerica and what is known about the level of civilization attained by its people, it is hardly surprising that, contrary to an opinion widely and rather uncritically accepted until a few years ago, the diversity of agricultural practices found in that area corresponds, as might be expected, to the variability of climate, relief, hydrography and soil.

We are concerned here only with those sections of the culture-area where unreliability or extreme seasonal limitation of rains, and excessive evapo-transpiration and run-off losses,[3] can be, and were, advantageously compensated for by means of irrigation and where land productivity was sustained by the application of techniques for the conservation of soil and water resources, allowing intensive exploitation. These regions correlate with the *Cw* and *Aw* zones, which constitute the greatest part of central, western,

1. Although a mid-eighteenth century eye-witness credits the Indians with a method to divert the overflow, building diagonal dikes of logs supported by poles driven into the river bed, and spreading the water into swales by means of earth dams disposed to form an incipient system of basin irrigation [19, p. 133].
2. The northern frontier of Mesoamerica can be defined in various ways, either on an archaeological or ethnological basis, but in any case it fluctuated through time. The 22° parallel constitutes a convenient geographical reference, although cultural influences can be traced far north of that line, to the north-west and north-east, and the Mesoamerican cultural pattern trespassed it at various places and periods; conversely, the farming frontier settlements had retracted southwards in the central section before the arrival of the Spaniards in the sixteenth century. The northern neighbours of the sedentary Mesoamerican people in the semi-arid zone of north central Mexico were the nomadic hunting-gathering Chichimecs. The southern limit of Mesoamerica does not concern the purposes of this paper.
3. Although I have not seen statistics on this subject, anybody familiar with these regions knows that evapo-transpiration losses must be inordinately high, owing to the rate of insolation and low relative humidity. With regard to run-off over the whole area under consideration, excluding the negligible *Cf* zone of the high mountains, rain almost always falls in torrential showers, thus failing to soak sloping ground. Ths is of special significance since, owing to the relative scarcity of flat lands, much of the cultivation is done on the hillsides or rolling ground.

and south-western Mexico, and the *BS* and *BW* climatic enclaves. Only a few instances of the application of conservation measures are known from places outside the limits outlined.

In almost any place within that area—with the exception of the few truly arid sections—rain farming is possible, although often aleatory and undependable (see, for example, Millon [57] on the Valley of Teotihuacán), and there is no question but that it was generally practised. The native method uses the slash-and-burn technique of clearing fields—wherever the vegetal cover makes it necessary—and alternate periods of cultivation and fallowing in short cycle, the fallow intervals approximating the number of years the field can be maintained under repeated cultivation. The long rest required for the restoration of the plant nutrients in most soils of the humid tropics, including the tropical forest in Mesoamerica that allows for jungle growth over a much longer period than that required for cultivation, is not necessary in the life zones that concern us here.

However, the productive capacity of rain farming under the climatic conditions prevalent in these zones is contingent upon the duration of the winter dry season and the intensity, reliability, and efficiency of the summer rains. The regularity in the beginning of the rainy season (the coming of Quetzalcoatl, the green-feathered serpent god, in native myth), as a determinant of the planting days, is also an important factor in the central plateau (the upper Lerma River valley, the basin of Mexico, the Tlaxcala and Puebla high plains, and the upper Moctezuma River drainage in southern Hidalgo), where the concentration of population in pre-Columbian times was greatest, for early frosts may injure the unripe crops when planted late.

In many places the all-year-round growing season permits, with irrigation, the continuous cultivation of the same plot and the harvesting of two annual crops uninterruptedly; that it was practised where environmental conditions allowed is confirmed by historical evidence [see, for example, sixteenth century quotations for the Coatlalpan province in 2, page 98]. Furthermore, irrigation permitted the growing of crops with special moisture requirements, such as cotton, and the cultivation of the drought-sensitive cacao tree in the warm seasonally arid sections of the Pacific versant [2, p. 86 and p. 111]. Nevertheless, not only commercial crops but also the basic subsistence culture of maize and chile peppers were given preference in irrigated fields.

It is well known that even under climatic conditions favourable to rain farming, supplemental irrigation increases yields per unit of cultivated land and improves the efficacy of fertility methods of conservation, such as the application of fertilizer. With regard to increased yield, it is interesting to see Palerm's [63, p. 30] comparison of productivity between the specialized permanent moisture *chinampa* system of the Valley of Mexico, the ditch irrigated fields at Tecomatepec, the fallowing supplemented by house gardens at Eloxochitlán, and the tropical slash-and-burn at Tajín. The comparative numbers indicating the amount of cultivable land needed to support the same numbers of people, approximate the series 1:2:12:24 respectively; reading it in inverted order we get an index to the theoretical relative density of population allowed by these farming systems.[1] Taking into consideration increased yield, continuity of land use, and possibilities of double cropping, the compounded effects of irrigation on food supply, and hence on density of population, must have been quite significant; available evidence confirms this assumption.

The subsistence basis of civilization in these regions, although resting to a large extent on the rain-farming fallowing system[2] cannot be properly understood if—as has been done too often—the importance attained there in pre-Columbian times by improvement and conservation methods, and consequent influence on population density and clustering, settlement patterns, and some fundamental aspects of the social and political sutructures, is minimized or ignored. There has been an awakened interest in the distribution of native irrigation agriculture by means of canals and ditches at the time of the Spanish conquest or shortly thereafter and, in a few concrete cases, in the historical information referring to late pre-Columbian times. A few results have been published since the late forties, covering the area north of the Isthmus of Tehuantepec : Sauer's investigations on the role of irrigation in the preconquest economy of the zone of Colima and neighbouring sections of Jalisco and Michoacan, in western Mexico [69]; my own research for most of the area that has been published in detail only for the part referring to the Balsas River drainage, which comprises, however, a large part of southern central Mexico and included the prized irrigation district of southern Puebla and eastern Morelos [2]; and Palerm's comprehensive paper for the whole area under consideration [62]. No similar studies have been made for some sections of Mesoamerica southward from the Isthmus of Tehuantepec where enviromental conditions might have encouraged analogous practices. However, a late sixteenth-century reference indicates irrigation for cacao-tree plantations at Santa Ana (western El Salvador), and it is implied for places in Xoconochco (the coast of Chiapas, Mexico), and farther south in Nicaragua and Costa Rica (to the peninsula of Nicoya), where native cacao culture is recorded and the long dry season would have made watering of

1. See also Sanders [67, p. 74; 68, p. 116].
2. With reference to its effects on the type of civilization, the uplands fallowing system is, anyway, twice as productive in proportion to the amount of cultivable land as the shifting-fields procedure typical of the humid lowlands [67, 63].

the orchards a necessity, despite the amount of annual rainfall [58, p. 66, p. 73, p. 76 and p. 111].

The studies mentioned in the preceding paragraph are based on sixteenth century historical or administrative documents, some of which are transcriptions of pre-Spanish traditional history, or pleas for confirmation of water rights by colonial authorities. Unfortunately, very little archaeological research has been done to date to substantiate the documentary evidence and to investigate the prehistory of irrigation works. A noteworthy exception is Wolf and Palerm's field survey of the extensive remains of aqueducts and canals in the piedmont of the Sierra east of the former Acolhua capital, Tetzcoco [90]. The longest aqueduct found is carried over an embankment 1,000 m. long and 12 m. high at the highest point, another although shorter (about 300 m.) reaches 20 m. of maximum height over the saddle of the ground [90, p. 269 and p. 272]. In those I have seen the channel is stone built, revetted with lime plaster and, in a short stretch over the hill at the entrance of the embankment leading to the royal gardens, the water conduit is cut into solid rock.

These authors did a splendid job of relating the ancient vestiges to sixteenth century documentary sources, and to present-day native irrigation in the area. Being familiar with these places, I fully agree with their conclusions that available evidence suggests a mid-fifteenth-century reclamation project, undertaken in Nezahualcoyotl's reign. Although hitherto usually referred to as the royal gardens of that king, it is clear in the field and supported by documentary evidence, that the regal domaine was only a part of a more extensive endeavour designed to benefit many communities. Mid-fifteenth century was a period of Acolhua preponderance in central Mexico, with King Nezahualcoyotl at the summit of power as political and military leader of the Triple Alliance, just before its decline and the accession of the kings of Tenochtitlan to pre-eminence within the framework of the expanding Aztec empire. However, I believe that extensive use of aerial photography and spade work, that has not been done, would not fail to reveal considerably older hydraulic works in that general section of the Valley of Mexico.[1]

The only excavations made in Mesoamerica to uncover and date vestiges of a prehistoric irrigation system are those of the dams and canal in a small valley between the Maravilla and Altatongo hills, in the neighbourhood of the ancient metropolis of Teotihuacan. The indications leading to the discovery were found by examination of aerial photographs, and the preliminary survey on the ground reported by Armillas, Palerm, and Wolf [3]. The subsequent excavations have been very ably conducted by Millon. His conclusions [59] are that this system may have originated in the Toltec period (*c.* A.D. 800-1200) or perhaps in older Teotihuacan times.[2] Millon has also made considerable research, most of which is still unpublished, to relate prehistoric, colonial, and modern practice of irrigation in the valley of Teotihuacan. The major canals which run through the valley today existed in 1580, and an abandoned canal has been discovered in the flat lands of its central section that looks a promising site for an investigation of the very origins of irrigation in the district of Teotihuacan.

In the Basin of Mexico, the shallow fresh water lakes of Zumpango, Xaltocan, Xochimilco, Chalco and parts of Lake Tetzcoco,[3] were conquered for *chinampa* agriculture, the so-called 'floating' gardens. [74, 84]. The *chinampas* are, and were, artificial islands built in shallow waters by piling up layers of aquatic plants and silt from the bottom of the lakes.[4] In order to keep the porous soil of the *chinampa* perpetually moist, by infiltration from the surrounding waters, and to facilitate supplementary manual irrigation, the islands are built in comparatively narrow, elongated strips. Also, the top plane is regulated—by adding or scraping top soil as required—in relation to the water level, so that moisture might reach the root-level. Additional moisture is supplied directly to the individual plants by lifting water from the surrounding canals by means of simple hand tools, such as cloth buckets mounted in a twig ring with a long handle or by wooden scoops. As the water is muddy and rich in organic nutrients, this amounts to the addition of new soil.

Besides the building of the land, infiltration of moisture, and manual irrigation, the *chinampa* farming system includes today, and seems to have included in the past, techniques such as the use of hotbeds—and consequently transplanting—and fertilizer. Indian seedbeds are depicted in Fray Bernardino de Sahagún's *Florentine Codex* (third quarter of the sixteenth century). Fray Alonso de Molina's *Vocabulario en lengua castellana y mexicana* (printed in Mexico City in 1571) provides some linguistic evidence about the fertilizers used—at least for the central Mexican area of Nahuatl speech, which includes the *chinampas* region. According to Molina, the verb *coquipachoa nitla*, is translated 'to dung the soil in some way', *coquiatl* is mud, bog, hence the verb means 'to muck', which describes well the practice

1. Perhaps related, and I mention it just as a possibility to be investigated, to the ruins of Cerro Portezuelo, an important settlement farther south in the same piedmont area.
2. In my opinion, the possibility of the system originating in the Teotihuacan period seems rather likely, although admittedly based on the faint evidence of the diversion of the stream from its natural watercourse [59, p. 164].
3. High salinity was apparently confined to the eastern parts of Lake Tetzcoco, but the flow and reflow of brackish water, depending on the fluctuations in water level within the intercommunicated system of lakes, affected its western section, around the island where the twin cities Tenochtitlan and Tlatelolco rose. The construction of the 'albarradón de Nezahualcoyotl' —a dike 16 km. long, built by the Aztecs under the guidance of Tetzcocan technicians in 1449—besides protecting the capital from flooding must have improved the possibilities of land reclamation, by means of *chinampas*, in the marshes of that area.
4. The *chinampa* system can thus be classified as drainage and irrigation. The building of the islands is a very effective means of reclamation and their cultivation is a specialized and sophisticated method of gardening.

in the *chinampas*; *cuitlauia, nitla*, means 'to manure', from *cuitlatl*, excrement. Aquatic plants and slime are currently used as fertilizer in the *chinampas* and Sanders has found that the compost pile (*tlaçotlalli*, cf. Molina : *cosa gomitada*, spewed matter) includes human excrement. Indeed, the ancient name Cuitlauac of modern Tláhuac, one of the main towns in the *chinampas* zone of the southern lakes, and its hieroglyphic sign (as seen in *Codex Mendoza*), indicate the practice of using excrement to fertilize the soil.

Indeed, the use of human excrement to manure the fields seems to have been widespread in the central Mexican area of intensive agriculture, to judge from the remark of an eyewitness that along the country trails it was collected from benevolent passers-by in places purposefully disposed (Bernal Díaz del Castillo, *Historia verdadera de la conquista de la Nueva Espana*, ch. XCII). Although, rather bafflingly, he mentions only its use for tanning, this might refer simply to the cargos sold in the great market place of Tlatelolco, where it was brought in canoes for industrial purposes; after all, tanneries were not so important in pre-Spanish economy.

Although the specialized technique of building artificial islands by piling up aquatic plants and silt was seemingly restricted to the lakes in the Valley of Mexico, the methods for intensive cultivation described above in association with the *chinampa* system—such as the use of seedbeds, transplanting, and manual watering of the individual plants using wooden scoops or other containers—appear to have been widely known in the districts of intensive agriculture. The modern Tarascan Indian gardens along the shores of Lake Pátzcuaro described by West [83, p. 47], merely represent the continuity of a pre-Columbian local technical tradition, to judge from allusive references in sixteenth-century documents.

Another aspect of ancient Mesoamerican improvement techniques that until now has been generally overlooked, is the importance of agricultural terraces, mainly as a basic conservation measure to prevent soil erosion and to retain moisture on the hillsides. An extensive system of irrigated terraces is known however—that of the piedmont area of the former Acolhua kingdom, mentioned above.

Dry terraces, faced with stone retention walls or protected with earth embankments hedged with maguey, are found, ruined or still in use, over a large area of central and southern Mexico north of the Isthmus of Tehuantepec, and in the humid zones of the Chiapas and Guatemalan highlands to British Honduras. Very large areas are so terraced in the mountains to the south of the Valley of Mexico, beginning at the plain's edge and mounting to the zone of the pine forest. Many terraced hillsides are seen in aerial photos of the mountainous Mixtec region of north-western Oaxaca. Old abandoned terraces were encountered by Dr. Sanders and myself near Iztacamaxtitlan, just north of the Tlaxcalan border, when we were retracing with sore feet a stretch of Cortés' route to the conquest of Mexico. For a résumé of the data on southern Mesoamerica see Lundell [48, p. 9].

The possible antiquity of most of these constructions has not yet been investigated. The 1579 'Relación de Chilchota', Michoacán, by a minor colonial officer, describes some stepped hills, cut into terraces about 84 cm. in width which were faced with stone retention walls, reputedly used in 'ancient times' to plant maize, which had been abandoned for an indeterminate but seemingly long period. Those of the British Honduras-Petén zone, on the limestone plateau between the rivers Macal and Chiquibul, have been tentatively dated by Dr. Eric Thompson (quoted in Lundell [48, p. 10]) as being of late Tepeu age (roughly A.D. 750-900).

The only irrigated terraces of which I have knowledge are those of the Tetzcocan piedmont area already mentioned. There, the hills are artificially reshaped in rather regular forms, cut in straight lines. The terraces are well levelled, and contoured with dry-masonry walls. The water was conveyed by the aqueducts described to the highest terraces, and distributed by branching canals from bench to bench down the stepped hillsides. The age and historical setting of the building of that system has been commented upon above. Most of the terraces are still in use and watered by the canals, although the highest ones in the royal gardens and in other places are abandoned and decayed, the same as the upper aqueducts that supplied them with water.

The functional relationships between the improvement of land use methods—with the techniques of reclamation and conservation, principally hydraulic works—and population, settlement pattern, and the social and political structures, within the Mesoamerican area of civilization, constitute a fascinating subject of research that has begun to be explored only recently.

The preliminary results of the studies made to date can be summarized as follows : it is true that over most of the area of seasonally dry climate outlined above, physiographic conditions in conjunction with the relative technological development, limited the irrigation to small-scale enterprises that could be accomplished with the resources of a single community, or a small cluster of local communities politically integrated in a small principality. Nevertheless, the significant fact is that it was not so everywhere.

In other zones, as for example the Nexapa River valley in southern Puebla, the disposition of the irrigated lands of many communities along a river must have made centralized control of water-use necessary. In fact, it is known that the Coatlalpan province—which includes the Nexapa Valley—and the adjoining province of the Amilpas (whose name derives from *amilli*, meaning irrigated fields) were prize irrigation districts, forming a key economic area. The famous religious and commercial centre of Chollolan was located on the upper end of this compact irrigation zone, that extended downwards to Atlixco and Itzocan, which were also important urban centres at the time of the Spanish conquest. In the lower parts of this irrigation district the lesser altitude permitted the cultivation of cotton—an important trade commodity in pre-Spanish times—which was not possible around Chollolan.

The relative importance of pre-Spanish irrigated lands and rain farming in the zone of Colima and surrounding sections of Jalisco and Michoacan has been investigated by Sauer [69]. His study shows how the contrast between the alluvial soils of the river valleys, which constituted districts of concentrated irrigation, and the clayey soils of the surrounding uplands, that were not too well suited for native methods of cultivation [69, p. 63], affected the distribution of population and the degree of urbanization. There were at least five aggregations of urban importance in the lowlands and three in the highlands, each one ranging from perhaps five to ten thousand people. While the capitals of the valleys were the centres of irrigation districts, those in the uplands were commercial towns concerned in different degrees with mining operations [69, p. 81], although small-scale irrigation was also practised in that zone.

But by far the largest and most compact district of intensive agriculture—with canal irrigation, *chinampas* and terracing—was the Valley of Mexico. This was, apparently, the only section where the term 'hydraulic agriculture' as defined by Wittfogel [89, p. 153] does apply. Some State enterprises for the construction and maintenance of productive and protective water works have been mentioned already, more are known from historical sources.

Sanders' detailed studies of population for the Valley of Mexico at the time of the Spanish conquest indicate a minimum of one million for 8,000 km.$^2$ of territory. The total population of the Aztec empire at that time can be calculated, on the basis of different studies by various authors, at between five and six millions, for an area of about 200,000 km.$^2$ Thus, in the Valley of Mexico with an extension of only one twenty-fifth of that of the empire, about 20 per cent of the total population was concentrated, notwithstanding the fact that the empire included some of the most densely populated areas of central Mexico outside of the valley. In relation to the whole area of Mesoamerican civilization and its estimated population the proportion is even more startling, for the Valley of Mexico, with an area of about a hundred-and-twentieth of the total, contained about 10 per cent of the population.

In the Valley of Mexico, and in the southern Puebla irrigation district as well, the number of inhabitants of a few nucleated urban centres ran into tens of thousands—and well passed fifty thousand in the empire's capital, Tenochtitlan-Tlatelolco. Many rural district centres were towns—with part-urban functions—of several thousand people.

It was on the foundation of the political unification of this nucleus that the Aztec empire was built, and archaeology reveals the paramount role played by that area in Mesoamerican prehistory, before the beginning of the Christian era; this suggests that a comparable situation, with regard to density and concentration of population and inferentially agricultural practices, existed during Teotihuacan times (from about 200 B.C. to A.D. 700).

## MESOAMERICAN FRONTIER ZONE

The northern Mesoamerican frontier zone in northern central Mexico is an exceedingly important area in which to investigate the interrelationships of natural and cultural factors in the history of land use.

Following the inland piedmont (from about 2,250 m. to 1,850 m. in altitude) of the Western Sierra Madre, at the edge of the juniper-oak-pine vegetation zone, and along the savanna *(Cw)* belt to the limit of the steppe *(BSkw)*, the Mesoamerican cultural pattern became established, either as a result of diffusion-acculturation or conquering colonization, after perhaps A.D. 700 (to judge from the earliest carbon-14 date obtained from the ruins of La Quemada, at the southern entrance to this corridor [24, p. 1104]). The northernmost extension of this pattern reached the present Durango-Chihuahua border [40, p. 132 and p. 138].

In the semi-arid zone of the central section of the frontier—a region of transition to the Chihuahua Desert province—the northern neighbours of the sedentary Mesoamerican farmers were the nomadic hunting-gathering 'Chichimecs' (the Zacatecs, Guachichiles, and Pames). The historic limit between sedentarians and nomads roughly coincides with the present borderline between *Cw* on the one hand, and *BSk* (in the west) or *BSh* (in the east) climates, on the other. In view of the known retraction of the agricultural frontier—attested archaeologically and by traditional history in territories formerly occupied by sedentary cultivators and taken over by the nomads at the time of the fall of Tollan (towards the close of the twelfth century, perhaps in the first half of the thirteenth)—it would be of great interest to investigate whether some minor climatic fluctuation triggered ecological changes, or improvident clearing of marginal lands for the expansion of cultivation induced aridity in that area.

The fact that similar and more or less contemporaneous troubles are recorded in the south-west of the United States (see previous remarks on Anasazi and Hohokam and bibliography [38, p. 120]), in the inland piedmont of the Western Sierra Madre [40, p. 139], and in the eastern margin of the Great Plains, tends to favour the hypothesis of climatic deterioration. It looks as if the North American arid zone was expanding in all directions between the late twelfth and early fifteenth centuries. Since local environmental and cultural factors intervene in widely separate places, it is not to be expected that the effects would have been strictly synchronous; twelve score years or so is not an inordinately large allowance.

The apparent coincidence might be a mirage, however, and certainly much more factual information in different fields of knowledge is needed to decide the question; new interdisciplinary approaches will have to be developed, to gather and digest all the pertinent data on this complex problem.

## PERU

The rise and progress of the ancient coastal Peruvian civilization are unequivocally related to the improvement of the techniques for full exploitation of the riverine oases by means of canal irrigation. Only in the Virú Valley has the history of the development of hydraulic engineering and its relation to population density and settlement patterns and, by inference, to the origins of the State, been studied in some detail [86, *passim*, specially, p. 361-371]. Generalizations on the history of irrigation works for the remainder of the zone are based on that sequence, and presumtively dated illustrative examples from other places.

We have already seen that agriculture—as distinct from cultivation supplementary to an economy based on wild life—became established after the introduction of maize, and that it was expanding in the early centuries of the first millennium B.C. There are no remains of canals or vestiges of irrigated plots that can be attributed to this period, but the attested expansion of settlement away from the shore-line, to bottom lands or on the valley margins, is presumed to be related to agricultural practices, possibly floodwater farming [22, p. 19].

In any event the tapping of the streams for irrigation may have begun before the middle of the millennium in the upper narrows of the rivers [8, p. 142; 86, p. 31, p. 361, p. 392, and in figure 82, note the clustering of sites at the Quebrada de Huacapongo]. The latter half of the millennium—archaeologists' Early Gallinazo period—saw the beginnings of large-scale irrigation works, with the related phenomena of marked increase in population and its spread into all parts of the valleys, and the formation of the first large agglomerated communities of several thousands of persons living within an area of two or three square kilometres [86, p. 396]. This indicates the attainment of a mastery of water control that must have required a period, however brief, of experimentation.

By Late Gallinazo times (early centuries of the Christian era), the Virú Valley canal system extended from the water intakes in the narrows (Quebrada de Huacapongo and Upper Virú) at the foot of the mountains to the sea. The old canal lines and distribution of settlements suggest that at least 40 per cent more land was under irrigation then than nowadays (9,800 ha. against 7,000 ha. maximum today) [86, p. 394, see also p. 20]. The difference probably does not indicate a change in the total volume of water discharged by the gorges; it may well be due to higher consumption per acre required by the commercial crops grown today, sugarcane in the upper valley and cotton in the lower section [5, p. 19].

Old irrigation furrows seen in the neighbourhood of Huaca Gallinazo, the site naming the period, that seems to have been occupied uninterruptedly for about one thousand years (from about 500 B.C. to A.D. 500), are depicted by Strong and Evans [78] and reproduced by Willey [86].

In the ensuing Huancaco period, during the middle centuries of the first millennium, the layout of the canal network and the distribution of population clusters changed somewhat, without noticeably affecting the total acreage of irrigated lands or the number of people; the irrigation and population maxima attained in former times seem to have been maintained. However, it occurs to me that the decrease in land usage in the sections intensively exploited in the previous period (according to Willey (86, p. 393]), might be very significant as regards possible causes of the general decline of the Virú Valley economy evident in later times.

In the neighbouring valley-oasis of Moche and Chicama, to the north, impressive remains of irrigation works are seen. Extensive canal systems were beyond reasonable doubt in operation—although direct dating of the vestiges has not yet been done so far as I know—during the Mochica period of the archaeological nomenclature; according to Collier's and Willey's synchronologies it overlaps Middle and Late Gallinazo and the following Huancaco periods of the Virú Valley, having lasted for about one thousand years, from before the beginning of the Christian era to one or two centuries prior to the close of its first millenary [22, 87].

The magnitude of the engineering work involved in the building of the irrigation systems can be best evaluated by the example of the Ascope aqueduct, admittedly one of the greatest accomplishments of the ancient Peruvian Indian engineers. The Ascope canal, generally believed to date from this period, follows the basal contour of the hills on the north side of the Chicama Valley, being conducted across a bay of the plain over an embankment built of earth and adobe, 1,400 m. long and 15 m. high above the adjacent valley floor, an estimated volume of 785,000 $m^3$ of earthwork [8, p. 157; 43, p. 71; 46, p. 162; 86, p. 411].

Also, inter-valley irrigation systems—implying the constitution of multi-valley political entities—were supposedly built in Mochica times [22, p. 21], and a canal over 120 km. long deviated water from the Chicama River into the lower Moche Valley, to the south [46; 65, p. 58].

Willey [86, p. 365] makes the interesting remark that the main irrigated section of the Virú Valley through the Gallinazo period was avoided in subsequent times. In my opinion, as pointed out above, this might have a bearing on the apparent weakening of the coastal States in later days, when they became an easy prey to the invading highlanders, coupled with the astonishingly disastrous effects of the Spanish conquest which followed, and also considering that—contrary to what happened in Mexico—no major epidemic was responsible for the decimation of the Indian population within half a generation after Pizarro's arrival. The social chaos brought about by the conquest, and the ravages caused by the faction wars between the *conquistadores*, were certainly contributing factors, but the deep causes of the decline of the coastal civilizations might go far back into times earlier than the coming of the bearded white men.

The trend to move away from the older fields, already started during Huancaco times, continued during the later Tomaval, La Plata, and Estero periods (from about A.D. 800 to the Spanish conquest). A new zone of settlement became occupied, since Tomaval times, along the coastal dune belt. This probably indicates the beginning of the practice of utilizing ground moisture by means of the *pukio* basins (see below) to raise crops [28, p. 34; 86, p. 368]. From about 1200 onwards diminution of population is evident; most of the valley-bottom dwelling sites were abandoned, habitation clustered in the upper narrows of the valley and along the dune zone. Notwithstanding that some canal irrigation was still operative in 1548, at the time of Cieza's visit, the pre-Columbian recession had been evidently aggravated by the effects of the Spanish conquest [21, chapter LXX, in which the Virú Valley is mentioned under the name Guañape].

The population decrease mentioned in the preceding paragraph has been tentatively explained as an effect of social and political disturbances [86, p. 421], but the alternative hypothesis of local failure of the irrigation system for purely technical reasons is worthy of consideration, since the abandonment of the ancient irrigated sections of the Virú seems to have begun before the major upheavals apparently brought about by the Tiahuanaco expansion and what followed. Soil salinization and excessive rising of the water table due to prolonged use of irrigation with inadequate drainage may have occurred. That salts may have given trouble to the native farmers in the Virú Valley and elsewhere in the Peruvian coast is borne out by Willey's remarks [86, p. 16] and also by Ford and Willey [28, p. 26], quoting Larco Hoyle. It is worth while to note that owing to mismanagement of water resources, salinization is affecting nowadays the districts of Piura and Pisco [65, p. 20 and p. 45].

The soldier and chronicler Pedro Cieza de León—writing of the Chilca Valley, 40 miles south from Lima, in about the middle of the sixteenth century—expresses amazement that, in a rainless country and with no surface running streams available for tapping, the place was verdant with cultivated fields. To grow maize, vegetables, and fruit trees, the Indians planted in wide and deep basins purposely dug in the soil, to capture underground moisture at root level of the plants [21, chapter LXXIII].

Willey [86, p. 16] reports that there are archaeological remains of this practice in the dune belt fronting the ocean shore at the lower Virú Valley : basins—sometimes rectangular, sometimes irregular, varying in size from 100 × 50 m. to 30 × 30 m., sunk about 1 m. below the surrounding ground surface and separated by ridges 2 to 4 m. high, built up with the soil removed from the excavations—dug by man, serve to retain seepage water which lies closest to the surface near the beach [cf. 5, p. 19] on the groundwater level in this valley). These basins are known locally as *pukios*.

The only indications of age are the proximity of such excavated hollows to a ruin certainly dating from the Tomaval period (beginning towards the end of the first millennium A.D.) and surface potsherds from the same and subsequent periods, up to Colonial times, collected in another area of *pukio* cribs, both places being situated in the lower valley, not far from the beach. The concentration of habitation sites dating from the Tomaval and La Plata periods (up to the late fifteenth century) in the dune belt, where the groundwater level is higher, suggests a relationship between the shifting of population to that zone and the beginning of the practice [86, p. 368]; whether it might be older in other places is not known.

Horkheimer [37, p. 78] also mentions this ancient technique for obtaining undersurface watering, and describes two such great basins, one of them about 500 m. long and 10 m. deep, surrounded on three sides by ridges and open on the fourth side facing the sea. This basin was dug a short distance from the beach near the ruins of the former Chimu capital of Chanchan (fourteenth and fifteenth centuries), on the north coast of Moche Valley. The same author quotes Regal [64, p. 104] for similar ancient hollows in Chala, Mala, Atiquipa, Atico, and Pica. Reparaz [65] illustrates modern cultivation of cotton utilizing underground moisture in the desert Pampa de Villacurí, between Pisco and Ica.

An excellent report on the state of native irrigation in the coastal valleys in 1548-1550, after the catastrophic depopulation brought about by the faction wars among the Spanish *conquistadores*, is given by Cieza de León [21, chapters LVIII-LXXV]. This author had a remarkable understanding of the interrelationships between environment, technology, population, and society; to read his descriptions and pointed comments is an intellectual delight.

On vestiges of ancient hydraulic works, and on canals still in use but reportedly built in pre-Colonial times, see Horkheimer [37, p. 72].

## THE ANDEAN PLATEAUX

The southern highlands of Peru and the adjacent section of Bolivia at the southern end of Lake Titicaca, is a zone of great historical importance, since it was there that the powers that were to overrun the old coastal civilizations and to unify the Andean area (the uplands as well as the Pacific coast) originated and grew.

The first manifestation of these expansionistic tendencies is inferred from the archaeological record of the spread of the Tiahuanaco style, which for a comparatively short period after the eighth century A.D. extended from highland centres (Wari, near Ayacucho, and Tiahuanaco, Bolivia) over most of the area later incorporated into the Inca empire. It might have been diffused by penetration in some cases, by conquest in others. This may or may not have involved highland dominated political consolidation but, in any case, that expansion constituted a precedent of pan-Andean unification by influences derived from the central highlands, and therefore foreshadowed the *Tawantinsuyu*, the Land of the Four Quarters mastered by the Inca lords.

The second manifestation was the expansion of the Inca empire, from its nucleus in the high Cuzco Valley, to engulf the huge area that extends from northern Ecuador to south central Chile and northwestern Argentina. It is even more astonishing that this was accomplished in the short span of three generations (from the crowning of Pachacuti, 1438, to the death of his grandson Huayna Capac, 1527).

On what basis of manpower, and hence, of subsistence economy and land use, did the power of these conquerors originally rest? The archaeology of the Andean hinterland being, as yet, insufficiently known, it would be unwarranted to attempt a historical account—with dimension of time-depth—of the development of land use methods. What follows, therefore, is founded mostly on the ethnographic record dating from the time of the Spanish conquest.

Morphology has a paramount importance in determining the ecological conditions over the area which concerns us here. The high plateaux surrounded by snow-covered mountain ranges are much too high for prosperous agriculture, or above the uppermost limit of cultivation (punas). The altitudes more favourable to diversified farming are found in a few mountain valleys, on the steep slopes of the deep river canyons, or in their narrow bottoms. The dominant type of climate in the inhabited zones is mesothermal savanna, with cool summers and a winter dry season lasting from April or May to October or November *(Cwb)*. However, changes in altitude produce, of course, great thermic differences within very short distances.

Sixteenth century geographical descriptions indicate that the Quechua Indians preferred to settle at an altitude intermediate between the puna pastures and the tillable land of the valleys and canyons [44, p. 332]. From the viewpoint of productivity, it is noteworthy that the Spanish feudalistic *encomiendas* were preferentially established in the deeply dissected country, leaving the high plateau region free from colonial interference until well after the middle of the sixteenth century [44].

The Indians mastered this rather difficult environment by means of altitudinal zoning of land use and land reclamation and soil conservation by terracing and irrigation.

Altitudinal zoning of land use presupposes progressive adaptative and selective improvement of cultivated plants to grow under quite astringent environmental conditions, and the taming of grazing animals to utilize the meagre resources of the high punas above the uppermost limit of cultivation or in places otherwise unsuitable for agriculture. Maize was the main subsistence crop below about 3,400 m., although some was grown in sheltered sun-warmed slopes above Lake Titicaca as high as 3,900 m. [70, p. 490]. Diversified cultivation with maize and potatoes shifting in relative importance with the altitude, centred in the 3,000-3,500 m. zone. At higher altitudes, to about 4,250 m., microthermic frost-tolerating plants such as quinoa *(Chenopodium quinoa)*, bitter potatoes, and oca *(Oxalis cremata)*, were grown to the upper limit of cultivation. Higher still (to about 4,500 m.) the high punas were utilized for pasturage of llamas and alpacas.

It is worth while to note that the efficient use of the available subsistence resources was greatly increased by the development of techniques for food preservation by means of drying and freezing [6, p. 15; 37, p. 56], and preparation of otherwise unpalatable foods, such as the bitter potatoes [70, p. 516].

The long dry season and low rain efficiency due to very high run-off losses, make irrigation necessary nearly everywhere in the deeply canyoned sections of the highlands, although some quick-growing crops can be raised without it in the rainy season [66, p. 211], and the Collas of the high-plateau area of the north Lake Titicaca basin depended on rain-farming exclusively, being subject to famine when rains were deficient [21, chapter XCIX].

The valleys are generally deep and narrow, and the amount of irrigable bottom land very limited. Furthermore, valley fields are liable to be washed over by the flood from the precipitous slopes in the rainy season.

The second, but not the least, achievement of the highlanders to master their environment was the reclamation for agriculture of the steep mountainsides by means of stone-faced irrigated terraces.

Incredibly steep slopes were conquered for cultivation by terracing and sometimes whole valleys were reshaped and regraded. Rowe [66, p. 210] mentions as outstanding examples those at Yucay and Ollantaytambo, and Cieza de León [21, chapter XCI) refers with admiration to those at the Valley of Xaquixaguana. A series of amazing air and ground views of terraced steep slopes in the Colca and Andagua valleys, north-north-west from Arequipa, were published by Shippee [75]. Detailed descriptions, maps, and photographs of ancient terraces in the Vilcabamba mountain range are found in the report of the Viking Fund's explorations [27].

Irrigation canals often ran for miles along the side of a valley to irrigate a comparatively small terraced area [66, p. 233].

Not very much is known of the origins and development of the techniques of reclamation by means of terrace construction, although many of the complicated terrace arrangements could be assigned to the first millennium of the Christian era, according to Bennett's remarks [6, p. 21; 8, p. 157]. Some of the ancient terraces are still cultivated but many are abandoned.

## THE CHILEAN DESERT

The resources that the desert extending along the Pacific from latitude 18° S. to about 30° S. offers for the survival of populations with simple technologies are severely limited. As along the Peruvian coast to the north, rainfall is sporadic—no rain may fall for years, but here, because of the composite effects of the Humboldt cold current parallel to the shore and the prevailing winds, even the slopes of the Andes are dry and bare; no permanent stream reaches the ocean between Pisagua and Copiapó. Nevertheless, the dryness is lessened at times by sea fogs, especially in winter (climate *BWkn*); from just north of Taltal to the south, the desert coast is fringed by a belt of *loma* vegetation (annual grasses and herbs) which increases in width southward [9, 10, *passim*].

Similar ecological conditions may have prevailed for a long time in the past, for, in his excavations at several places along this coast, Bird [9, p. 314] found no evidence for any significant change in precipitation or wild life within the known period of human occupation, extending back, presumably, over 4,000 years [see 87, figure 11, sequence chart]. Nor does Bennett [6, p. 600] see the need to explain by climatic change the fact that vestiges of irrigation ditches are found in some now waterless sections or of old algarrobo trees partially buried by sand; such occurrences, he writes, might be accounted for in other ways. However, a more general distribution of springs and groundwater is implied by the location of sites, and is borne out by some of Bird's own remarks.[1] This is pointed out by Schaedel, who also makes an interesting reference to the observed changing dip of the water table [73, p. 34].

Prior to the introduction of agriculture the early inhabitants of the driest sections had no alternative but marine subsistence, since game must have been always too scarce to be even of secondary economic importance. The choice of camp locations for the shore-dwelling people was further restricted by the prevalence of heavy seas, scarcity of sheltered places, and irregular availability of drinking water. South of the 25° parallel, land game, supported in limited numbers by the coastal vegetation, allowed them to supplement fishing with hunting; also, a water supply is less difficult to secure. Agricultural expansion was restricted by the limited volume of water available for irrigation and the small size of the valley bottoms; along much of the coast between Arica and Coquimbo, farming never replaced entirely the mode of life based on fishing and hunting.

In the far north, incipient cultivation appears perhaps at about the beginning of the Christian era,[2] with maize, gourds, and cotton, the latter possibly cultivated but perhaps wild [9, p. 248]. However, the pattern of well-established agriculture found in Inca times in the valleys of the Arica hinterland—the year-round flowing Lluta River and the Azapa, of intermittent streams now running only with occasional floods—does not appear to have developed until the close of the first millennium, coinciding with the Tiahuanaco expansion from the central Andes that also influenced this zone.

Farther south, the incipient farming stage is represented by maize, gourds, and cotton, found in the trash deposits at the ancient fishing station of Punta Pichalo, by Pisagua, showing evidence of cultivation in the vicinity of that site beginning, apparently, very early in the Christian era. Nevertheless, the economy of these people basically depended on the products of the sea : fish, shell-fish, and sea mammals [9, p. 273 and p. 276; 8, p. 92].

In the Atacama hinterland, population centred in the Calama oasis, on the Loa River. Irrigated agriculture was the basis of Atacameño subsistence, and aqueducts are known that conveyed water for considerable distances; however, the very limited productivity of the area impeded any growth. Herding was also of great importance; the llamas and alpacas

1. At Quiani 'perhaps water was formerly secured from a well or spring in the bottom of the gully'; at Punta Pichalo 'perhaps, in former times, a spring was available' [9, p. 232 and p. 253].
2. In the phase Quiani 2, possibly contemporaneous with Pichalo 1 [cf. 9, p. 277; 87, p. 370].

grazing in the neighbouring punas supplied meat, as well as wool and other raw materials. Llamas also served for transportation, as pack animals, and there is evidence that the Atacameños acted as middlemen between the coast and the interior, to north-western Argentina [6, p. 38; 7, p. 600, and p. 606; 8, p. 90]. The Atacameño culture of the Chilean oasis looks like a peripheral extension of a large zone of puna-adapted mixed economy, i.e., combined, limited oasis irrigated agriculture and herding, as mutually complementary activities for the exploitation of the meagre resources of the environment (Schaedel and Munizaga [73, p. 33] mentioning Bowman). The antiquity of this pattern in the Chilean section does not seem to be earlier than the latter half of the first millennium of the Christian era.

The southern Andean arid zone agriculture-and-grazing pattern of land use extended over all north-western Argentina—the cold desert high punas, the intermontane dry valleys, and the piedmont steppes and savannas to the Pampean Sierras—and the zone of transition between the northern desert and the central Chilean 'mediterranean' climates, in the present day provinces of Atacama and Coquimbo.

The remains of agricultural terraces are found in the high punas, the Quebrada de Humahuaca, and the Santa Victoria range in the north.[1] Their frequency appears to diminish to the south, although the Calchaquí Diaguita that inhabited the southern part of the zone are credited with irrigation and stone-faced terraces for farming [8, p. 88].[2] Irrigation was important in the Quebrada de Humahuaca. Speaking in general, for the whole area, both irrigated and rain-farming terraces are mentioned in the available summaries, but their respective distribution does not seem to have been mapped in detail.

The extension of the limited intensive agriculture and grazing pattern of land use over north-western Argentina does not, however, seem older that the latter part of the first millennium of the Christian era, as in northern Chile. It was evidently derived from influences emanating from the central Andes, that also brought into these regions elements of the Tiahuanaco style. Intensity diminishes towards the periphery.

Although incipient farming (with maize, at least), possibly depending on heavy summer rainfall, appears earlier than that—perhaps in the early centuries of the Christian era—in La Candelaria section (climate *Cwa*) of the Province of Salta, no details are known of this culture's pattern of land use [85, p. 663] [for dating see 87, figure 12, sequence chart].

At the time of the Spanish exploration, river flood-plain farming was practised in the *tierra bañada* along the Dulce and the Salado rivers of Santiago del Estero; native economy depended upon cultivation of maize, quinoa, beans, and pumpkins, gathering of wild plants, hunting and fishing, and llama herds [55, p. 657]. Further south, the Comechingón Indians of the provinces of Córdoba and San Luis, whose dwelling sites were found near streams or small springs, are also credited with cultivation and herding by the early Spanish reports [1, p. 676]. This marks the extreme south-eastern limit of native American cultivation. Beyond, the Pampas and Patagonia were inhabited by nomadic hunting bands.

1. For an example of irrigated terraces in the high punas see Krapovickas [42, p. 11] on Tebenchique or Tebenquiche, an ancient settlement at 3,500 m. altitude, in the bleak area north-west of Antofagasta de la Sierra. As typical examples of terraces in the Puna, Casanova [17, p. 620] mentions stepped hillsides at Sayate and Casabindo; it is not clear from this reference whether those were irrigated or dry. He also mentions Coctaca and Alfarcito in the Quebrada de Humahuaca. In the Santa Victoria area, Mârquez Miranda [56, p. 24] mentions Higueras and Huaira-huasi.
2. However, Márquez Miranda [54, p. 640] states that in the whole Diaguita area agriculture depended on rain, and that terraces (apparently found only or mostly in the Calchaquí sub-area) were a means of increasing rain efficiency, while Bennett [6, p. 40] minimizes the importance of Diaguita terracing.

# BIBLIOGRAPHY


1. Aparicio, F. de. The Comechingón and their neighbors of the Sierras de Córdoba. In : *Handbook of South American Indians, Vol. 2 : the Andean civilizations.* Washington, 1946. p. 673-685. (*Smithsonian Institution, Bureau of American Ethnology, bulletin*, no. 143.)
2. Armillas, P. Notas sobre sistemas de cultivo en Mesoamérica : cultivos de riego y humedad en la cuenca del río de las Balsas. *Anales del Instituto Nacional de Antropología e Historia*, vol. III (1947-1948). México, 1949. p. 85-113.
3. ——; Palerm, A.; Wolf, E. R. A small irrigation system in the Valley of Teotihuacan. *American Antiquity*, vol. XXI, no. 4, 1956. p. 396-399.
4. Barghoorn, E. S.; Wolfe, M. K.; Clisby, K. H. Fossil maize from the Valley of Mexico. *Botanical Museum Leaflets, Harvard University*, vol. 16, no. 9, 1954. p. 229-240.
5. Bennett, W. C. *Archaeology of the North Coast of Peru : an account of exploration and excavation in Viru and Lambayeque Valleys.* New York, 1939. (*The American Meuseum of Natural History, anthropological papers*, vol. XXXVII, pt. I.)
6. ——. The Andean Highlands : an introduction. In : *Handbook of South American Indians, Vol. 2 : The Andean Civilizations.* Washington, 1946. p. 1-60. (*Smithsonian Institution, Bureau of American Ethnology, bulletin*, no. 143.)
7. ——. The Atacameño. Ibid. p. 599-618.

8. ——; Bird, J. B. *Andean culture history.* New York, 1949. (*The American Museum of Natural History, handbook series*, no. 15.)
9. Bird, J. B. *Excavations in northern Chile.* New York, 1943. p. 169-318. (*The American Museum of Natural History, anthropological papers*, vol. XXXVIII, pt. IV.)
10. ——. The cultural sequence of the North Chilean coast. In : *Handbook of South American Indians, Vol. 2 : the Andean civilizations.* Washington, 1946. p. 587-594. (*Smithsonian Institution, Bureau of American Ethnology, bulletin*, no. 143.)
11. ——. Preceramic cultures in Chicama and Virú. *A reappraisal of Peruvian archaeology.* Menasha, 1948. p. 21-28. (*Memoirs of the Society for American Archaeology*, no. 4.)
12. Braidwood, R. J.; Reed, C. A. The achievement and early consequences of food-production : a consideration of the archaeological and natural-historical evidence. *Cold Spring Harbor Symposia on Quantitative Biology*, vol. XXII, 1957. p. 19-31.
13. Brew, J. O. *Archaeology of Alkali Ridge, southeastern Utah.* Cambridge, 1946. *Peabody Museum, Harvard University, papers*, vol. XXI.)
14. Bryan, K. Flood-water farming. *Geographical Review*, New York, vol. XIX, no. 3, 1929. p. 444-456.
15. ——. Pre-Columbian agriculture in the south-west, as conditioned by periods of alluviation. *Annals of the Association of American Geographers*, vol. XXXI, no. 4, 1941. p. 219-242.
16. Carter, G. F. *Plant geography and culture history in the American South-west.* New York, 1945. (*Viking Fund publications in anthropology*, no. 5.)
17. Casanova, E. The cultures of the Puna and the Quebrada of Humahuaca. In : *Handbook of South American Indians, Vol. 2 : the Andean civilizations.* Washington, 1946. p. 619-631. (*Smithsonian Institution, Bureau of American Ethnology, bulletin*, no. 143.)
18. Castetter, E. F.; Bell, W. H. *Pima and Papago Indian agriculture.* Albuquerque, University of New Mexico Press, 1942.
19. ——; ——. *Yuman Indian agriculture : primitive subsistence on the lower Colorado and Gila rivers.* Albuquerque, University of New Mexico Press, 1951.
20. Chard, C. S. New World origins : a reappraisal. *Antiquity*, vol. XXXIII, no. 129, 1959. p. 44-49.
21. Cieza de Leon, P. de. *Primera parte de la crónica del Perú.* (Several printings, edition quoted : *La crónica del Perú 'Colección Austral'*, no. 507. Buenos Aires; México, Espasa-Calpe Argentina, 1945. English translation : *The travels of Pedro de Cieza de León*, A.D. *1532-1550*, London, Hakluyt Society, 1864.)
22. Collier, D. Development of civilization on the coast of Peru. *Irrigation civilizations : a comparative study.* Washington, 1955. p. 19-27. (*Pan American Union, social science monographs*, I.)
23. Colton, H. S. Sunset Crater : the effect of a volcanic eruption on an ancient Pueblo people. *Geographical Review*, New York, vol. XXII, no. 4, 1932. p. 582-590.
24. Crane, H. R.; Griffin, J. B. University of Michigan radiocarbon dates II. *Science*, vol. 127, no. 3306, 1958. p. 1098-1105.
25. Dressler, R. L. The pre-Columbian cultivated plants of Mexico. *Botanical Museum Leaflets, Harvard University*, vol. 16, no. 6, 1953. p. 115-172.
26. Engel, F. Sites et établissements sans céramique de la côte péruvienne. *Journal de la Société des Américanistes*, Paris, vol. XLVI, 1957. p. 67-155.
27. Fejos, P. *Archaeological explorations in the Cordillera Vilcabamba, south-eastern Peru.* New York, 1944. (*Viking Fund publications in anthropology*, no. 3.)
28. Ford, J. A.; Willey, G. R. *Surface survey of the Virú Valley, Peru.* New York, 1949. (*The American Museum of Natural History, anthropological papers*, vol. 43, pt. 1.)
29. Forde, C. D. Hopi agriculture and land ownership. *Journal of the Royal Anthropological Institute of Great Britain and Ireland*, vol. 61, 1931. p. 357-405.
30. Gregory, H. E. *The Navajo country : a geographic and hydrographic reconnaissance of parts of Arizona, New Mexico, and Utah.* Washington, 1916. (*Department of the Interior, Geological Survey, water-supply paper*, 380.)
31. Hack, J. T. *The changing physical environment of the Hopi Indians of Arizona.* Cambridge, 1942. (*Peabody Museum, Harvard University, papers*, vol. XXXV, no. 1.)
32. Haury, E. W. The Snaketown canal. *Symposium on prehistoric agriculture.* Albuquerque, 1936. p. 48-50. (*University of New Mexico, anthropological series.*)
33. ——. The Snaketown canal. In : Gladwin, H. S.; Haury, E. W.; Sayles, E. B.; Gladwin, N. *Excavations at Snaketown, I.* Globe, 1937. p. 50-58. (*Medallion papers*, no. 25.)
34. ——. *The excavation of Los Muertos and neighboring ruins in the Salt River valley, southern Arizona.* Cambridge, 1945. (*Peabody Museum, Harvard University, papers*, vol. XXIV, no. 1.)
35. ——. Speculations on prehistoric settlement patterns in the south-west. *Prehistoric settlement patterns in the New World.* New York, 1956. p. 3-10. (*Viking Fund publications in anthropology*, no. 23.)
36. Hoover, J. W. Tusayan : the Hopi Indian country of Arizona. *Geographical Review*, New York, vol. XX, no. 3, 1930. p. 425-444.
37. Horkheimer, H. *La alimentación en el Perú prehispánico y su interdependencia con la agricultura.* Lima, 1958. Mimeographed. (*Unesco, Programa de estudios de la zona árida peruana.*)
38. Jennings, J. D. *et al.* The American south-west : a problem in cultural isolation. *Seminars in archaeology : 1955.* Salt Lake City, 1956. p. 61-127. (*Memoirs of the Society for American Archaeology*, no. 11.)
39. Kelley, J. C. Factors involved in the abandonment of certain peripheral south-western settlements. *American Anthropologist*, vol. 54, no. 3, 1952. p. 356-387.
40. ——. Settlement patterns in north-central Mexico. *Prehistoric settlement patterns in the New World.* New York, 1956. p. 128-139. (*Viking Fund publications in anthropology*, no. 23.)
41. ——. The desert cultures and the Balcones phase : archaic manifestations in the south-west and Texas. *American Antiquity*, Salt Lake City, vol. XXIV, no. 3, 1959. p. 276-288.
42. Krapovickas, P. *El yacimiento de Tebenchique (Puna de Atacama).* Buenos Aires, 1955. (*Universidad de Buenos Aires, Instituto de Arqueología, Publicaciones*, III.)
43. Kroeber, A. L. *Peruvian archaeology in 1942.* New York, 1944. (*Viking Fund publications in anthropology*, no. 4.)

44. KUBLER, G. The Quechua in the Colonial world. In : *Handbook of South American Indians, Vol. 2 : the Andean Civilizations.* Washington, 1946, p. 331-410. (*Smithsonian Institution, Bureau of American Ethnology, bulletin,* no. 143.)
45. ——. Towards absolute time : guano archaeology. *A reappraisal of Peruvian archaeology.* Menasha, 1948. p. 29-50. (*Memoirs of the Society for American Archaeology,* no. 4.)
46. LARCO HOYLE, R. A culture sequence for the north coast of Peru. In : *Handbook of South American Indians, Vol. 2 : the Andean civilizations.* Washington, 1946. p. 149-175. (*Smithsonian Institution, Bureau of American Ethnology, bulletin,* no. 143.)
47. LIBBY, W. F. *Radiocarbon dating.* Chicago, University of Chicago Press, 1955.
48. LUNDELL, C. L. The 1936 Michigan-Carnegie botanical expedition to British Honduras. *Botany of the Maya area : miscellaneous papers.* Washington, 1940. p. 1-57. *(Carnegie Institution of Washington, publication 522.)*
49. MACNEISH, R. S. A synopsis of the archaeological sequence in the Sierra de Tamaulipas. *Revista Mexicana de Estudios Antropológicos,* Mexico, vol. XI, 1950. p. 79-96.
50. ——. Ancient maize and Mexico. *Archaeology,* vol. 8, no. 2, 1955. p. 108-115.
51. ——. Prehistoric settlement patterns on the northeastern periphery of Mesoamerica. *Prehistoric settlement patterns in the New World.* New York, 1956. p. 140-147. (*Viking Fund publications in anthropology,* no. 23.)
52. ——. *Preliminary archaeological investigations in the Sierra de Tamaulipas, Mexico.* Philadelphia, 1958. (*American Philosophical Society, transactions, new series,* vol. 48, pt. 6.)
53. MANGELSDORF, P. C. New evidence on the origin and ancestry of maize. *American Antiquity,* Salt Lake City, vol. XIX, no. 4, 1954. p. 409-410.
54. MARQUEZ MIRANDA, F. The Diaguita of Argentina. In : *Handbook of South American Indians, Vol. 2 : the Andean civilizations.* Washington, 1946. p. 637-654. (*Smithsonian Institution, Bureau of American Ethnology, bulletin,* no. 143.)
55. ——. The Chaco-Santiagueno culture. ibid. p. 655-660.
56. ——. *Región meridional de América del Sur.* Instituto Panamericano de Geografía e Historia, Comisión de Historia, México, 1954. *(Programa de historia de América, período indígena: 10.)*
57. MILLON, R. Irrigation at Teotihuacán. *American Antiquity,* Salt Lake City, vol. XX, no. 2, 1954. p. 177-180.
58. ——. When money grew on trees : a study of cacao in ancient Mesoamerica. (Unpublished doctoral dissertation, Faculty of Political Science, Columbia University, 1955.)
59. ——. Irrigation systems in the Valley of Teotihuacán, *American Antiquity,* Salt Lake City, vol. XXIII, no. 2, pt. 1, 1957. p. 160-166.
60. O'BRYAN, D. The abandonment of the northern pueblos in the thirteenth century. *Indian tribes of aboriginal America : selected papers of the XXIXth International Congress of Americanists.* Chicago, University of Chicago Press, 1952. p. 153-157.
61. OSBORNE, D. Western American prehistory—an hypothesis. *American Antiquity,* Salt Lake City, vol. XXIV, no. 1, 1958. p. 47-52.
62. PALERM, A. La distribución del regadío en el área central de Mesoamérica. *Ciencias Sociales,* Washington, Unión Panamericana, vol. V, nos. 25 and 26, 1954. p. 2-15 and p. 64-74.
63. ——. The agricultural basis of urban civilization in Mesoamerica. *Irrigation civilizations : a comparative study.* Washington, 1955, p. 28-42. (*Pan American Union, social science monographs,* I.)
64. REGAL, A. Política hidráulica del imperio incaico. *Revista de la Universidad Católica del Perú,* Lima, vol. XIII, no. 2-3, 1945. p. 75-110.
65. REPARAZ, G. DE. La zone aride du Pérou. *Geografiska Annaler,* Stockholm, vol. XL, no. 1, 1958.
66. ROWE, J. H. Inca culture at the time of the Spanish conquest. In : *Handbook of South American Indians, Vol. 2 : the Andean civilizations.* Washington, 1946, p. 183-330. (*Smithsonian Institution, Bureau of American Ethnology, bulletin,* no. 143.)
67. SANDERS, W. T. The anthropogeography of central Veracruz. *Huastecos, totonacos y sus vecinos,* Mexico, Sociedad Mexicana de Antropología, 1953. p. 27-78.
68. ——. The Central Mexican symbiotic region : a study in prehistoric settlement patterns. *Prehistoric settlement patterns in the New World.* New York, 1956. p. 115-127. (*Viking Fund publications in anthropology,* no. 23.)
69. SAUER, C. *Colima of New Spain in the sixteenth century.* Berkeley and Los Angeles, University of California Press, 1948. *(Ibero-Americana : 29.)*
70. ——. Cultivated plants of South and Central America. In : *Handbook of South American Indians, Vol. 6 : physical anthropology, linguistics, and cultural geography of South American Indians.* Washington, 1950. p. 487-543. (*Smithsonian Institution, Bureau of American Ethnology, bulletin,* no. 143.)
71. ——. *Agricultural origins and dispersals.* New York, The American Geographical Society, 1952.
72. ——. The agency of man on the Earth. In : *Man's role in changing the face of the Earth.* Chicago, University of Chicago Press, 1956. p. 49-69.
73. SCHAEDEL, R. P.; MUNIZAGA, C. *Arqueología chilena : contribuciones al estudio de la región comprendida entre Arica y La Serena.* Santiago de Chile, Universidad de Chile, Centro de Estudios Antropológicos, 1957.
74. SCHILLING, E. *Die 'schwimmenden Gärten' von Xochimilco.* Kiel, 1939. (*Schriften des Geographischen Institüts der Universität Kiel,* vol. IX, pt. 3.)
75. SHIPPEE, R. Lost valleys of Peru : results of the Shippee-Johnson Peruvian Expedition. *Geographical Review,* vol. XXII, no. 4, 1932. p. 562-581.
76. STEWARD, J. H. *Basin-Plateau aboriginal sociopolitical groups.* Washington, 1938. (*Smithsonian Institution, Bureau of American Ethnology, bulletin,* no. 120.)
77. STEWART, O. C. Fire as the first great force employed by man. In : *Man's role in changing the face of the Earth.* Chicago, University of Chicago Press, 1956. p. 115-133.
78. STRONG, W. D.; EVANS, C., Jr. *Cultural stratigraphy in the Virú Valley, northern Peru : the Formative and Florescent epochs.* New York, Columbia University Press, 1952. (*Columbia studies in archaeology and ethnology,* vol. IV.)
79. TOLSTOY, P. The archaeology of the Lena Basin and its New World relationships, Parts I and II. *American Antiquity,* vols. XXIII and XXIV, 1958. p. 397-418 and p. 63-81.
80. WEDEL, W. R. Some aspects of human ecology in the

Central Plains. *American Anthropologist*, vol. LV, no. 4, 1953. p. 499-514.

81. ——. Changing settlement patterns in the Great Plains. *Prehistoric settlement patterns in the New World.* New York, 1956. p. 81-92. (*Viking Fund publications in anthropology*, no. 23.)
82. ——. Las Praderas Centrales de Norteamérica ¿naturales u obra humana? *Estudios sobre ecología humana.* Washington, 1958. p. 39-69. (*Unión Panamericana, estudios monográficos*, III.)
83. West, R. C. *Cultural geography of the modern Tarascan area.* Washington, 1948. (*Smithsonian Institution, Institute of Social Anthropology, publication*, no. 7.)
84. ——; Armillas, P. Las chinampas de México. *Cuadernos Americanos*, México, Ano IX, no. 2, 1950. p. 165-182.
85. Willey, G. R. The culture of La Candelaria. In : *Handbook of South American Indians, Vol. 2 : the Andean civilizations.* Washington, 1946. p. 661-672. (*Smithsonian Institution, Bureau of American Ethnology, bulletin*, no. 143.)
86. ——. *Prehistoric settlement patterns in the Virú Valley, Perú.* Washington, 1953. (*Smithsonian Institution, Bureau of American Ethnology, bulletin*, no. 155.)
87. ——. Estimated correlations and dating of South and Central American culture sequences. *American Antiquity*, Salt Lake City, vol. XXIII, no. 4, 1958. p. 353-378.
88. ——; Corbett, J. M. *Early Ancón and early Supe culture : Chavín horizon sites of the Central Peruvian Coast.* New York, Columbia University Press, 1954. (*Columbia studies in archaeology and ethnology*, vol. III.)
89. Wittfogel, K. A. The hydraulic civilizations. In : *Man's role in changing the face of the Earth.* Chicago, University of Chicago Press, 1956. p. 152-164.
90. Wolf, E. R.; Palerm, A. Irrigation in the old Acolhua domain, Mexico. *Southwestern Journal of Anthropology*, Albuquerque, vol. 11, no. 3, 1955. p. 265-281.
91. Wormington, H. M. *Ancient Man in North America.* Denver, 1957.

# POST-COLUMBIAN DEVELOPMENTS IN THE ARID REGIONS OF THE UNITED STATES OF AMERICA

by

RICHARD F. LOGAN

*Associate Professor of Geography,*
*University of California, Los Angeles, USA*

Despite the natural handicaps imposed by its climate, the arid western portion of the United States plays an important role in the economy of the nation. This has not always been the case. In earlier times, it was a great empty void—neither contributing to nor detracting from the value of the country. Later it became a nearly impassable barrier between two prospering areas, and had the sense of unity and common interest between the two parts not been so strong, it might well have caused a splitting of the one country into two separate entities. Today the two parts are strongly bound together, thanks to modern technology, and the intervening area—the desert—is rapidly developing in its own right. In the pages that follow, we will trace the economic development of the arid portion, show its present situation, and attempt to predict its immediate future.[1]

## THE PHYSICAL SETTING

Since we are concerned only with the arid regions, the area will be largely confined to the intermontane west—to the area between the coastal ranges and the main divide of the Rocky Mountains. Only in southern New Mexico where the Rockies are absent as a bordering range, does the arid land extend eastward into the edges of the central lowlands of North America; and only at the Mexican border itself do arid conditions extend westward to the Pacific side of the coastal mountains. Large tracts of semi-arid lands in the north-western States of the Union and in the Great Plains are omitted by definition.

### LANDFORMS

Mountain- and bolson-topography characterizes the greater part of the North American desert. High rugged mountains of complex geology, arranged in linear patterns often resulting from block-faulting, rise abruptly above broad alluvium-filled basins. In some areas, drainage is centripetal, terminating in a central *playa* or salt flat. Elsewhere, basins have been amalgamated, and drainage is external, by way of the Colorado or the Rio Grande. The basins are flanked by tremendous arrays of coalesced alluvial fans, gravelly or sandy in composition, smooth surfaced, and sloping at low angles toward the distant basin centre. Precipitation falls chiefly in the mountains, yet only rarely are permanent streams or even springs to be discovered there, for the run-off is rapid and there is little soil to retain a supply. Surface water is almost totally lacking in the basins. In many bolsons, an abundant subterranean supply is available in the underlying alluvium; its quality usually varies from good about the margins of the bolson to highly saline near the central *playa.*

The major streams, such as the Rio Grande and the Colorado and the tributaries of the latter—the Salt, the Gila and the Virgin—are exotic streams rising in the better-watered lands peripheral to the desert and flowing from bolson to bolson across it. Others, such as the Mojave and the Humboldt, similarly pass from basin to basin, but eventually terminate in the desert itself, losing their waters so rapidly by evaporation that they never reach the sea.

The plateaux of north-eastern Arizona and southern Utah, and the plains and plateaux of eastern New Mexico and adjacent Texas are exceptions to the above. There, nearly horizontal sedimentary strata, some with overlying lava flows, create areas of sweeping skylines and great flatness. In some places, however, these plateaux have been etched into majestic relief through the carving of deep canyons by their streams; there, bare rock predominates and the land is worthless for agriculture and of low value even for grazing.

1. No attention is given herein to the extraction of minerals.

CLIMATE

Among these widely diverse landforms, the distribution of precipitation is extremely varied. In the mountain and bolson country, the ranges often raise their heads up out of the desert into a subhumid environment, thanks to the high incidence of orographic precipitation; but the adjacent basins very often have annual totals of less than three inches of precipitation. On the western and southern faces of the great plateaux of northern Arizona, too, orographic precipitation is heavy owing to the rise of air up the escarpment; yet on the surface of the plateau a few score miles to the leeward of the escarpment edge, desert conditions prevail. In south-western Arizona, and in southern New Mexico, where none of the ranges reaches high enough to cause orographic rainfall, desert conditions prevail throughout the land.

Moisture comes to the desert country from two different sources, and falls in two different forms at opposite times of the year in two distinct regions. From the warm Gulf of Mexico, moist air is drawn in during the summer across southern Texas and occasionally penetrates the deserts of New Mexico, Arizona and even south-eastern California. The air is expanded by strong surface heating, convectional currents develop and short-lived torrential downpours ensue. From the Pacific, in contrast, moisture-laden air passes inland during winter in association with frontal disturbances, and soaking rains occur over the deserts as far south as central California and the Arizona Plateaux. It is at such times that the orographic factor is strongly exerted. Thus two rainfall régimes characterize the American desert—winter rains in the north-west, and summer rains in the south-east. A large area in south-eastern California and south-western Arizona lying between these two zones, seldom receives either winter or summer precipitation in abundance, and hence is the driest part of the country.

Thermally, the desert may be divided into two zones, based upon the mean minimum temperatures of the coldest month. One zone, consisting chiefly of the Salt and Gila River valleys of Arizona, the lower Colorado River valley, and the Imperial and Coachella valleys of California, has January minima normally above freezing, and hence is close to being a tropical desert. The remainder of the western desert country has cool to cold winters. Dawn temperatures in Nevada, the plateaux of Arizona and the higher basins and valleys of New Mexico often approach zero (Fahrenheit) in January.

VEGETATION

From the standpoint of its economic value, the vegetation of the American desert can be divided into six regional types: short grass, desert grass, pinyon-juniper, sagebrush, creosote bush and Sonoran.

The south-eastern deserts, areas of summer rainfall, are predominantly grasslands, whereas in the winter rainfall country of the north-west, brush is dominant. Large expanses of the plateaux of Arizona, New Mexico and western Texas have an open cover of short grass, which provides excellent grazing. The dominant species, blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchloe dactyloides*), are both short in stature and highly nutritious. When overgrazed, however, as many of these ranges have been, the grasses are replaced by various worthless shrubs, including *Yucca* spp. and *Gutierrezia sarothrae.* For the most part, these grasslands constitute land capable of being grazed the year round.

Open stands of desert grass cover the bolsons of south-eastern Arizona and southern New Mexico. While pure stands of grass are sometimes encountered, the grass is usually accompanied by a considerable scattering of shrubs, notably creosote bush (*Larrea tridentata*) soapweed (*Yucca elata*), catclaw (*Acacia greggii*), mesquite (*Prosopis juliflora*) and various cacti, especially *Opuntia* spp. The major grass is the highly nutritious black grama (*Bouteloua eriopoda*). Overgrazing tends to increase the shrub cover, in part by the increase of minor species such as *Gutierrezia sarothrae* and *Aplopappus fruticosus*, and in part by an increase in the amount of cactus. These year-round grazing ranges are surprisingly productive, being capable of supporting an average of fifteen head of cattle per square mile.

The winter rain areas of the American desert are characterized by an open cover of shrubs. Over wide reaches of the cooler desert (Nevada, western Utah and adjacent areas), the Great Basin sagebrush (*Artemisia tridentata*) is the dominant plant, accompanied by yellowbrush (*Chrysothamnus viscidiflorus*) and shadscale (*Atriplex confertiflora*). These shrubs provide good forage, particularly for sheep. As a result of overstocking, many areas have been badly overgrazed. The normal carrying capacity for cattle is between ten and fifteen acres per animal per month.

The deserts of California and north-western Arizona have a very open cover of creosote bush (*Larrea tridentata*) and burroweed (*Franseria dumosa*). The former is worthless as a browse plant. Herbaceous annuals and some grasses flourish for a few weeks in the spring of wet years, and are grazed by herds or flocks transported to the area on a temporary basis. The permanent carrying capacity is very low, probably requiring more than 100 acres per head of cattle.

In southern Arizona, where the summer rainfall is heavier than in adjacent California, large cacti and thorny shrubs and sub-trees characteristic of nearby Sonora dominate the vegetation. Although a scattering of grass occurs, very little nutritious feed for animals is available, and most of the area is essentially ungrazed.

## HISTORY

### EXPLORATION AND EARLY SETTLEMENT

Until the middle of the nineteenth century the vast arid and semi-arid region lying between the Rocky Mountains and the ranges bordering the Pacific Ocean was virtually unknown to the white man. A century earlier Spanish missionaries had penetrated a small part of southern Arizona, had founded a scattering of missions there and had made occasional trips across the intervening desert to the chain of similar missions along the California coast. During and following the 1820s parties of American trappers and traders had penetrated the area in search of beaver pelts. Neither group wrote detailed descriptions nor published maps of the region and hence there was virtually no knowledge of it in the outside world.

During the 1840s this situation began to change. Between 1842 and 1848, General John C. Fremont made a series of scientific expeditions into California and Oregon and reported in detail on the country visited. In 1848 the entire territory comprising the present states of California, Nevada, Utah and Arizona, much of New Mexico and Colorado and a portion of Wyoming was ceded to the United States by Mexico. Almost simultaneously gold was discovered in California. During the next decade tens of thousands of people crossed the region en route to the gold fields, but their passage actually had little effect upon it. The area lay virtually empty and unused until the latter part of the 1860s.

Actually the area was and had been since time immemorial sparsely inhabited by migratory Indian tribes with a hunting and gathering culture. These people were generally considered by the white man as having no rights whatever. Where weak, scattered and disunified, they were simply ignored by the white man or were displaced by him if in his way. Where war-like and united under a strong leader, military measures were taken to suppress and subjugate them. From the ownership point of view it was generally assumed that the land was unoccupied and unowned and hence open to claim by anyone. In some instances title to vast areas was obtained by the federal government through treaties with the resident Indian tribe.[1]

It is most unfortunate that these vast unoccupied areas could not have been systematically studied and subdivided prior to settlement. Had such been possible, natural and human resources could have been conserved. However, the American administrative and political system was not yet ready for such an orderly procedure.

In the late 1860s an influx of potential settlers began, chiefly comprised of graziers from the semi-arid region farther east. At this time conditions in the arid west were far from stable. The nation was recovering from the Civil War—a long and all-consuming conflict waged between the northern and southern parts of the nation primarily over the issue of slavery. The sparsely settled western territories were poorly administered and the military and police forces were inadequate. Consequently the period was one in which force and violence often triumphed over justice and the gun often took the place of the law. Some of the newcomers were recently discharged or even renegade soldiers of both sides—men accustomed to violence and not loath to continue it in a new area. The chaos that resulted has been the background for many of the 'Wild West' motion pictures and stories.

### LAND OWNERSHIP

The ensuing half-century was the era of the 'open range'. Graziers laid claim to the widely-separated watering places and thus held practical, although not legal, control over vast waterless grazing lands. In course of time, the authority of the General Land Office was extended to the range country, and claims to the water sources were legalized under its procedures.

Since the General Land Office exerted a profound effect upon settlement in the arid west, it is appropriate here to review that organization and its policies.

#### *The General Land Office system*

The General Land Office was an agency of the federal government created to administer and apportion the public lands of the United States. Under its auspices a citizen could acquire title to the public land by several different methods:

1. By pre-emption, a citizen having settled on 160 acres of land before its being officially opened for settlement and having erected a dwelling and having made certain prescribed improvements, could become the owner of the tract by paying $1.25 or $2.50 per acre, depending upon the location of the plot relative to the existing railways.
2. Lands were sold to the highest bidder at public auction.
3. Lands offered but not sold at such public auction could be purchased at $1.25 or $2.50 per acre.
4. Under the Homestead Act any citizen could obtain title to 160 acres by paying a nominal filing fee (usually $10), residing on the land at least 7 months per year for a period of 5 years, and making certain improvements on the land.

1. The Indian irrigation agriculturalists were treated in quite another manner. Their history and present situation will be dealt with later on in this chapter.
In certain areas which had been settled by the Spanish or Mexicans earlier, existing land grants were recognized and validated, and hence did not fall within the categories of federal lands. The chief area of such land holdings was in the Rio Grande Valley of New Mexico. The Spanish settlements in California did not extend into the arid tracts.

The General Land Office system of land division had been devised for the apportionment of large unoccupied tracts east of the Mississippi River. For those humid and rather uniform plains, a rectangular survey plan was originated, dividing the landscape into parcels of 80 or 160 acres each. As the American frontier of settlements pushed westwards, this system of land apportionment went along with it. Whether the rainfall was 40 inches or 10 inches, whether the area was suitable for intensive agriculture or for range grazing, whether it consisted of flat monotonous plains or high rugged mountains, the basic unit of land ownership was not permitted to exceed 160 acres.

In the humid area of the United States for which the system was conceived, 160 acres was a generous allotment of land upon which a family unit could, by either the earlier subsistence economy or by the later commercial agriculture, maintain itself at a moderate to high standard of living. On the other hand, it is obvious that land holdings of such small size are totally inadequate for enterprises in a semi-arid or arid pastoral region. In most arid regions, 160 acres would support no more than 2 head of cattle even if a water supply were included on the holdings; and most tracts would be totally waterless.

Realizing that these provisions were inadequate for the handling of irrigable desert tracts, the Desert Land Act of 1877 provided that title might be secured to a full section (1 square mile or 640 acres) by the payment of 25 cents per acre at the time of filing of the claim and by reclaiming part of the land within 3 years and paying an additional $1 per acre at that time. The Act had only a limited effect however. The law required that part of the land be irrigated—and most of the land in the arid west was not irrigable. At the same time, irrigable land could be had virtually free of cost under the Homestead Act. Thus the Desert Land Act did not improve the situation in the irrigable tracts, nor did it do anything to make range land available to the graziers.

In 1879 a federal commission headed by John Wesley Powell turned in its report on the governmental policies concerning the public lands of the arid west. The report stated that 'a very great proportion of the lands of the west cannot become settled and pass into private ownership because under the terms of the existing laws it is not desirable for settlers to acquire them. . . . The Homestead and Pre-emption Laws are not suited for securing the settlement of more than an insignificant portion of the country'.

The report went on to suggest :

1. That land should be scientifically appraised and classified before settlement and that each category should be handled under laws specifically applicable only to it.
2. That land must be disposed of in quantities sufficient for the establishment of a working enterprise and that the price of such a grant must be kept low. At least 4 square miles (2,560 acres) was proposed as a minimum.
3. That farm (ranch) residences be grouped to permit a form of social life not possible on isolated ranchsteads.
4. That surveying should deviate from the rectangular systems where necessary to properly divide waters.
5. That because of the great expense required to develop irrigation, irrigation schemes should be undertaken under the auspices of the federal government.

Unfortunately no action was taken by the Congress of the United States on these suggestions. The General Land Office had for long been so deeply involved in politics that most legislators were reluctant to alter it, either in personnel or in policy; and the programme was so visionary as to be far ahead of the thinking of its time. Today, in looking back over the past, it is apparent that it was an ideal and logical group of suggestions, but in its time it was so regarded by only a handful of legislators, and its influence was not great. Its greatest effect was to attract public attention to the fact that the arable public lands were fast approaching exhaustion.

## BEGINNINGS OF CONSERVATION

During the next half-century public opinion changed greatly regarding the role of the federal government in the arid west. The 1890s saw a great rise in public and political interest in conservation measures. In 1891 the first National Forest was created, with the intention of conserving for continuing use into the future the forest lands atop the mountains of the west and the grazing areas that lay therein. While these were not themselves arid land, they had a most salutary effect upon the desert areas nearby in providing summer grazing for flocks and herds from those less well-provided regions. While small additions were made to the national forest holdings during the 1890s, the movement received its greatest impetus under President Theodore Roosevelt after 1906.

But while tens of millions of acres were set aside for forest conservation, the rest of the public domain lay unadministered for decades. The grazing lands remained open range, grazed by holders of local water rights in any way they deemed advantageous. Many of these operations covered tremendous areas. Some were operated by private individuals, others by large companies. Since ranchers had neither permanent control nor legal rights to the range, there was little tendency towards conservation measures, or towards improvement of the existing conditions. Many of the herds were quite migratory, traversing great distances over a period of years. The land was not obtainable under any legal system then in existence.

In 1916 an attempt to remedy this situation, through the passage of the Stock-raising Homestead Act proved quite fruitless. In theory, this act was designed to give cattlemen an area large enough to raise 50 head of cattle —an economic unit supposedly large enough to support a family. The area agreed upon was one section, or 640 acres. In an area where from 50 to 100 acres are required to support a single beef animal, such a proposal was far from realistic; the short-sightedness of legislators and administrators of that day regarding the nature of the west is astounding. As a result, the act had little effect on landholdings in the desert west and the bulk of the public domain still remained uncontrolled and unadministered.

During the long period of unrestricted grazing the range country was subjected to terrible misuse. The philosophy of 'first come first served' created vast barren areas. The range was always overstocked, ranchers were not interested in grassland management, and, under the form of uncontrolled grazing that existed, everything edible was consumed by the flocks or herds. The result is that some technicians today estimate the carrying capacity of the range at only two-fifths of what it was three-quarters of a century ago.

### THE TAYLOR GRAZING ACT

While many conservationists realized the short-comings of this situation, nothing really tangible was done about it until the passage of the Taylor Grazing Act in 1934. This legislation stabilized the situation existing on the open range by providing for the creation of grazing districts within which grazing would be permitted under management and control of the federal government, and also for the leasing of lands outside such districts for private use. At the same time, it finally put into operation one of the recommendations made by Powell 55 years earlier : a general land classification authority was established. Where the land was classified as suitable for agricultural use, homestead claims were permitted. All other land came under the jurisdiction of the Grazing Service of the Department of the Interior (later this activity was transferred to the Bureau of Land Management).

The Act specified that 'reasonable' fees should be charged for the use of public land by graziers. The original intention was that these fees should be low enough to provide only for the cost of administering the Act. In practice, no fee was charged for the first year. Subsequently a nominal fee (5 cents per head per month for cattle and 1 cent per head per month for sheep) was established. The rate charged was the same in all areas, regardless of the nature of the range. These fees proved to be totally impractical, but efforts to alter them were unsuccessful, since a three-fold impasse developed in Congress: (a) The Grazing Service asked for direct appropriations from Congress; (b) the Congressional Appropriations Committee demanded that the fees be raised to cover the cost of the Grazing Service; (c) western senators, representing their cattlemen constituents, demanded continuation of the low fees.

The Act was finally amended in 1947 by providing that the fees must be large enough to support the administrative costs, and that the administration was to be measurably increased at the local level. The total fee was to be divided into two parts: a grazing fee (as previously), and a range improvement fee. In 1951 the fees totalled 12 cents per head per month for cattle, and 2.4 cents per head per month for sheep. In 1955 it was again revised upwards, this time being made variable in order to conform with the current livestock prices. One serious fallacy still remains in the writer's opinion, however : the same fees are charged in all grazing districts regardless of the seasonality of use or the amount of forage available.

Previous to 1947, 50 per cent of the fees were paid to the local county, which turned it over to the local grazing district for use in making range improvements; and 25 per cent was used directly by the federal government for the same purpose. The remainder was paid into the federal treasury. Since 1947 only 12.5 per cent is paid to the counties; the remainder is paid into the federal treasury. Essentially equal amounts are then expended by the federal government on range improvement and administration.

Under federal control, the number of animals is regulated to approximate a balance between range use and the forage-producing capacity of the lands.

It was fortunate that the Act was passed and implemented during the depths of the drought and depression of the middle 1930s, for during that period the numbers of animals were already sharply reduced. The administration therefore had only the problem of not permitting their increase, rather than of having to bring about a drastic reduction. For administrative purposes a system of range inspection and evaluation was inaugurated to check on different stocking and management programmes. Relative stability has characterized the western desert ranges since about 1937.

## THE GRAZING INDUSTRY

### THE OPEN RANGE

Most of the elements of the open range grazing of the early days of the arid west have been well preserved in song, story and motion picture, so that everywhere in the world today this era of the cowboy, the Texas Longhorn cattle, and the great trail drives is well known. Because of the rigorous conditions existing then, Texas Longhorn cattle, well adapted to travelling long distances on little food and going with a minimum of water, were the characteristic breed. These rangy animals produced only minimal quantities of low-quality meat but the very fact that they were able to exist under the prevailing conditions made them the dominant animal of the range.

Control of the land was exerted through control of the water supply. By law or by force, the cattle owner retained control of water holes, springs or river banks and was thereby able to graze his animals over sweeping expanses of territory. By mutual agreement with other cattlemen the herd sometimes travelled hundreds of miles cross-country, utilizing neighbours' water holes, in search of more verdant pastures. In times of drought, herds were often combined and driven tremendous distances. Such mixing of herds resulted in problems of the recognition of ownership of individual animals, a problem easily solved by branding. At least once a year a 'round-up' was held at which time all the animals of a region were driven to a central point where the cattlemen of the district gathered. There the calves were branded to conform with the ownership mark of their mother and at the same time those animals to be sold to market were selected.

The industry suffered seriously from lack of transportation. The market for beef was centred principally in the rising urban areas of the eastern part of the United States, one to two thousand miles away. Railroads had not yet penetrated the desert country. Consequently, it was necessary to drive these animals overland to the nearest railhead.

The famous trail driving of Texas (which gave rise to the Chisholm and Goodnight trails) stemmed from areas of semi-arid rather than arid country. In the arid region cattle were neither as numerous nor as concentrated as in the Texas region and hence trails were not as well established; but the problem was the same and it was met in the same manner. In the early days of the range grazing of the arid west, it was not uncommon for cattle to be driven a thousand miles to market.

The result was, of course, a great loss of weight and much toughening of the meat. A high-bred animal of today would not survive on such a trek and if it did the meat would be of such low quality as to be unmarketable by modern standards.

The cattlemen of that period led a semi-migratory existence. Most outfits had a home ranch based on some reliable water supply and usually with good grazing in the environment; but with the herd spread over wide ranges of territory and having to be shifted over even greater areas in times of drought, the cattleman did not spend much of his time at home. Cattle were herded by cowboys on horseback, supplies were hauled in wagons drawn by teams of mules, and a party on the range became very nearly self-sufficient.

Over large areas of the desert country, rains come in the form of convectional summer thunder showers. Since these are very irregular in their distribution, so also is the occurrence of grass and other forage. Consequently cattlemen ranged over wide expanses of country in search of grazing for their herds. On the other hand, in the mountain and bolson country of Nevada, in the valleys adjacent to the Sierra Nevada, and in the plateau country of Utah and northern Arizona, animals often wintered in the valley bottoms and summered in the grassy meadows of the higher mountain and plateau areas. This transhumance took on a fairly seasonal regularity which came to be stabilized in many cases after the establishment of the National Forests in the better-watered, higher areas.

In addition to the home ranch, the cattleman often established a string of 'out-riders' camps' or 'line camps'. When necessary, a party of cowboys would leave the home ranch and ride cross-country to the camp, taking with them enough supplies to last the expected duration of activity. Establishing themselves temporarily at the camp, they would carry on cattle herding operations from that base.

## SHEEP VERSUS CATTLE

The chief animals of the open range were cattle but in some areas sheep were of considerable importance. The relative merits of sheep versus cattle was for a long time the basis for great disagreement among graziers. Cattlemen complained bitterly of the depredations of sheep on the range. Their tendency to pull up grass, roots and all, thereby destroying the plant and leaving the ground open to wind and water erosion, is in marked contrast to the habits of the cows which merely nibble off the tops of the grass, leaving the roots intact. At the same time cattle have the tendency to wander separately and graze individually, whereas the sheep, travelling in a compact mass, eat and trample everything in their path.

The disagreements between sheepmen and cattlemen went far beyond the stages of a technical discussion. Shooting affrays occurred, and homicide sometimes resulted. The repercussions reached into Congress where the much stronger and wealthier cattle interests were sometimes very successful in hampering by law the operations of sheepmen.

Actually sheep are more adaptable to the arid conditions of the south-west than are cattle. Requiring smaller units of forage per animal they are better able to make use of the sparse vegetation of the region. But because of strong popular feeling they were totally eliminated from many areas. That this prejudice is quite unfounded and that the two are not incompatible is well shown by the fact that in Mormon communities sheep and cattle live side by side and graze on adjacent ranges and in many cases one person is at the same moment a sheepman and a cattleman.

## CATTLE VERSUS FARMING

When the Homestead and Desert Land Acts were extended to the desert areas of the west, lands became open for settlement by farmers. In most cases the cattle men ranging the territory or the cowboys in his employ took up legal claims upon all of the existing water holes and thereby ensured the continued domination of the surrounding grazing lands. However, in many instances, due to oversight, improper filing of claims or simply because of the belief in the persuasive power of their own force, cattlemen neglected to do this and were suddenly chagrined to find homesteaders filing claims on land that had long been considered the property of the cattlemen. Under the law the homesteader was forced to clear for cultivation and plant a crop upon a portion of his land in order to prove title to it. To do so required, of course, the fencing of the property to keep out the cattle. To thus fence off a water hole meant that miles of adjacent country would become worthless for grazing purposes. As a result, such fencing frequently led to violence. The cattleman considered the use of the waters his right since he had been in the area for a long time and had made regular use of them. On the other hand the law backed the homesteaders who had done legally what the cattlemen neglected to do. The resulting difference of opinion had no easy solution.

Not only as the result of such conflicts, but because of the wide difference in the nature of the ways of life, the cattlemen had no respect for and no desire to become farmers. In many ways this was most unfortunate, for the dependence upon the natural forage of the arid lands is unreliable to say the least. When emotion could be removed from the situation, the homesteader and the cattleman found many reasons for interdependence. Crops of alfalfa raised by the homesteader could be stored for use by cattlemen during times of drought and lack of natural feed. In course of time many cattlemen came to develop irrigated alfalfa land for their own uses and thus became in part farmers themselves.

Through most of the intermountain regions today, irrigation agriculture is a standard supplement to range operations wherever water is available. Combinations of public range and private irrigated homesteads are common everywhere.

## STABILIZATION OF RANCHING

During the 1870s, barbed wire had become plentiful and relatively inexpensive. But fences were basically inimical to the idea of the open range in the mind of the rancher. Since rains were extremely sporadic and widely spread, the rancher deemed it necessary to be able to graze his animals over an unlimited expanse of territory and the construction of fences prevented his doing so. However, as many ranchers began developing their own sources of alfalfa and other supplementary feeds, the necessity for such long drives came to be less important, and a sense of ownership of various areas of range began to arise in their minds. Eventually by common consent drift fences came to be constructed along what were recognized as common boundary lines and thereby the open range as such ceased to exist. Such fencing was at first actually illegal since it enclosed for private use portions of the public domain which had never been allocated to any individual and which as we have seen above, could not legally be so allocated. It was not until the establishment of the Taylor Grazing Act in the mid-1930s that such practices were legalized.

Technological advances gradually altered the nature of the cattle industry. By far the most important of these was the extension of the railway lines into the desert area thereby providing rapid transportation of animals to market without accompanying loss of weight. Such railways were not built for the purpose of serving the cattleman. Rather they were transcontinental railways built to connect the east coast with the west, but since they passed through the arid regions, the cattlemen took advantage of their presence to get their cattle to market. The principal railway construction in the region was during the period from 1875 to the turn of the century.

The demand of the eastern markets for improved quality of beef resulted in the selective breeding of cattle on stock farms and the introduction of higher grade animals on to the ranges of the west. With the termination of the period of the great cattle drives and the improving of grazing and watering conditions on the range, the hardiness of the Texas Longhorn was no longer essential and the breed was replaced gradually by other less hardy but higher quality animals. In time the Hereford, product of the humid British Isles but eventually quite adapted to the arid conditions, came to be the dominant breed. To combat some of the fly-borne tropical diseases in southern Texas, Brahman cattle were imported from India and cross-bred with animals of better conformation from north-western Europe. The result has been a number of cross-strains, the most famous of which is the Santa Gertrudis—a Brahman-Shorthorn cross.

A series of mechanical inventions greatly altered the way of life on the western cattle ranch. The invention of the windmill (more properly the wind-pump) permitted inexpensive lifting of water from wells of moderate depth. The adaptation of the internal combustion engine as a well-pump removed man from reliance upon the vagaries of the wind and increased both the volume and possible depth of wells. Finally, the development of mechanical well-drilling equipment permitted the tapping of aquifers at great depths. Such inventions released cattlemen from dependence upon surface water supplies and thereby allowed the utilization of areas of range forage formerly untouched because of the distance from a water supply.

### MODERN RANCHING TECHNIQUES

The operation of a modern cattle ranch in the arid lands is a far cry from that of three-quarters of a century ago. Mechanization, the application of modern scientific methods in breeding, range management, feeding and veterinary medicine, and the stability that goes with a sense of ownership have brought a new way of life to the desert ranch.

Ranches are still very large in area, averaging over 20,000 acres in the desert regions. But in the arid west, the size of operations are usually measured in numbers of animals rather than in acres. For a family-sized operation with only the owner and his immediate family to do the work, 100 head of cattle is the absolute minimum and at least 150 head are required for maintaining a decent standard of living under modern American conditions. Of such ranches, only a small proportion of the land is actually owned by the rancher himself. The remainder is leased under the Taylor Grazing Act. The fees paid by the rancher for use of the public domain have been returned to the ranch in various forms of range improvement, often visually evident by such things as fences and improved water supply.

Today a fair proportion of the ranches have been surrounded by exterior fences and migratory herding is almost entirely a thing of the past. Regular seasonal movement of cattle to and from the ranch still continues, but even during droughts the animals no longer travel great distances cross-country in search of better pastures. Fences are usually constructed of barbed wire with four strands placed one above the other at intervals of about a foot. Fence posts are usually of wood, juniper or 'cedar' where this is available, and elsewhere often of discarded railway ties (sleepers) split longitudinally into parts. Electric fences, usually operated from a storage battery, have achieved some popularity; but in areas where the soil remains dry for too long a period, the shock to the animal upon encountering the fence is weakened and the animals eventually tend to disregard it.

The control exerted over cattle by fencing has permitted a considerable degree of pasture management. By interior fencing ranchers are able to practise controlled grazing, in the form of either deferred grazing, rotation grazing, or deferred rotation grazing. Deferred grazing is the practice of keeping cattle off a particular plot of land until the most important forage plants have matured their seed. Rotation grazing refers to the alternation of grazing between various units of land. Deferred rotation grazing is a combination method of considerable popularity in the south-west. The range is divided into several units, grazed in rotation, with the grazing of one or more of them being deferred until after seed maturity.

Although range reseeding has been effective in many areas of higher precipitation in the west, it is not commonly practised in the desert region because of the low and unreliable rainfall.

By far the most important aspect of range improvement in the west has been the development of stock-watering facilities. Since most of the desert ranges lack water over most of their area, maximum utilization of their forage requires that sources of water be developed within the forage area or that water be hauled out to the animals. In the mountain and bolson areas, springs are most commonly found in the canyons near the foot of the mountains and gravity flow of water is possible for miles from such water sources down the slopes of adjacent alluvial fans. Such alluvial fans are usually devoid of water supply, and yet have areas of good forage and browse. Miles of pipeline have been constructed during the last two decades by ranchers with the assistance of the federal government and the local county agencies. Much attention has also been devoted to the construction of large storage tanks of metal, cement or masonry. These are usually filled by gravity flow from springs, by windmills or by gasoline pumps, and are used to supply water to troughs with the flow automatically regulated by a float valve.

Most modern ranchers engage in the supplementary feeding of their range cattle. Such feeding takes several forms : feeding of cows during pregnancy and immediately after calving in order to ensure an adequate milk supply for the calves and continued good health and weight of the cows; the feeding of calves after weaning; to correct a mineral deficiency in the indigenous vegetation; to correct a seasonal imbalance in the food supply; during droughts of a long-continuing nature—in this case often with imported feed and federal aid in some form; during winter emergencies, especially if the range becomes snowbound and the animals are unable to get about to forage for themselves.

The supplemental feed takes various forms. In a few areas, particularly in Nevada where hay meadows are available, natural hay is cut and stacked for seasonal or emergency uses. Elsewhere baled alfalfa hay may be imported from adjacent irrigated districts. Other feeds, used singly or in combination and variable dependent upon regional and temporary changes in price, include cottonseed cake, flaxseed cake, sugar beet pulp, copra meal, fish meal, and a wide range of commercial mixtures. Salt in either the cake or granular form is normally provided for animals. To it is added, in a number of forms commercially available, various minerals such as iodine, sulphur, copper, cobalt and iron to make up for local deficiencies. Wherever possible part or all of the herd is normally removed from the range during the summer period and transported to higher mountain or plateau pastures. But in the south-western desert area, few such facilities are available, and there the cattle must be carried through the entire year on the home range. Where transhumance does occur, the animals are today transported almost entirely by truck rather than by driving them overland on foot. The cost of transportation is more than offset by the maintenance of bodily weight. Mountain grazing is quite frequently carried out under United States Forest Service permits.

Since World War I, the old vicious spiral of poor feeding practices, of low quality of beef and of lack of public discrimination in regard to the meat it ate has been broken. In its place there has come to be an abundance and diversity of supplementary feeds, consumers who are quality conscious, and a strong sense of mutual dependence between livestock producers, feed producers and processors, and meat packers. Today the great emphasis is placed upon improved quality of meat and early maturity of the animal, both of which are attained through selective breeding. In addition, the cattle industry is constantly seeking higher percentages of calf-crops and improved growth of young cattle through better feeding procedures. Through the past two decades the range cattleman has had the choice of shipping his cattle to farmers who will fatten them on irrigated pasture and alfalfa; to commercial feed lots near the stockyard, where they will be fed on imported grains and alfalfa; or of holding them on the home range in the hope of rains which will produce good grass-fattened animals. The result has been a great change in the nature of the cattle. In the days of the Texas trail drives, the longhorn steers reached a weight of 1,000 lb. at the age of 4 to 5 years. They were tough, stringy animals with most of the meat in the neck, shoulders and brisket and would be marketed as a 'common grade' today, if indeed they were marketable at all. A modern white-faced Hereford of the desert ranges of Arizona or New Mexico will normally weigh 650 lb. as a yearling steer and can be marketed as a 1,000-lb. animal at the age of only 2 years. Furthermore, most of his weight lies in the choicer meat cuts. This improvement has resulted almost entirely from breeding pure-bred bulls with ordinary range cows.

Today three cattle ranching economies prevail on the desert ranges of the south-west :

1. *Steer*—young steers are bought on the open market and raised to heavier weight on the natural forage.
2. *Cow and calf operations, type I*—this involves the maintenance of a good breeding herd consisting of bulls and bearing heifers in a ratio of 25 to 1 (varying greatly, depending upon the age of the bull and the nature of the range). Calves are usually sold in the fall shortly after weaning. Heifers to replace the cows of calf-bearing age are selected out of the calf crop.
3. *Cow and calf operation, type II*—this is the same type of operation as that described above with the exception that the end products are steers sold at the age of two or more years depending upon range conditions.

In a breeding herd operation, cows are kept separate from the bulls except during the desired breeding periods. Calves are dropped when the annual feed approaches its maximum stage, in order to ensure a good condition of the mothers at calving time and a good milk supply thereafter. Calves are allowed to nurse until the sixth month, at which point the milk supply begins to diminish since the mother has been bred again, and since she needs to put on flesh to carry her through the feedless early winter. Calves are separated from their mothers in corrals, and are given supplementary feed, chiefly commercial protein concentrates. Breeding cows are kept until their tenth or twelfth year, when they are cut out of the herd, fattened up on natural feed and marketed at the end of the good feed season.

Until a decade ago animals were usually marketed by driving them on foot to the nearest railway and shipping them to market in well-ventilated slat-sided railway cars. Today, however, most of the animals travel to market in trucks and trailers over the public highways. Some ranchers deliver their own animals, but in most cases the transportation is by custom hauler—companies whose sole business is cattle transportation. Cattle are similarly transported between summer and winter pastures over the public highways.

The modern ranchstead has most of the advantages and items of equipment to be found in the modern city homes. Most are provided with electricity either from a gasoline-powered plant on the premises or by connexions through a line constructed by the federal government through the Rural Electrification Administration. Nearly all ranch houses have telephones, radios (not only for entertainment but for the daily weather and marketing reports), a mechanical refrigerator powered by either electricity, gas or kerosene, and running water both for drinking and for bathing.

The rancher spends most of his nights at the ranch house. Gone are the long periods spent at distant outriders' camps. Today with a pick-up truck pulling a horse trailer, he drives over roads constructed with his own tractor and scraper, to distant corrals and watering places, does a day's work there, and returns at night.

## THE SHEEP INDUSTRY

Although they are better adapted to desert range conditions than are cattle, sheep have never become a really major item in the livestock picture in the arid south-west. This is in part because the American taste in food runs more to beef than to lamb and mutton, and in part because the more powerful cattle interests have secured passage of legislation favourable to cattlemen and unfavourable to sheep raisers.

In the mountain and bolson country of Nevada, and the adjacent plateau country of Utah and northern Arizona, sheep are secondary to cattle. But in the warm winter south-western deserts (south-eastern California and south-western Arizona) sheep play only a very minor seasonal role.

In Nevada and Utah, sheep operations are invariably based on transhumance. The flocks winter in the bolsons, browsing on the sagebrush and shadscale of the alluvial fans and about the edges of the dry lakes. In emergencies, usually as the result of snowbound conditions in midwinter, the animals may receive some supplementary feed in the form of baled alfalfa or natural hay, and such feed is usually given to the ewes about lambing time. With the coming of spring, the animals are driven into the adjacent mountains where they spend the summer grazing on the upland meadows under Forest Service permits. Where distances are fairly short (usually under 100 miles) the animals are driven afoot along fenced driveways. Where distances between winter and summer pastures are greater, the animals are transported in double-decked truck and trailers over the public highways and Forest Service roads.

Unlike cattle, which graze freely within the confines of their huge fenced pastures or even over entire ranches, sheep are normally herded by a man and a couple of dogs. In Mormon areas, the sheepherder is usually a member of the local community. Elsewhere Basque herders are employed. These French or Spanish citizens enter the United States and stay for long terms under special passport and visa arrangements.

Ewes with lambs travel in bands of 500 to 1,000 animals. After the lambs have been marketed, the bands are united into flocks numbering from 2,000 to 4,000 animals.

With the development of good transportation in the last several decades, mutton has become of increasing importance, and today the range sheep is a dual-purpose animal, the meat and the wool being of approximately equal value. The ewes are usually wool sheep of Rambouillet and Merino breeds. They are crossed with rams of mutton breeds, particularly Hampshire, to produce lambs of high mutton quality. The cross-bred lambs are not kept for replacement however; females are purchased from breeding establishments in order to maintain the fleece quality in the ewe herd.

In the desert portions of California and south-western Arizona, permanent range livestock operations are almost totally lacking south of the Santa Fe Railroad (about the 35th parallel) except along the bordering mountain ranges to the west. As described above under vegetation and climate, this area is deficient in both rainfall and palatable vegetation, and hence quite undesirable for livestock raising.

In the years in which good winter rains occur over the area, as spectacular growth of herbaceous annuals suddenly carpets the desert basins with a profusion of foliage and blossom. At such times large bands of sheep are moved into the area by truck, often from distances of more than 500 miles under special short-term permits from the Bureau of Land Management. Since this is public domain not allocated under the Taylor Grazing Act, these animals do not compete with permanent livestock operations. Because of the cool weather prevailing at this season of the year and the high moisture content of the herbaceous forage, the low water requirement of the animals can easily be met by hauling water to the flocks in tank trucks.

### THE GOAT INDUSTRY

Nowhere in the desert country of the south-western United States is the goat of any economic or ecological significance, nor have they ever been of any consequence.

## DRY FARMING

As is obvious to anyone aquainted with the principles of water effectiveness, dry-farming techniques can never be successful in arid regions. The dry farming of grain, cotton and other crops has been carried on successfully in the semi-arid regions bordering the south-western deserts of the United States : in the Palouse region of Washington, in the plains and valleys of southern Idaho, along the foot of the Wasatch range in Utah, in parts of the high plateaux of southern Utah, about the margins of the Antelope Valley of California, on the plateaux of northern Arizona, New Mexico, and in the Great Plains region east of the Rockies.

Unfortunately, the deep wells of human optimism frequently lead prospective agriculturalists into attempting the impossible. Again and again in all parts of the arid south-west, land has been hopefully cleared under the terms of the Homestead Act, and crops of grain have been planted under dry-farming techniques. In some instances where the original planting happened to coincide with years of greater moisture, crops were actually harvested and title to the land secured in good faith. But all such enterprises have been doomed to inevitable and usually immediate failure. There have also been, of course, other cases in which land has been cleared and planted with dry-farmed crops merely to secure title to the land, and with the certain knowledge of the 'farmer' that his enterprise was doomed to agricultural failure.

It is unfortunate that Powell's plans for classification of the western country could not have been carried out early enough to prevent the widespread hopeless and abortive attempts at dry farming, which accomplished nothing but to lay the land open to the possibilities of serious erosion by wind and rain.

## IRRIGATION AGRICULTURE

### HISTORICAL DEVELOPMENT

In prehistoric times at least one aboriginal group carried on extensive irrigation agriculture in part of the south-west. The Hohokam group of Indians dwelling in the Gila and Salt River valleys of central Arizona constructed large diversion canals by which water was carried for distances of as much as twenty miles to their agricultural lands. Their successors, the Pima Indians, were still utilizing some of these canals when the first Spaniards visited the area and some of the canals were used as guides for the location of modern irrigation systems.

In the Rio Grande valley of New Mexico and in scattered places in the plateau country farther west, Pueblo Indian groups were carrying on fairly intensive agriculture under irrigation at the time the Spanish *conquistadores* first visited them. Many of these groups are still farming in practically the same manner in the same area today.

With the establishment of the first missions in southern Arizona, Spanish irrigation techniques were applied to the land. To the corn, squash and beans of the Indians were added the whole range of European crops then available to the Mediterranean agriculturist and certain other crops such as the potato and tomato which had been encountered by the Spanish in Mexico or Peru. The result was a very intensive albeit small-scale agricultural production in the vicinity of each of the mission establishments.

For the Spanish the practice of irrigation in the arid south-west did not constitute a great cultural change, for irrigation had long been practised in the Mediterranean world from which they came. To the Anglo-Saxons, however, irrigation agriculture constituted a totally different way of life, one for which they had no precedents whatever in their culture. In Mediterranean coastal California a few Anglo-Saxons came in contact as individuals with the irrigation agriculture of the missions, but it was not until the 1840s that an Anglo-Saxon community was forced to take up irrigation agriculture.

When the Mormons[1] came into the Salt Lake area of present-day Utah, there to found their 'State of Deseret', they realized at once that irrigation was absolutely essential. Since State and Church were inseparable in the Mormon philosophy, it was relatively easy for them to establish a communal irrigation system and thereby to allocate the land and water rights and obligations.[2]

Each of the many streams issuing forth from the west face of the Wasatch Range was diverted by means of low weirs into distribution canals and thereby led to the fields. Unlike most other American agriculturalists who tend to live in dispersed patterns each on his own individual farm, the Mormon agricultural groups lived in farm villages and travelled out to the fields afoot each day. Soon a string of Mormon farming communities developed along the western foot of the Wasatch, each associated with a particular canyon mouth.

Unlike the Spanish, who brought Mediterranean crops to the south-west, the Mormons concentrated upon the raising of the crops of the north temperate regions with which they were already familiar. In common with the Spanish, they raised wheat and barley, but the citrus, olives and other subtropical and Mediterranean fruit were replaced here by apples, peaches and other deciduous fruits, while various root crops also came to be important. Their large herds of range cattle were raised primarily for beef purposes, rather than for hides and tallow, as were those in California and Arizona. In addition, they had flocks of sheep, as well as large numbers of dairy cattle for which extensive irrigated pastures and alfalfa fields were prepared. In short, both the Mormon and the Spanish mission communities were religious in origin, dependent on irrigation agriculture and almost totally self-sufficient, but their crops and their ways of life were strikingly different.

In the ensuing decades the Mormon community expanded rapidly, northward along the foot of the Wasatch and adjacent mountains into Idaho and southward across the whole length of the present state of Utah into southern Nevada. A short-lived attempt was even made to establish a community at San Bernardino, California, within the shadow of the Spanish missions. Later expansion carried the Mormon communities across the plateaux of south-eastern Utah and Arizona into parts of New Mexico and the adjacent state of Chihuahua in Mexico.

Throughout the latter half of the nineteenth century and well into the twentieth century small scale irrigation enterprises sprang up at many scattered localities throughout the arid west. Some of these were Mormon, operating under the control and direction

1. Properly known as the Church of Jesus Christ of Latter Day Saints.
2. Actually, the Mormons seem to have obtained their knowledge of irrigation from the Spanish (Mexicans) in New Mexico. Certain of their leaders, such as John D. Lee, had been in Santa Fe, and a portion of their group, en route to Utah, had spent some time along the Arkansas River in Colorado, where Mexican groups from Santa Fe were already practising irrigation. Furthermore, in the Weber River valley near present Ogden, Utah, an Englishman named Kells, who had lived in Mexico, was carrying on irrigation before the coming of the Mormons.

of the local church authorities, as mutual enterprises involving all members of the community. Elsewhere, the enterprise was sometimes the work of a single individual, but in most cases, because of the size of streams involved, the length of canals necessary and the large expense of the undertakings, the enterprises were the work of companies or associations. Such organizations normally fall into two classes: water companies and mutual water associations. In the first instance, a party of businessmen organized for profit a company to develop water and to sell it to prospective farmers on the irrigable land. While most of these were operated honestly and for reasonable profit, some were corrupt organizations with the aim of extracting as much tariff as the traffic would bear. In the second case, a non-profit organization formed by the local landowners to develop water resources on a share-the-expense basis, usually worked out to mutual advantage. Some, of course, were failures due to poor planning, poor management or lack of an adequate water supply especially during drought years, but by and large the mutual water association has proved to be a most successful undertaking.

## SURFACE WATER LAWS

The fact that the Anglo-Saxon immigrants into the desert lands had no previous experience with irrigation is strongly reflected in their confusion and inexperience in handling the legal aspects of water problems.

From the outset is was assumed that each state had jurisdiction over the waters within its boundaries. Each state consequently adopted principles which, at least at the time of their adoption, seemed best suited to its own physical condition. Where experience has shown that these principles were not suitable, changes have gradually been brought about, largely as a result of court decisions. Hence today there is wide disparity between the different parts of the country, and variation is the rule, rather than homogeneity.

As each state or territorial government was established in the west, it was necessary for its legislature to adopt a code of laws by which the area would be governed. While it was, of course, possible for such a legislature to draw up a totally new set of ordinances, it was much easier and seemingly more logical to adopt an already existing code of law. In each case the bulk of the legislators were of Anglo-Saxon origin, and naturally, therefore, tended to develop a body of law based on the common law of England, which had been 'transplanted' to the humid eastern United States early in its history.

England, however, is an area of humid climate where the principal demands for water have always been domestic, stock and industrial uses and the harnessing of water power for the operation of factories. Irrigation, by which water is removed from a stream and not returned, is unknown; the other uses of water result in its return to the stream in essentially the full volume from which it was removed. Hence, under English law, the *riparian doctrine* prevailed : the owner of land in contact with a stream is entitled to have the stream continue to flow past his land undiminished in quantity and unpolluted in quality except for the use of the stream by other riparian owners above him. This means that he has full rights to the use of the water of the stream with the implicit understanding that he must return the same amount of water to the stream at the lower end of his property.

On the other hand, the earliest use of water in the western states by Anglo-Saxons was in conjunction with the placer mining in the goldfields of California. Since these areas were being mined prior to the extension of normal legal systems to the region, certain customs grew up among the miners in lieu of law. Chief among them was what has since come to be termed the *appropriation doctrine*. By its terms the first man utilizing the water of a stream has the right to as much water as is required to carry out his individual mining operation. Such water need not be returned to the stream. Each succeeding miner has similar rights, priority being established on a 'first come, first served' principle. Thus the rights of the earliest man on the stream cannot be taken away from him by later comers so long as he continues to exercise the use of his rights.

Some of the western states adopted the English riparian principle outright. In other states the legislature by statute, or by judicial rulings through the courts, added to the English common law certain of the customs which had already developed within the state based upon the appropriation principle. In any case it is quite apparent that the riparian and appropriation doctrines stand in sharp contrast to one another, and that two such contrasting doctrines could not exist side by side without the likelihood of violent conflict. Controversies were very soon brought into the courts, and it was left to the courts to decide which system should dominate in the particular area in question. In several states it was early realized that the physical conditions were such that the riparian doctrine could not be applied, and consequently the appropriation doctrine was adopted as a sole basis for the distribution of water. In certain other states the courts decided to hold fast to the riparian principle. In general, the more arid states rejected the riparian rights and adopted the appropriation system. Many of the states, however, have endeavoured to amalgamate the two in their legal systems : a decision which has been far more profitable for the lawyers than for the water users.

It is interesting that the system of appropriation rights developed in the early western mining camps by Anglo-Saxons embodies most of the principles inherent in Spanish and Mexican water law which was already in operation in the Spanish-settled portions of the south-west. However, the appropriation system as now used in the west is a spontaneous growth rather than an adoption of a neighbouring legal system.

The regulatory system established by the state of California served as a model for some of the other western states. These regulations were very simply expressed in statutes passed by the legislature in 1872; but as a result of subsequent court decisions and administrative regulations, they have now been expanded into several score pages. In essence, however, they may be stated as follows: a person may appropriate water from a flowing stream for any beneficial purpose but the right to divert such water ceases when he ceases to use it for such a purpose. Once a right has been acquired, the point of diversion may be shifted, the rights may be transferred to another party, the destination may be changed, and the water may even be turned into another stream and then withdrawn from that stream without a second appropriation right. An individual desiring to appropriate water must post a notice at the point of its tended diversion, stating the amount claimed, the purpose of diversion, and the place of intended use, and must file a copy with the proper local authority.

While the posting and the recording of the notice are required items in the acquisition of water rights, no limit was placed on the amount of water that might be claimed. Many of the early appropriators actually had little knowledge of what their eventual needs might be, and consequently tended to post notices far in excess of their actual requirements. Many notices actually claimed all of the water in the stream and the sum total of such notices on nearly every western stream is well in excess of the total volume of the stream. An investigation made by the federal government of the claims to the San Joaquin River in California showed six separate notices claiming the entire flow of the stream, with total claims amounting to nearly twenty times the maximum flood flow of the stream.

In spite of the detailed provisions associated with the appropriation principle of water rights, riparian rights have also been recognized in principle in California and applied in practice as well. Some of the other western states have abrogated riparian rights and today recognize only the appropriation system. In general, it was stated that the riparian proprietors are entitled to a reasonable use of the waters of the stream for the purpose of irrigation. The definition of 'reasonable use' is not made clear, and is said to depend upon the circumstances appearing in each particular case.

The attempt to apply both doctrines to Californian water rights has resulted in a vast amount of litigation over the past three-quarters of a century—an indication in itself that the two doctrines are mutually incompatible. It is self-evident that no attempt should ever be made to apply both concurrently.

The difficulty resulting from the attempted application of both principles simultaneously is well illustrated by the litigation and legislation in conjunction with the use of storm floodwaters on certain of the Californian streams—notably the San Joaquin River. Certain water users in the lower reaches of the San Joaquin objected on several occasions to the impounding of floodwaters for irrigation or power purposes during low water stages. Court decisions placed all the water of the San Joaquin River under the riparian doctrine, thereby precluding diversion of storm-waters by appropriators and insisting that the full volume of the flood waters be allowed to discharge down the main channel of the stream (and thereby be wasted into the sea). The decision aroused such a storm of protest that a conservation-minded legislature in 1928 added an amendment to the constitution of the state declaring that in the interest of conservation, riparian rights should attach to only the normal flow of the river, such as might be used for reasonable and beneficial purposes, and that water in excess of demands for such reasonable uses could be impounded and diverted.

In all of the arid states administrative officers have been empowered to regulate diversion from streams in accordance with the existing legal code. Such administrative officials are usually called water commissioners or water masters.[1] Usually these officials are under the direction of the state engineer.

## RIGHTS TO UNDERGROUND WATER

In American legal systems, two classes of groundwater are recognized: (a) water flowing in definite underground channels; and (b) waters percolating in a diffused pattern.

In the first instance, the channel must be well defined. Such cases are limited to streams flowing in limestone caverns or lava tubes, and the underflow of well-defined surface streams, particularly those which cease to flow on the surface during dry periods. Even through some degree of 'subterranean channelling' may sometimes be detected in alluvial fans, groundwaters under such circumstances are usually considered to be percolating. However, three states (Nevada, New Mexico and Oregon) have statutes requiring that well-defined artesian basins be considered as the equivalent of subterranean channels.

Water rights to subterranean channels follow the set of rules applied to surface streams in the local

1. In Spanish-speaking areas these men may be referred to as *zanjeros*.

area—either the riparian or the appropriation doctrine being invoked. The same sort of situation is in effect in the artesian basins just mentioned.

According to English common law, the landowner has absolute ownership of the percolating waters which underlie his property and he may use them in any way he sees fit. According to this doctrine, water is in the same classification as minerals, and is treated accordingly. On the other hand, water is mobile and removal of groundwater from beneath one parcel of land may reduce the supply of groundwater beneath adjacent parcels. Some states still adhere completely to the English system; others have introduced various modifications of it.

The principal modification, which is termed the *rule of reasonable use* or the 'American rule', originated in California. The earliest Californian decisions regarding percolating waters adhered strictly to the English common law. In the last decade of the nineteenth century, however, extensive use of groundwater in California resulted in general lowering of water levels, and cases involving disputes over this matter awakened the attention of the Californian courts to the need for reconsideration of the law.

As the situation stands today, the rights of the landowner utilizing water on his own land are paramount to the rights of owners appropriating water for use on other lands. Such rights, however, extend only to the quantity of water that is necessary for use on the local land; the surplus may be appropriated by the adjacent landowner. If one owner does not use the water, his neighbour may appropriate all of the supply and transport it to distant areas. If both of the owners desire to appropriate water for use on distant land, then priority becomes the determining factor.

Obviously under such laws the user of groundwater is not assured of the maintenance of the physical conditions which originally existed beneath his property. Continued use by either himself or his neighbours may result in the loss of artesian pressure and eventually in the reduction of the level of the standing water in his wells. One landowner cannot prevent his neighbour from distributing water to distant areas even though his own water table is being thereby reduced. Only if the landowner can show unreasonable use, extraordinary damage, or malice does he have recourse to law.

Each of the arid states has its own set of statutes and decisions regarding subterranean water rights. The entire matter is in a state of confusion and there seems to be little hope of clarification and simplification in the near future.

## WATER MEASUREMENT

A curious indicator of the role of the miner in water lore in the west is the method of water measurement in vogue nearly everywhere—even in irrigation districts in which mining has never been carried on. Rather than order water from the water master in acre-inches (by which the amount required will be determined by the farmer) or in cubic feet per second (the standard measurement of the engineer), the order will be written in miner's inches. A miner's inch is the flow of water through a one-square-inch aperture, under a head of either four or six inches (dependent on the local regulation).

## METHODS OF OBTAINING AND CONVEYING WATER

On small streams, simple diversion of the surface water is accomplished by the construction of a low weir to divert flow into a canal. Large modern irrigation projects are often associated with power production and flood control, and storage of part of the peak flow for use in low-water periods is desirable. Consequently, the storage dam takes the place of the weir. In America, water is usually stored in the stream channel itself; off-stream storage is not commonly practised.

In some areas, wells encounter strata in which the hydrostatic pressure is sufficient to force the water to the surface, creating an artesian well. Continued use, however, normally results in the lowering of the hydrostatic pressure until it eventually becomes necessary to pump the well. Very few artesian wells are still flowing in the arid portions of the United States.

Wells may be pumped by several different types of equipment. The oldest and simplest is the windmill, but its yield is so low and its operation so unreliable that it is used for little more than garden irrigation. Various types of mechanically-operated pumps have taken its place.

The earlier of these, the reciprocating pumps, have largely been replaced by rotary centrifugal or 'turbine' pumps. Since the motor is at the surface, and the centrifugal impeller is located at the bottom of the well, a long drive shaft is required. In order to overcome the mechanical difficulties inherent in crooked wells, a submersible pump, consisting of an electric motor connected directly to the impeller, and sealed tightly against water, is put into operation at the bottom of the well, thereby completely eliminating the need for a drive shaft. Most pumps are powered by gasoline- or diesel-operated internal combustion engines, or by electricity.

Water is conveyed from a well or from the point of diversion to its ultimate destination in the field by means of open ditches or by pipes under pressure. To reduce water loss by percolation, canals are usually lined with cement in areas of porous soil. Where water is brought to the field in concrete pipes, the hydrostatic pressure is controlled by the adjustment of the water level in large standpipes. Water is then discharged onto the surface through adjustable apertures in a miniature standpipe or 'hydrant' at the head of each individual field unit. Water is applied to the field by several techniques: furrow, basin or border and sprinkler. In the first case furrows are prepared in the field by means of a tractor and drab, and the head of each furrow is connected by hand to the corresponding hydrant aperture. Each aperture is then opened to what in the experience of the operator appears to be a desirable amount. The value controlling the total inflow into the hydrant is adjusted until it equals the sum total of the outflow through the various apertures. The same process is repeated at each hydrant. When all is ready, the valve is opened at the intake of the major standpipe for the area. The water surges upwards in the standpipe, places hydrostatic pressure on the entire underground supply line, causes water to rise in each of the individual hydrants, whence it flows out through the apertures into the furrows. After a period of time a check is made of the water position at the lower end of each furrow, each aperture is adjusted accordingly and the total flow at the standpipe is adjusted to compensate for the aperture changes.

Basin or border irrigation consists of the flooding of areas with sheets of water spread evenly across a field. Fields so irrigated are usually divided into rectangular sections by means of low earth banks which direct the flow of the water.

In fields where hydrant systems have not been provided, water is distributed from the main standpipe to the heads of furrows or to the basins by means of large portable aluminium pipes laid over the surface. These are equipped with adjustable apertures identical with those of the hydrants. In areas of well irrigation, water is often pumped direct from the well to the standpipe and then distributed by the means described above.

In some cases, particularly in the raising of seasonal vegetable crops, where it is undesirable to have a fixed field pattern, the hydrant system is replaced by siphon irrigation from a master ditch. From the main canal or from the major standpipe, or from the well itself, a large canal with firm walls of earth is constructed across the head of the field. Water is then siphoned over its side through short curved lengths of plastic tubing or aluminium piping.

Since fields irrigated by surface methods are often very large, heavy machinery is used to grade them to the slope required for proper water flow. Where the irrigated area is on so steep a slope that soil would be eroded by the flow of irrigation water, over-head irrigation or sprinkling is commonly used. Sprinkling is also used to an increasing extent on gently-sloped land.

Sprinkling is accomplished by the use of portable aluminium pipes with built-in sprinkler heads. In areas where gravity flow by pipe is available, the sprinklers merely operate by hydrostatic pressure; elsewhere the pressure is supplied by small pumps. While it is true that there is considerable evaporation loss from sprinkler irrigation in high-temperature low-humidity areas, field experimentation has shown that it is not as great as the downward percolation loss by furrow irrigation, especially in areas of porous soils.

Soil samples taken at the root level of the crop are analysed to determine their water content as a means of determining the date of the next required irrigation. Experience in the past has shown that most farmers tend to over-irrigate their crops with resultant deterioration of the root systems and wastage of water. The sampling is done by field laboratories under contract to individual growers, or by the county extension services of the local, state, and federal government.

Today all fertilizer is applied to the field directly through the irrigation system, being introduced in highly concentrated form into the irrigation water at the major standpipe.

Since many of the best agricultural lands of the arid south-west lie in the lower portions of basins, in areas of heavy soils and with but very little slope, high water tables are frequently encountered with their attendant problems of excessive salt accumulation and root deterioration. To combat these problems it has frequently been necessary to construct master drainage systems and to underlay all fields with unglazed clay drainage tiles at depths somewhat below the lowest level of ordinary root penetration. Today a very large portion of the irrigated lands of the United States are tile drained.

In areas suffering from soil impermeability due to black alkali (in which sodium attached to the clay particles has brought about impenetrability) application of sulphur, usually in the form of gypsum, through the irrigation water has had a most beneficial effect.

## THE RECLAMATION ERA

The suggestions of Powell in 1879 that the federal government should undertake the sponsorship of irrigation in the West went unheeded for several decades, but when developing technology made the harnessing of the larger streams possible, the vast sums of capital required for such ventures could not be raised by groups of farmers, and the federal government finally entered the scene. Furthermore, most of the undertakings were of a multipurpose nature, involving flood control, power production and municipal water supplies as well as irrigation. Concurrently there developed a new philosophy of public responsibility, engendered largely by the late Theodore Roosevelt.

The result was the so-called 'Reclamation Era' which began in the earliest days of the twentieth century and which probably reached its peak during the administration of President Franklin Roosevelt. This era saw the harnessing of all of the major streams of the west with multi-purpose dams and the extension of irrigation to vast areas of desert and semi-desert country. Outstanding among these undertakings have been the Grand Coulee Dam in Washington, the Boulder or Hoover Dam on the lower Colorado River, and the Shasta and Friant Dams of the California Central Valley Project.

Reclamation has greatly altered the economy and the aspect of the arid west and has also had a pronounced effect upon the rest of the United States. Large areas which heretofore had been worthless have become valuable agricultural lands. Many of the areas have long, hot summers which promote the rapid growth of plants and thereby permit several crops per year to be harvested with consequent lowering of production costs. These same areas normally have long growing seasons and frostless winters and hence are able to raise subtropical plants such as cotton, citrus and dates. In less favourably endowed areas with shorter growing seasons and longer, colder winters, cheap and abundant feeds for the fattening of cattle are produced. With a rapid and efficient transportation network, the temperature control of railway cars, and the absence of tariff barriers, the western states have been able to supply winter fruits and vegetables to snowbound eastern markets. With the development of food-processing techniques such as canning and freezing of fruits and vegetables, crops raised inexpensively in summer on irrigated tracts can be made available throughout the year both locally and to distant parts of the country. Thus the reclamation of the west has permitted a tremendous broadening of the diet of all parts of the country.

## REPRESENTATIVE IRRIGATED AREAS

A picture of the irrigated agriculture of these desert areas can best be obtained through a contrasting pair of type studies : one of the Imperial-Coachella Valley in the warm winter Colorado desert area of California and the other of a representative valley of the cold winter desert of Nevada.

The Imperial-Coachella Valley is a structural trough bounded on the south-west, north and north-east by high rugged mountains, and to the east by lower desert hills. It is open southwards to the Gulf of California, from which it is separated only by the low alluvial delta-fan of the Colorado River. It is floored with alluvium derived from the surrounding mountains and by the fluvial deposits of the Colorado River which has at times discharged into the area. It drains centripetally, the central portion being occupied by a brackish water body known as the 'Salton Sea'. In popular parlance the southern half of the trough is termed the Imperial Valley; the northern section is called the Coachella Valley. In actuality, the two combined constitute a single trough.

When first visited by white men the central portion of the valley was a shimmering expanse of salt, more than 200 feet below sea level. In 1901 irrigation was commenced by means of a canal cut through the river bank just south of the international border. In 1905 the Colorado River turned into this canal during a flood and poured northwards down the slope of its old delta-fan and inundated the lower portion of the basin creating the Salton Sea. The breach was eventually closed, the river returned to its normal channel, and irrigation was resumed.

The All-American Canal (so called because it does not enter Mexican territory) was constructed by the Bureau of Reclamation of the federal government and took the place of the earlier system in 1942. Water is diverted from the Colorado River at the Imperial Dam north of Yuma, Arizona. After passing through a series of settling basins wherein its silt load is deposited the cement-lined canal passes through a belt of huge sand dunes before entering the valley. It carries a volume of 10,000 cubic feet per second. One branch of it passes northwards around the Salton Sea to serve the lower part of the Coachella Valley to which it delivers 1,500 cubic feet per second.

The Imperial Valley has a grid of canals of two types: supply canals and ditches bringing irrigation water to the land; and drainage ditches carrying the excess 'tailwater' with its accompanying salts to the Salton Sea. An even finer but invisible grid is also present: the network of tiles underlying the fields to aid in the drainage of subsurface water and the lowering of the water table.

The original development of irrigation in the Coachella Valley was based on a good supply of artesian water supplied originally by run-off from the surrounding mountains. The exploitation of this reserve had of necessity to await the development of well-drilling equipment capable of tapping it. Between 1900 and 1907 over 400 wells were drilled in the lower part of the valley, about three-fourths of them with artesian flow. With the improvement of pumping equipment, other wells were drilled farther northwards and agriculture was extended into that area. Because of poor drainage in the heavy soil of the lower portion of the valley, salinity problems became acute after the first few years and many areas were abandoned. An insufficient supply of water, however, in 1918 brought about the organization of the Coachella Valley Water District with the aim of conserving the local supply and importing water from the Colorado River. The District entered into an agreement with the Federal Bureau of Reclamation by which water was eventually delivered in the early 1950s to the valley by means of the Coachella Branch of the All-American Canal.

Since the construction of the All-American Canal the inflow of water into the Imperial-Coachella Basin has increased greatly. Subterranean seepage from the irrigated fields and the discharge of tailwater into the drainage ditches has increased accordingly, and the level of the Salton Sea (held essentially stationary since the closing of the Colorado River breach in 1907) has been rising steadily for the past decade. It has resulted in the inundation of some of the lowest fields of both the Coachella and the Imperial Valleys and the rise of the groundwater table and attendant salinity problems in the adjacent areas. As it expands, its evaporating surface increases and hence an eventual state of equilibrium will be reached—but not until considerable valuable farm land has been sacrificed.

With its warm winter, its long hot summers and its plentiful irrigation water the Coachella Valley has become an important region for the raising of several subtropical fruits. Dates occupy 5,700 acres and yield about 90 per cent of the American crop. The date groves are located on the sandy soil of the middle and upper portions of the valley in a salt-free, well-drained situation.

Over 7,000 acres are devoted to the raising of Thompson seedless grapes, a table variety marketed long before any other grapes have become ripe in the United States. Approximately 2,500 acres are planted to citrus, notably grapefruit. In many places, these groves are interplanted with dates. The grapefruits are marketed in midwinter when they find a ready sale in the cold eastern markets.

Largely because of its much heavier soil, the Imperial Valley has not specialized in the raising of fruits and vines. The emphasis, rather, is upon a number of varieties of field crops and row crops. Nearly 64,000 acres are devoted to the raising of truck crops, particularly during the winter for sale to eastern markets and the cities of coastal California. Since quick freezing of fruits and vegetables has become important in American processing and marketing there has been a marked change in the varieties of vegetables raised here. Today, the principal winter truck crops are lettuce, tomatoes, peas, melons and carrots. Most of them being highly perishable, they are delivered to the market areas in temperature-controlled railway cars or trucks travelling on expedited schedules. The long hot summer, the very dry harvesting season and the ease of controlling crop pests has led to the growth of 28,000 acres of cotton.

An even greater area (34,000 acres) is devoted to the raising of sugar beets, part of which are processed in a local refinery, while the remainder are shipped by rail to refineries in the coastal area.

The Imperial Valley and portions of the Coachella Valley play important roles in the livestock economy of the south-west. About 170,000 acres are devoted to the raising of alfalfa and several thousand more to the raising of hay and irrigated pasture. The role is dual: animals from the desert ranges come here for fattening before being shipped to the Los Angeles market: and herds of cattle and bands of sheep are moved here by truck and train for winter grazing. Besides grazing on the alfalfa and pasture lands, the animals act as gleaners after the vegetable harvests and are fed the culls and trimmings from the packing houses. Much alfalfa is cut for hay, baled and trucked to the dairy farms of the Los Angeles area; some is dehydrated and becomes an ingredient in commercial stock feeds; and some is fed to local dairy breeding herds.

All phases of the agriculture are highly mechanized. Many of the operations are carried out by custom outfits who perform a particular operation for an individual farmer under contract. Much of the land is owned by large companies or by absentee owners; the operations are looked after by a resident manager and most of the labour force consists of itinerant workers, largely Mexican citizens who enter the United States under short-term labour contracts. With the rapidly increasing mechanization, however, the number of manual labourers required has declined markedly.

Alfalfa is mowed, turned, raked, baled, loaded on to trucks and stacked entirely by machinery with men being needed only to steer the equipment and drive the trucks transporting it. Sugar beets and cotton are harvested chiefly by machine. For the harvesting of lettuce, a conveyor belt mounted on a truck passes slowly across the field, covering a score of rows at a time. Workers afoot cut off the mature heads with a knife and place them on the belt. Other workers on the truck grade them roughly and pack them into field boxes in which they are transported by other trucks to the packing house. The high degree of mechanization is in part a reflection of the high cost of American labour.

The irrigated agricultural areas of Nevada present a much simpler picture. The cold of winter precludes the growing of sensitive crops, hence there are no winter truck products, no subtropical fruits and no cotton. The major emphasis is upon the raising of alfalfa and the maintenance of irrigated pasture, both associated with the transhumance of the local cattle and sheep economy. Herds and flocks summer in the high mountain country and winter on the irrigated lands of the basins, grazing in the late fall and early spring on the irrigated pastures and subsisting during the winter on the accumulations of alfalfa hay produced during the preceding summers. A few areas produce summer crops of celery and sugar beets, but the chief emphasis is upon the livestock feed.

## THE ECONOMY OF THE DESERT INDIAN

When first contacted by the white man, the Indians of the American deserts consisted of a number of widely varied groups. Some, such as the Papago of south-western Arizona, were primitive hunters and gatherers. Other hunters and gatherers, like the Apache, had recently acquired the horse, and had had their economy greatly strengthened thereby. A third type, represented by the Pueblo tribes of the Rio Grande Valley of New Mexico, carried on intensive irrigation agriculture.

Equally varied were their relations with the white man. Some, like the Papago, living in undesirable country, were ignored by the newcomers and still live today in the same primitive manner, with but little modification from the contact. The Apache vigorously opposed the advance of the white man and fought long and bloody campaigns before their eventual capitulation. The peaceful Pueblo farmers accepted Spanish control three centuries ago and have continued their agricultural pursuits with only superficial changes until the present day.

The Papago today occupy a large reservation in south-western Arizona. From its Sonoran-type vegetation, the sparse population manages to eke out a scanty existence by hunting and gathering and by herding a small number of cattle and other semi-domesticated animals. Because of the dry winterless climate, their dwellings need be little more than shelters. Many of the men, and sometimes entire family groups, work as farm labourers from time to time in the adjacent irrigated lands along the Salt and Gila Rivers, and some of the more ambitious leave the reservation permanently for employment elsewhere. Generally speaking, however, most of the tribe seems to prefer the simple and easy-going reservation life. Their purchasing power is low, but their needs are not great.

This tribe has been less affected by the advent of the white man than any other group in the United States. Efforts of the Indian Service of the federal government to improve their way of life have been only moderately successful. The greatest advances have been made in the improvement of cattle and the development of better water supplies. One thing should be clearly understood—these people have not been pushed from better lands into the undesirable desert tract they now occupy. The present reservation is their traditional home, and they now live there by choice.

The Apache formerly ranged all of southern Arizona and all but the north-eastern portion of New Mexico. Before the advent of the white man they were a warlike group, recurrently fighting with similarly warlike neighbours and preying upon the peaceful Pueblo tribes. When they obtained the horse[1] their capacity for war was increased immensely, and for two centuries they terrorized the south-west.

Today they are peaceful, industrious cattlemen. Their extensive reservations include large areas of high mountain country, ideal for summer grazing, and lowland tracts for wintering their cattle. Many of the herds are composed of well-bred Herefords, developed in part through the assistance of the Indian Service, and in part through their own efforts.

These people have found a secure place for themselves in the modern American economy by adjusting their former way of life, with its attendant love of horsemanship and the open country, to the continuing demand for good beef. Thus their former hunting and gathering culture has been exchanged for a profitable commercial pastoralism.

On the other hand, their relatives and neighbours, the Navajo, have not been so adaptable. Originally a warlike, nomadic group, they waged a long and bitter war with the whites, and were eventually settled on a reservation in northern Arizona. But while the reservation is large in area, it is steppe and desert country and the carrying capacity of its range is very low. In the last half-century, the Navajo have increased greatly in population, and their herds and flocks have multiplied accordingly. Today, the Navajo reservation presents a sorry picture of overgrazing, range destruction, and poverty.

The Navajo has not been able to adjust to the modern economy. Rather than raise marketable beef cattle, they raise large flocks of sheep and goats and droves of horses. Most of these are quite worthless, both to the Navajo and on the open market, yet they are a portion of the tribal tradition with which the people refuse to part. In religion, custom and dress, too, the Navajo cling to the old ways more than any other Indian group.

Some cash income is provided by seasonal employment of men off the reservation—particularly as railway and agricultural workers. Some Navajos engage in the weaving of woollen rugs and blankets, woven in keeping with ancient traditions, and in the production of silver and turquoise jewelry, at which they are remarkably expert.

The Navajo situation is something of a national disgrace, and has so been for over half a century. Part of the blame is to be placed on the Indians themselves, for their inability or refusal to alter their ways; but much of the blame must be placed on the federal government. Long ago the reservation should have been enlarged to include areas of good arable land and better grazing tracts, and more effort made to introduce better animals, better grazing techniques and better agriculture. Something is being done in this way today, but it is half a century too late.

With the control of the Colorado River by the construction of the larger dams, the parts of the Indian reservations along its banks which were formerly subject to annual floodings have become available

1. The horse was first introduced into America by the Spanish. Feral animals spread rapidly and certain of the western tribes obtained mounts even before the arrival of the white man in their particular territory.

for agriculture. Selected families from the Navajo and other reservations have moved to these areas and carry on agriculture there by modern mechanized techniques.

In the Rio Grande Valley and at several places in the plateau country to the westward, groups of Pueblo Indians carry on irrigation agriculture in much the same way their ancestors did in pre-Spanish times. Since they were peaceful sedentary agriculturists, their rights to land and water were respected by the Spanish and later by the American Government.

Today their ancestral fields lie within their respective reservations. Water is supplied in some cases by simple weirs of their own construction, and sometimes by larger structures built by the Indian Service. All of the older crops are still raised: corn (maize), beans, squash and melons; but to them have been added certain European imports, such as the deciduous fruits. While the people are theoretically Christian, they still scrupulously practice all of the ancient rites associated with agriculture. Cultivation is still carried on by hand, yields are low, and almost no saleable surplus is produced. Hence this is still essentially a subsistence form of agriculture.

Some of their villages have, however, undergone a certain degree of modernization. Glass windows have been placed in formerly windowless houses; some dwellings have been electrified, and have not only lights, but radios, electric refrigerators and even washing machines. A few trucks are present in each village; some are privately owned, and others are the communal property of the group. The money necessary for such purchases is derived from the non-agricultural pursuits of the people: some work off-reservation as agricultural labourers; others engage in the making of silver and turquoise jewelry and beautifully proportioned pottery.

## RECREATION AND URBANIZATION

A tremendous recreational development has occurred in the warm-winter portions of the American desert within the past few years. The interest began a couple of decades ago with small-scale tourist developments at several of the more attractive spots, and since World War II it has expanded into a tremendous recreational boom. It has taken on several aspects : gaudy, highly publicized Las Vegas, lavish Palm Springs, middle-class Twenty-Nine Palms—all weekend or winter vacation resorts; Phoenix and Tucson —combinations of resort and retirement centres; and Apple Valley and Lucerne Valley, California, and Wickenburg, Arizona—dude ranch centres.

The desert has drawn people to it for a variety of reasons : to relax, to hike, to ride horseback, to swim in artificial pools, to enjoy the beauty, the climate, the solitude. Just as people in other parts of the world are drawn to the seashore or the mountains, so in the west they are drawn to the desert. They paint or photograph its landscapes, ride its trails, study its birds and plants. There are even magazines devoted entirely to it, such as *Desert Magazine* and *Arizona Highways*, replete with colourful illustrations and recounting of desert lore.

Obviously the greatest users of such desert resorts are people from the nearby cities, particularly Los Angeles. To an increasing degree, however, people from the east and the middle-west are coming to the desert for mid-winter vacations, to bask in the sun, swim out of doors and play golf while their friends at home are snowbound.

The federal government, realizing that large tracts of desert land would never pass into private control even under the Taylor Grazing Act, has recently made large areas available for private recreational use under the Small Tracts Act. By its provisions, individuals can obtain title to 5 acres of desert land for merely the cost of a filing fee and the construction of a small, inexpensive building.

A great many of the weekend occupants of such desert areas are escapists—fleeing from the smog, the congestion, the hurried pace of modern urban life. Eventually some of them, living on pensions or investments or earning a living by some occupation which does not require continued presence at an urban desk or machine, decide to remain in the desert permanently.

Because of the necessity of being accessible to utilities, most of these new desert dwellers come to live within the limits of the areas where water, electricity, etc., are provided, thereby creating open, sprawling communities. Their presence creates a need for services, and commercial centres develop to provide them—thereby providing a means of livelihood for still other 'escapists'. As a result, a 'rurban' aspect has already developed over certain parts of the southwestern deserts.

In the minds of people from other parts of the country, such year-round occupance of the desert seems unattractive, if not impossible. There is always the idea of a desolate environment, unpleasant in all ways. Such was actually the case with early desert dwellers, suffering from heat, short of water, isolated by poor roads, and lacking all amenities. But today, with modern technology, desert living is very pleasant. With homes designed to reduce glare and reflect rather than absorb heat, with air-cooling facilities an integral part of every building, with swimming pools, mechanical refrigeration, adequate water supply and sewerage, with paved roads, telephone, radio and television to overcome the isolation, the desert becomes an ideal place for living. Actually it is no more difficult or unreasonable to cool a house against the heat of the desert summer than it is to heat it against the cold of a New England winter.

## THE FUTURE

Part of the future of the arid lands of America is to be seen in the recreational and 'rurban' developments just described. But in the writer's opinion, even greater and more drastic developments lie ahead, which will completely revolutionize the present concept of the desert. Before discussing them, however, let us list the present uses and evaluate the problems of these areas.

Areally, by far the greatest part of the desert is devoted to the grazing of livestock. Without question, this is the best use for the land, and one that will remain far into the future in many areas. On the other hand, it is an extensive form of activity, yielding only a low return per square mile; economically, it is therefore a poor competitor, likely to be displaced by an activity that yields at a higher rate per unit of land. It is for this reason that the grazier has already been displaced from the irrigable lands by the agriculturist.

Irrigable land is very productive and very valuable, particularly in the warm-winter southern deserts. Despite common notions to the contrary, however, irrigable land in the United States has about reached its practical limit under existing technology. This is not due to a shortage of potentially irrigable land (many untouched bolsons still have plenty of that), but rather is due to a shortage of available water. Underground basins are being exploited to the extreme; exotic streams have already been tapped to their fullest extent. Additional supplies can come only from extra-desert sources by large-scale diversions, greater than anything we have seen heretofore. For the most part, it will be a case of diverting water from humid lands into the arid. From the engineering viewpoint, this is neither impossible nor impractical, but it will be expensive, requiring heavy appropriations from governmental sources. More significant, it will raise important political issues, many of them based on deep-seated sectional emotionalism. For years the state of California has been torn asunder politically by the conflict between the humid north and the semi-arid south over the water diversion issue. It is far more likely that the politician will find such proposals inexpedient than that the engineer will find them impractical.

In short, the likelihood of large-scale expansion of irrigation in the American desert is not great, under existing circumstances. However, it is very likely that future technological advances will alter the situation completely.

If the desalinization of sea water can be cheapened to the point where agriculturists can use its product on their lands, large areas might become available for irrigation. More probably, such water will be used for urban supplies, releasing more of the water from exotic streams for agricultural use.

The present 'rurban' developments will undoubtedly continue to expand rapidly, until very large areas of desert country are occupied by them. Their expansion will be partly at the expense of the graziers, and partly at the expense of the agriculturist—both of whom they can displace economically, for the value of land for residential use, even in the desert, is higher than any agricultural or pastoral use.

Some of the desert areas are developing still another economic base for occupational activity—and thus, in the writer's opinion, portending the future basis for growth in the American desert: in an already very significant manner, industry is being established in the desert landscape. Two areas are pioneering along these lines: the Antelope Valley of California, and the Phoenix area of Arizona. The former is the site of several large aircraft plants, while the latter has a mixed group of industrial enterprises. Both are, in a sense, climatically based : the former because the high incidence of good flying weather facilitates testing operations; the latter because management and employees alike found the climate to their liking.

It is probable that in the near future a means of utilizing solar energy as a power source will be developed. At that time, the American desert will undoubtedly undergo a tremendous industrial development. Cheap power for the industrial plants themselves will be available, as well as for the accompanying residential and commercial areas. At the same time, some of the harnessed solar energy can be used for pumping and desalinization of sea water, so that adequate water supplies will be available. It is even possible that agricultural areas may expand with water from this source.

In short, it seems quite safe to predict that the desert area of the United States will, during the immediate future, develop steadily as a recreational, residential and 'rurban' area, that its agriculture will continue at its present high level, and that the future holds a reasonably good promise of industrialization.

# BIBLIOGRAPHY


1. BENNETT, Russell H. *The complete rancher.* New York, Rinehart, 1946.
2. CLAWSON, Marion; HELD, Burnell. *The federal lands: their use and management.* Baltimore, Johns Hopkins Press, 1957.
3. HARDING, S. T. *Water rights for irrigation.* Palo Alto, Stanford University Press, 1936.
4. HIBBARD, B. H. *A history of public land policies.* New York, Macmillan, 1924.
5. JOHNSON, Douglas W. Relation of the law to underground waters. *Water-Supply Paper 122.* Washington, United States Department of the Interior, Geological Survey, 1905.
6. PEFFER, E. Louise. *Closing of the public domain.* Palo Alto, Stanford University Press, 1951.
7. POWELL, John Wesley. *Report on the lands of the arid region of the United States.* Washington, United States Geographical and Geological Survey of the Rocky Mountain Region. 1879.
8. ——. Institutions for the arid lands. *Century Magazine,* vol. XL, May 1890, p. 111-116.
9. STODDART, Laurence A.; SMITH, Arthur D. *Range Management.* New York, McGraw Hill, 1943.
10. THOMAS, George. *Early irrigation in the western states.* Salte Lake City, University of Utah Press, 1948.
11. TURNER, Frederick Jackson. *The frontier in American history.* New York, Holt, 1920.
12. WEIL, Samuel C. *Water rights in the western states.* San Francisco, 1911. 2 vols.

# LAND UTILIZATION IN THE ARID REGIONS OF SOUTHERN AFRICA
## Part I: SOUTH AFRICA

*by*

William J. Talbot

*Professor of Geography, University of Cape Town, Union of South Africa*

### THE CHARACTER, EXTENT, AND PRE-EUROPEAN OCCUPANCE OF THE ARID REGIONS

Aridity, perennial or seasonal, and drought, recurrent or occasional, are keynotes in the landscape and the economy of South Africa; water was, is, and will always be omnipotent. Water directed the footsteps of its pioneers, circumscribes its agricultural economy and may largely dictate even the prospects of industrial expansion in its economic heart-land, the High Veld. Over more than 300,000 square miles, nearly two-thirds of the Union, the mean annual precipitation is less than 20 inches; over 85 per cent of the country most of the precipitation falls in summer when evaporation and transpiration are most rapid. It is estimated that only about 6 per cent of the precipitation becomes available as surface run-off and, although probably half of this flows through the arid regions, lack of suitable storage sites and irrigable land limit the extent to which this can be used to supplement the scanty rainfall. Consequently, although the arid regions include more than 60 per cent of the land in farms, they include only about half of the area under irrigation and less than 15 per cent of the cultivated land, 45 per cent of the sheep but less than 20 per cent of the cattle, only 20 per cent of the rural Whites and, with a rural density of the order of two per square mile, less than 10 per cent of the rural population of all races.

Like most of Africa, much of the Union is a land of relatively level landscapes, remnants of ancient erosion surfaces whose level profiles are paralleled, emphasized, and continued over the whole of the Orange Free State and most of the Cape Province between 30° S. and 33° S. by the innumerable dolerite dikes that invade—and in Basutoland by the immense basaltic lava flows that overlie—the otherwise scarcely disturbed sandstones and shales of the Karoo system.[1]

Its elevation has been determined largely by recurrent epeirogenic movements (particularly those of the mid-Tertiary) that raised these almost level surfaces to form the broad 2,000-6,000-foot high plateaux that occupy most of the Union. The rejuvenation resulting from these movements added two spectacular features to the relief: renewed erosion carved from the seaward edge of the plateaux the 3,000-10,000-foot high Great Escarpment that extends under many local names[2] from beyond the Orange River in the north-west to the Soutpansberg in the north-east and, from the bevelled roots of an early Mesozoic mountain system, sculptured the 5,000-7,000-foot high sandstone and quartzitic ranges whose rugged crestlines now dominate the landscapes of the southern Cape Province.

Extending from 22° S. to 35° S., most of the Union lies within the summer rainfall belt. In summer, relatively high temperatures prevail despite the altitude and low barometric pressures occur over the interior and facilitate the indraft of marine subtropical air from the east and north-east. Orographic effects make precipitation fairly dependable on the windward slopes east of the Drakensberg, but beyond the crestline, where the relatively even surface descends gradually westwards, summer precipitation is dependent almost entirely upon frontal disturbances and other atmospheric instabilities and decreases in amount, frequency and reliability towards the interior. In winter, when the depressions generated along the polar front approach more closely to Africa, frontal precipitation is fairly widespread in the coastal regions of the southern and south-western Cape Province, but sparse and unreliable north of 33° S.

1. Deposits ranging in age from late Carboniferous to lower Jurassic, well developed within the Karoo but extending far beyond its geographical limits to outcrop also over Basutoland, much of Natal, and most of the Orange Free State.
2. Kamiesberg, Roggeveldberg, Nieuweveldberg, Sneeuwberg, Stormberg, Drakensberg, and others.

Thus in the Union a typical subtropical west coast arid region extends far into the interior. A southern annexe thereto in the Little Karoo extends eastwards into the Groote, Sundays, Great Fish, and tributary valleys in the lee of the Cape Ranges, while in the Transvaal, the low elevation of the Limpopo Valley and the sheltered situation of the Low Veld in the lee of the Lebombo Range have condemned both of these areas to high summer temperatures and a scanty, uncertain rainfall.

These arid regions, that altogether comprise more than 60 per cent of the total area of the Union, may be delimited approximately by the 10-inch (25-cm.) mean annual isohyet in the winter rainfall region and by the 16-inch (40-cm.) isohyet in the summer rainfall region or may be defined more closely in terms of precipitation-evapotranspiration equations [69, 70].[1] But inasmuch as the character of the natural grazing is the most significant determinant of contemporary land use in the semi-arid/subhumid marginal zone, the area now occupied by the arid and semi-arid types of veld[2] provides the most practical definition of the arid regions of South Africa for our present purpose (Fig. 1). This definition, of course, does not define a stable area. In fact no fixed limit to the arid regions can be postulated. So long as injudicious land use continues to impair the extent to which precipitation is made available to the living plant, so long will actual run-off and actual evapotranspiration depart unpredictably from computations of their potential values and arid landscapes will continue to invade subhumid climates.

South of the Orange River, most of the arid interior is known generally as the Karoo or is referred to more specifically in terms of its physical subdivisions : the Little Karoo (between the Langebergen-Outeniqua Range and the Swartbergen), the Great Karoo (between the Swartbergen and the Nieuweveld-Sneeuwbergen escarpment), the Upper Karoo (north of the escarpment), and the Doorn Karoo (between the Cedarbergen Range and the Bokkeveld Range on the west and the Roggeveld escarpment on the east). Derived from a Hottentot word: *!garob* signifying parched or desiccated, the term Karoo has become also a synonym for the desert-shrub vegetation characteristic of these regions where the scanty precipitation varies widely from year to year in both amount and seasonal distribution. Small-leaved evergreen woody shrubs, 1-2 feet (0.3-0.6 m.) high and widely spaced over generally bare ground, present a deceptively monotonous appearance that masks an exceptional wealth of species (including grasses) except when timely and effective rains transform the wilderness into a floral paradise.

West of the plateau edge, where more than three-quarters of the precipitation normally occurs in the winter half-year, April to September, desert succulents are conspicuous and locally dominant. In the Coastal Sandveld—a zone of frequent sea-fogs and heavy dews—succulents and low sclerophyllous bushes are intermingled and grasses were originally abundant.

In the south the Little Karoo is also characterized by a succulent bush, though of a taller growth habit and of different species. In the semi-arid sections of the valleys of the Groote, Sundays, and Great Fish rivers, this passes into a succulent scrub that is dominated by thorny euphorbias and aloes.

Locally, mountain ranges introduce areas of higher precipitation and lower night temperatures and, therewith, representatives or relatives of plant species characteristic of the sclerophyll bush of the south-western Cape Province. Broken relief, whether in mountainous country or in areas of active stream dissection in the vicinity of escarpments or of incised rivers such as the Orange, also introduces local variations in edaphic conditions that interrupt the broader stretches of uniform vegetation by mosaics of different Karroid plant associations—aptly termed *gebroke* veld or broken veld.

North of the Orange River, where more than 70 per cent of the rainfall usually falls in the summer half-year, October to March, grasses become dominant and the vegetation assumes the character of a generally open savanna, with scattered kameeldoorn (*Acacia giraffae*) and other small deciduous thorn trees. Similar savanna vegetation covers much of the Kalahari and, with more abundant and varied tree growth, the Limpopo Valley and the Low Veld of the eastern Transvaal.

In their primeval condition these regions, despite their aridity, supported a surprisingly numerous and varied fauna : the wooded savannas were the haunt of buffalo, elephant, kudu, and giraffe; wildebeest, hartebeest, gemsbok, and innumerable other fleet-footed antelopes shared the open country with the wild ostrich; springbok abounded in the Karoo and, even towards the end of the nineteenth century, occasionally swarmed across the country in herds numbering several hundred thousand; the hippopotamus inhabited perennial rivers everywhere; the eland, the zebra, and the carnivores that preyed upon all—the lion, leopard, hyaena, wild dog, and jackal—were ubiquitous [71].

In this Eden the Bushmen, survivors of a Mesolithic hunting people who at one time roamed most of

1. The figures in brackets refer to the bibliography at the end of the chapter.
2. The term 'veld' (pronounced 'felt') has various meanings, according to the context. 'It may mean the countryside as opposed to the town. It may be used with a descriptive adjective either to distinguish a particular kind of area, e.g. sandveld, hardeveld, and bushveld, or to signify a broad natural region, e.g. High Veld, the term "veld" then being used in the same sense as *pays* or *Landschaft*' [76, p. xi]. Similarly it may connote either grazing land in general, e.g. veld or *weiveld*, or a vegetation type, e.g. thorn-veld.

Grazing land is usually characterized as sweet veld, sourveld, or mixed veld according to its palatability to livestock throughout the year. Sweet veld remains palatable and provides fairly nutritious grazing at all seasons; sourveld is palatable and nutritious in the early part of the growing season but the grasses become hard, fibrous, and of low digestibility and nutritive value with the approach of the dormant season [76, p. xi and map IV, p. 245-250].

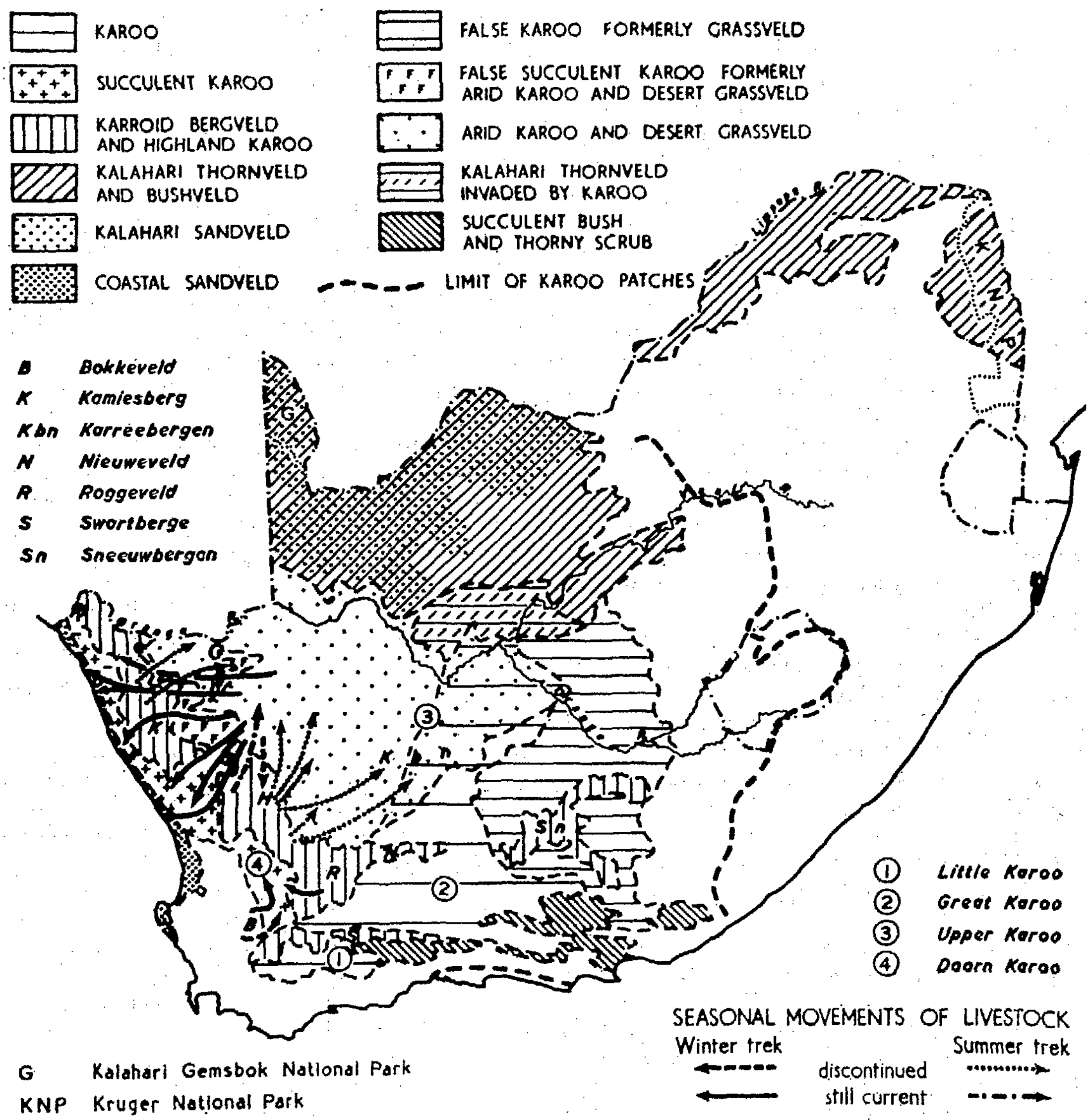



FIG. 1. Veld types and seasonal movements of livestock. (Veld types generalized from Acocks [1].)

the African grasslands, found their last asylum in the Karoo and the Kalahari. Omniverous and resourceful, skilled hunters and trackers, the Bushmen were masters of the art of survival. With short bows and fragile arrows, made lethal with a wide variety of poisons, and with ingenious snares, traps and decoys, they were deadly hunters; with traps and spears they fished the rivers; with simple digging sticks they collected a great variety of edible roots, fruits, herbs, insects, reptiles, eggs, honey, and other *veldkos* (wild food). Finally, with their stamina, experience, and intimate knowledge of their habitat they could, when necessary, survive for months—like the gemsbok—in areas devoid of free surface water. Few in number and nomadic within the confines of the hunting territory of their respective bands, they left no scars upon the landscape and history may well honour them, not as Africa's most primitive, but as one of her least destructive peoples.

The Hottentots, relatively late-comers to the South African scene, appear to have moved across the lower Orange River with their cattle and sheep sometime before the fourteenth century [67, p. 20-50] and thence to have moved southwards to occupy the areas of succulent Karoo and of arid broken veld in Namaqualand and the sclerophyll bush in the south-western Cape Province, whence they spread eastwards through the Cape Ranges and the Great Karoo. Although they were primarily pastoral nomads, their staple diet of curdled milk was supplemented occasionally by hunting, fishing and gathering—activities in which they employed many techniques obviously derived from the Bushmen. Among them each tribe claimed as its territory all the land where its stock were regularly grazed during the year. However, since they migrated seasonally (and in times of drought migrated far) in a sparsely peopled country, it appears unlikely that any of their tribal areas were rigidly defined [66, p. 286]. Among the Hottentots all of the tribal territory was regarded as the inalienable common property of the members of the tribe. A chief might either gratuitously or on payment grant a stranger permission to water or to graze his stock on tribal land but such permission granted *usufruct* only—although too often misinterpreted by early European colonists as a grant of title.

The livestock of the Hottentots are of particular interest. Not only were they the source of the slaughter stock to provision ships—initially one of the chief reasons for the establishment of the first European outpost on the South African coast—but they also became the foundation stock of the flocks and herds that later provided the economic basis for the expansion of the embryonic European colony far into the interior. The cattle, vari-coloured but largely of the lateral-horned zebu type [21, p. 621], were the parent-stock from which the colonial farmers, through two centuries of selective breeding for teams of powerful, evenly matched, reddish-brown draught oxen, derived the modern Afrikander cattle [8, p. 9]. The Hottentot, or so-called Cape, sheep appear to have been of mixed origin, stemming from at least two non-woolled strains : one a long-tailed breed (long preserved fairly pure among the Namaquas in the north-west) and the other a broad-tailed, fat-rumped breed (the dominant strain today in the 'Ronderib' Afrikander breed) [30, p. 643; 73]. Hardy and better able to range widely in search of grazing than the woolled sheep of a later era, they were destined to become in the eighteenth century in the hands of the colonial farmers not only the chief contributors to the economic wealth of the Colony but also its most effective promotors of frontier advancement. Goats were apparently acquired relatively late by the Hottentots (possibly from the Bechuana who were known to them as the Birina, i.e., goat people) and were never held in high regard. Large, prolific, hardy, and showing many variations of form and colour, the native goats have been little improved by European stock-breeders and survive today virtually unchanged in the ubiquitous 'Boer' goats.

## THE KAROO AND OTHER ARID REGIONS SOUTH OF THE ORANGE RIVER (THE EUROPEAN OCCUPANCE, 1730-)

### THE HINTERLAND OF A VICTUALLING STATION (1730-1800)

The European occupance of the arid regions did not begin until after 1730, three-quarters of a century after the first European settlement in South Africa was established. This was a re-victualling station on the 12,000-mile voyage between western Europe and south-eastern Asia—established to perform a function that remained the keynote of the country's economy for two hundred years. Table Bay—situated approximately midway and, moreover, near the intersection of the outward and homeward bound sailing routes—offered a sheltered anchorage, abundant fresh water, slaughter stock to be bartered from the natives, and cultivable and irrigable land in a healthful 'Mediterranean' climate of mild, rainy winters and dry, sunny summers [77, p. 57). The Dutch outpost established there in 1652 became the nucleus of a colony producing livestock, vegetables, fruit, wine, brandy and grain primarily for passing ships. It received few immigrants but after the first few decades its white population began to grow rapidly in numbers. They developed grain and wine farms particularly on the well-watered piedmont sites within 40-50 miles of Table Bay and, beyond the limiting radius of economic wagon transport of such produce, turned increasingly to stockbreeding—an enterprise that everywhere demanded less capital and drudgery than arable farming and generally provided more profit and adventure, especially when combined with hunting and with illicit bartering with and stock-thieving from, the Hottentots beyond the official frontiers. In this way the European community became innoculated with the yeast whose ferment was to cause it to spill over 'the Mountains of Africa' —the mountain chains that had confined it for half a century to the lowlands west of the 19° E. meridian—and to spread far to the north along the Atlantic slope.

The first-settled areas, although enjoying adequate winter rains, were conspicuously poor in summer grazing. Through barter and natural increase the colonists' sheep and cattle became more numerous and therefore the seasonal transfer of stock to more distant pastures became a necessity. Although at first the movement was opposed by obtuse officialdom, after 1703 it was officially recognized and legalized by the issue of grazing licences [105, p. 67]. To conserve their own animals for breeding and for market, the colonists had become accustomed from the early days of the settlement to take advantage of the abundance of wild game, to shoot for the pot and to stock their larders with *biltong* (dried venison). But as the game in the settled areas was killed off or scared off, it became necessary to go farther afield for *biltong* and hippopotamus bacon that had become part of the South African diet and for the horns and ivory that had become common supplementary sources of cash income to many colonists. And as hunting provided incentives to open new trails farther into the wilderness, the hunter scouted the country ahead of the advancing herdsman—at first northwards until impeded by lack of water beyond the Olifants River and, later, eastwards to where the coastal plain was pinched out between the forested mountains and the sea beyond Mossel Bay.

The Hottentots, never great warriors, offered little effective opposition to European encroachment upon their territory and none at all after 1689. After some hostilities in the early years of the settlement they either withdrew as tribal groups before the Whites or became economically dependent upon them as individuals, serving as shepherds, hunters, guides, and interpreters. Furthermore, they died by the hundreds in the smallpox epidemic of 1713; rater many of the survivors trekked into the interior to save their animals from the unusually virulent stock diseases[1] prevalent at the time so that by 1727 it was reported that no Hottentot encampments remained within 250-300 miles of Table Bay.

By 1730 pioneer colonists were poised on the southwestern fringes of the arid interior; in 1744 war between Britain and France brought warships and troopships into Table Bay to swell the growing stream of shipping demanding produce and slaughter stock —amounting in some years to more than 10,000 head of sheep [56, p. 49], a far greater number than the dilatory stockbreeding and irregular trading of the Hottentots could ever have provided. Herein lay the colonists' opportunity and the economic incentive to carry their pattern of extensive pastoral land use from the lowlands of the Cape far into the arid interior. For more than two hundred years, from its foundation until the Suez Canal and the steamship changed the pattern of the sea routes between the Atlantic and the East, the Colony was to continue to enjoy a foreign market for fresh meat and butter literally at its very doorstep [56, p. 175]. It could offer the seafarer tough beef or tender mutton —and of the latter the supply was potentially unlimited when the Karoo could offer 100,000 square miles of grazing where the hardy fat-tailed sheep could wax so fat as to be still in prime condition after being driven 150-200 miles to the coast [83, p. 153].

Thus in South Africa, as in Australia, it was the sheep that pioneered the colonization of the arid interior—but the movement was a century earlier, in a pre-industrial era, and was based upon mutton and tallow, not upon wool.

## ADVANCE OF THE GRAZIERS

The advance of the graziers was closely controlled by relief, natural vegetation, and surface waters—the three factors that, together with the distribution of Bushmen and Bantu, were also to determine the frontiers of settlement for many decades. From the Swellendam grassveld in the south they filed through the *poorts* (water gaps) in the Langebergen, some to settle by piedmont springs around the periphery of the Little Karoo and others to spread eastwards towards Algoa Bay along the wide intermont valleys of the Cape Ranges. From the uplands of the Bokkeveld they trekked across the Doorn Karoo towards the Great Escarpment, some to spread northwards along the crest of the Roggeveld and others to follow the scarp-foot spring-line eastward salong the foot of the Nieuweveldbergen and Sneeuwbergen to the headstreams of the Sundays River. There—where the eastward-moving Whites were stayed by collision with the westward-moving Bantu and were held on their northern flank by the Bushmen entrenched in the fastnesses of the Sneeuwberge—Graaff-Reinet, the fourth town to be founded in the Colony, was established as a frontier outpost and magistracy in 1786. Meanwhile in the west, other graziers, in smaller numbers, infiltrated northwards beyond the Olifants River to settle where the aridity of Namaqualand is ameliorated by altitude on the Kamiesberg.

## LAND TENURE

Land tenure beyond the limits of the Cape-Stellenbosch-Drakenstein settlements was initially on a basis of grazing licences, at first valid for a few months and later for a year. Each conferred freely the right to as much grazing as the licensee needed in a vaguely defined area of unalienated land. This system had evolved in the southwest in a society where the 'Vereenigde Oost Indische Compagnie' was tacitly accepted as the owner of all land not specifically assigned to private ownership. It regulated satisfactorily the use of common grazing by the relatively limited numbers of livestock in the possession of the first agrarian communities. To the individual grazier, as each first moved into the hinterland, the system was equally satisfactory inasmuch as, with its vague phraseology, the grazing licence legalized nomadism and entitled him to move on to new pastures—as the Hottentot had done—as often as need or desire might dictate. Later, when the nomads found the spots best suited to settlement, they began

1. *Geilsiekte*, a form of cyanide poisoning that follows grazing on certain plants, especially wilted young growth, and which appears to have been unusually widespread after the first rains that broke the 1714-1715 drought. Furthermore, in 1723 the first recorded epidemic of foot-and-mouth disease swept the Colony [81, p. 263].

to request not licences to use an ill-defined range in community with others but exclusive grazing rights in specified localities of their own choice, named in the document and identified by a beacon or by farm buildings in the field. Thereupon, without formality, from small beginnings in 1708 the loan-farm system came into being [105, p. 75]. The first-comers took the best spots, camped there seasonally (or in some instances erected buildings and corrals) and at other seasons resumed a transhumant or a nomadic existence. Later-comers established their claims between or beyond them but everywhere with the realization that it would be mutually advantageous to settle sufficiently far from one's neighbours so as to restrict the grazing area of none. This condition was easier to fulfil in 1750 than in 1790 but by then custom had established an unwritten law that prescribed a minimum distance of one hour's walk between farmsteads. Farm boundaries remained undefined but the extent of a farm was generally accepted as the area within the radius of half an hour's walk from the farmhouse or farm beacon.

The system was well suited to the arid interior and to the near-penniless pioneer. It gave him, besides unlimited grazing on unalienated land, individual and indivisible rights to nearly ten square miles in return for an annual fee of less than £5.[1] Although theoretically it gave no security of tenure beyond the year's end, it was administered in a manner that gave complete security in practice and that guarded the land against partition into sub-economic units.

Nevertheless by 1809 the British administration was convinced that it had outlived its usefulness and, after 1813, replaced it by the *eeuwigdurende erfpacht* or so-called 'perpetual quitrent' tenure. Under this system an accurate survey of each farm by a qualified land surveyor was prerequisite to the issue of a title deed. Property holders were given all the rights and security of freehold tenure (apart from the government-reserved rights of way for public highways and rights to mine precious minerals) in return for an annual rental equal to 5 per cent of the real value of the farm as judged from its extent, the quality of soil and grazing, and other relevant circumstances. Later, under Act 14 of 1878, provision was made for the purchase of the freehold of any such property by payment of twenty times the annual quitrent [24, p. 155].

The conversion from the old to the new system was a Herculean task, far beyond the immediate capacity of the civil service. Confusion continued for years during which, pending the arrival of the government land surveyor, no one received a legal title of any kind but continued to occupy land without payment, in some instances for as long as fifteen years. New farms (*rekwesplase*) were taken up with no more formality than the filing of a request for permission to occupy an area, defined as under the earlier loan-farm system, and everyone proceeded on the tacit assumption that in due course occupation *de facto* would be officially recognized as occupation *de jure* [104, p. 127].

An unpopular measure introduced in 1831 was the Auction of Crown Lands Ordinance. Henceforth new farms ceased to be the birthright of each rising generation but became instead privileges that must be purchased at public auction. At a time when little good land remained unalienated within the Colony this Ordinance provided only another stimulus to the northwards movement of the colonists across the frontier. In terms of later Acts, grazing on Crown lands was made available under leases that gave title to large areas of non-arable land for periods of five years or longer and under short-term grazing licences that conveyed the right to graze specified numbers of animals according to the fees paid. Finally, the legislation separately enacted in the Cape Colony, the Orange Free State and the Transvaal was supplemented after Union[2] by the Land Settlement Act of 1912 which not only governed the subdivision and alienation of Crown lands but provided for State assistance to settlers on both private and Crown lands, including assistance in locating and tapping water.

## CONDITIONS OF SETTLEMENT AND SEASONAL MIGRATIONS

By the end of the eighteenth century the European had practically displaced and absorbed the Hottentots throughout the Karoo. But the system of land use with which they supplanted that of the Hottentots was not entirely new; on the contrary it was based not only on the livestock of their predecessors but also upon the experience, knowledge,and loyal co-operation of the countless Hottentot herdsmen, shepherds, wagon drivers, and trainers of draught oxen who had entered into the service of the Whites and without whose help the rapid expansion of the Colony could not have taken place [56, p. 74].

Apart from the Sneeuwbergen where the colonists were repelled by the Bushmen and the Nieuweveld where their isolated farmsteads were made unsafe by them, the frontiers of settlement were determined by water. Around the margins of the Little Karoo, along the wide intermont valleys between the Cape Ranges, and around the margins of the Great Karoo isolated farmsteads appeared wherever piedmont

1. From 1714 to 1732 the annual fee was 12 rix dollars and from 1732 to 1812 24 rix dollars or 3 oxen [15, p. 155]. Until the collapse of the colonial currency early in the nineteenth century, the rix dollar was equivalent to four shillings, but later declined to about one shilling and sixpence [23, p. 40].
2. The incorporation in 1910 of the former colonies, the Cape of Good Hope and Natal, and the former republics, the Orange Free State and the South African Republic of Transvaal, as a legislative union.

springs and perennial streams permitted permanent settlement. Others, fewer in number, appeared out in the plains, wherever a dike or other rock-bar across a major river brought water to the surface of the otherwise normally dry river bed. Along the high south-western and western rim of the Upper Karoo, from the Roggeveld and the Hantam to the Kamiesberg and adjacent uplands of Namaqualand, other farms appeared by the sources and head-streams of rivers that start but rarely progress far from the water-parting between the ocean and the Karoo.

From their *woonplase* or home farms in these better-watered zones, adjacent pastures and more distant 'trekveld' were used as grazing grounds according to season and to need. Especially in the transitional zone, between the winter rains of the Atlantic slope and the erratic summer thunderstorms of the Upper Karoo, transhumance became strongly developed (see Fig. 1).

In winter the Roggeveld farmers regularly sought refuge from the snows and bitter winds of the high plateau and took their ewes down to lamb in the Doorn Karoo. The Karoo, then at its best with the lush growth of annuals brought forth by winter rain, attracted great numbers of sheep also from the Bokkeveld to the west of it where the frost-killed sourveld at that season is practically worthless.

Many Roggeveld and Bokkeveld farmers who trekked regularly to the Karoo established claims to *legplase* there, holdings where their stock 'lay' in winter. These were either additional loan farms or recognized out-stations legally annexed to the home farms [15, p. 230]. The choice of localities suitable for such farms was less restricted than that of home-farm sites because after the winter rains surface water was fairly widely available for some months in pools along the stream channels.

In Namaqualand the incentives to transhumance were and remain even stronger than in the highlands overlooking the Doorn Karoo. The seasonal alternation in the carrying capacity of the grazing is an alternation between feast and famine, between a condition of water everywhere and water almost nowhere. Throughout much of the year surface waters are pitifully few and far between and forty acres may scarcely support a single sheep. But given soaking winter rains, the bushes put on new growth and the dry earth brings forth an abundance of remarkably nutritious annuals—whose spring flowers in some years spread a carpet of incredible brilliance and beauty over thousands of square miles of erstwhile desert—and the veld at its best will fatten four sheep to the acre [107, p. 201; 36, p. 5]. Moreover, the grazing is so succulent that animals have no need to drink, the absence of surface water becomes inconsequential, and the stock can be taken to graze and to lamb in waterless areas where at other seasons they could not survive.

These customs, established in the pioneering days, persist today for still another reason. Some land near the farmhouse is usually ploughed and lightly sown to wheat each autumn; the rains are scanty and uncertain but the soil is a rich unleached pedocal and the ploughman's optimism is rewarded in some years by yields of between one and two bushels per acre.[1] The Namaqualanders, like most farmers along the Atlantic slope, have always removed their stock elsewhere when there were growing crops on the unfenced fields. In the pioneer era there were, of course, no fences anywhere in the arid regions; in 1900 conditions were little changed in this respect, and today the relation between fencing costs and land values in Namaqualand is such that it is more economic to move the sheep and goats than to fence the crop lands.

In summer, graziers from the more northerly section of the Roggeveld, from the Hantam, and from Namaqualand took their stock into the Upper Karoo and its broad north-western annexe that is marked on most maps as Bushmanland—though it is more generally known to the inhabitants as *Die Bult* because it is so immense and so flat as to appear, like the ocean surface, slightly convex. This was *Die Trekveld*—waterless and uninhabitable, except briefly in the wake of summer thunderstorms. The rainfall averages less than 10 inches a year and in Bushmanland less than 5 inches,[2] but when thunderstorms break and soaking rains fall the vegetation grows quickly. Desert grasses (*Aristida obtusa* and *A. ciliata*) that regenerate rapidly from seed and the perennial *blomkoolganna* (*Salsola tuberculata*) provide excellent grazing and poisonous plants appear to be completely absent. Moreover, the silvery white natural hay from these grasses retains a relatively high protein and phosphorus content for years in this arid climate.

However, lacking water, much of this region was habitable only when and where the erratic summer rainstorms had filled the shallow *vleis*[3] that dot its surface. Here, therefore, there were no *legplase* and no other individual rights to grazing or to water. The trekveld could be used only on a communal basis that gave equal rights to all to follow the rains —like the springbok—and to pasture their stock by the *vleis* that held water. Furthermore, it was originally the hunting ground of the Bushmen and the Koranas (a Hottentot group whose ancestors had fled northwards from the smallpox and other calamities of 1713-1715); as such it was a region where stock-thieving followed inevitably on the

1. Between 1926 and 1938, in the 10 years for which agricultural census reports are available, the average yield of wheat in Namaqualand ranged between 0.4 and 2.1 bushels per acre.
2. At Pofadder in the 15 years between 1938 and 1955 for which records are available the precipitation of the hyetal year varied between 1.0 and 7.1 inches.
3. Local usage distinguishes between freshwater *vleis* (pronounced 'flays') and brackish water *pans* [107, p. 187].

intrusion of the graziers. In the clash between lawless elements on a lawless frontier, theft and reprisal flared into murder and massacre [53, p. 27]. Thereafter, until as late as 1869, it remained deservedly unsafe for colonists to enter the Bult for seasonal grazing as single households [57, p. 88].

The Hantam and Roggeveld graziers took their stock north-eastward to the Sak River area, where pools in the channels of the river and its tributaries usually held water for some months in the summer. Later the Roggevelders in particular began to trek regularly to summer grazing by the springs and seepage waters of the Karreebergen, after the extermination of the Bushmen there in the mid-nineteenth century. Other graziers from the high country west of the Hantam trekked northwards to the springs and wells that mark the southern edge of the Bult, while Namaqualanders sought summer pastures in the vicinity of the springs along its northern edge and in the adjoining broken veld along the Orange River.

In many of these movements the Whites were not only most probably following Hottentot precedents but their domestic animals were participating in seasonal movements similar if not parallel to those of the blesbok, springbok, wildebeest, and other game. Almost everywhere the summer trek was for the farmers a move not only to new pastures but to new hunting grounds where their supply of *biltong*—verily the staff of life in a breadless diet—could be replenished [43, p. 125; 48, p. 91]. In good seasons Bushmanland especially attracted both wild fowl and larger game in great numbers and provided excellent hunting.

In addition to their regular seasonal movements many farmers were compelled from time to time by drought, locusts, or *trekbokke* to seek other grazing for their stock. Recurrent droughts are, of course, part of

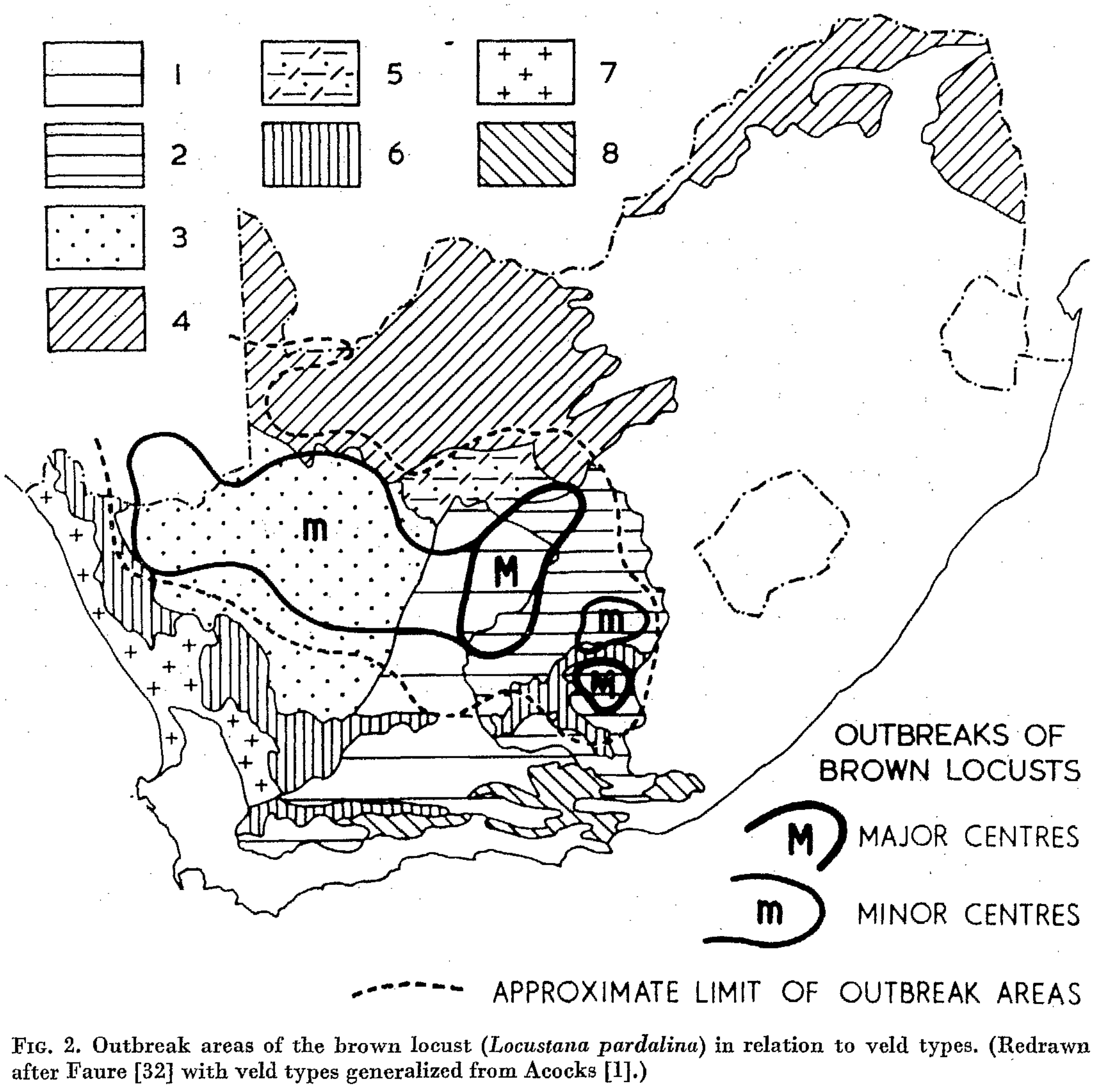



FIG. 2. Outbreak areas of the brown locust (*Locustana pardalina*) in relation to veld types. (Redrawn after Faure [32] with veld types generalized from Acocks [1].)

the climatic pattern in the South African as in most other arid regions of the world. Moreover, the breaking of a drought did not always end the period of adversity. It was followed in many instances by invasions of the brown locust (*Locustana pardalina*). This occurred widely in the solitary phase and from time to time would appear in swarms anywhere from South West Africa across the whole width of the arid region (Fig. 2). Such outbreaks, closely related to weather conditions affecting the hatching and to the state of the vegetation affecting the food supply of the insects, might be either local or extensive but appear to have been most frequent in areas where the mean rainfall exceeds 10 inches and the vegetation, especially grass, is more abundant and more vulnerable to drought than in the drier country farther west. However, from such outbreak-areas flying swarms might invade any part of the country [32]. At other times swarms of the African red locust (*Nomadacris septemfasciata*) would sweep in from the north but, being indigenous to tropical savannas, rarely invaded the Karoo [33, p. 10].

Immense herds of migratory springbok (*Antidorcas marsupialis marsupialis*), numbering in some well-authenticated instances several hundred thousand, were less frequent but far more destructive than locusts. When expelled by drought from their usual grazing grounds in Bushmanland and the Upper Karoo they sometimes came in such numbers as to destroy everything in their path; what they did not eat they trampled to dust and when they had passed, the country was left desolate until the next rains. Farmers had no choice but to trek with the stock that survived and it is claimed that the area devastated was in some instances so great that many of their animals died before they could reach grazing [82, p. 274; 71, p. 213].

Thus migrations, regular seasonal and occasional emergency movements alike, were part of the Karoo grazier's existence; mobility was for him the key to survival. Attachment to any particular loan farm was not essential; a man really needed only a flock of sheep, a covered wagon with a span of oxen, a horse, and a gun. Many spent their lives and raised families, and some even amassed modest fortunes, with little more equipment than these, their stock grazing on unalienated land that was free to all or on lonely farms where nomads might tarry a while as welcome guests—for visitors were only too rare and consequently welcome on many a backveld farm. Such was the nomadic *trekboer:* ever seeking green pastures, *die wapad was sy woning en die reën sy koning* (the wagon road was his home and the rain his king) [107, p. 244].

The products of the arid hinterland that were most in demand at the coast until the nineteenth century were, first, Cape sheep and other slaughter stock, secondly, the tail fat, soap, and candles that were derived directly or indirectly from Cape sheep, and, lastly, *biltong*, ostrich eggs,[1] and other products of the chase. Sheep's tail fat was widely used in cooking and at the table; for ships' stores it was preferred to butter. In the remoter districts, however, the chronic shortage of casks and the distance from markets made tail fat as such unsaleable. Much of it was, therefore, combined with the ash of Karoo bushes, particularly the *brak ganna* (*Salsola aphylla*), to make soap or mixed with the harder goat tallow to make candles—both products economically transportable from the frontier, especially when part of the wagon load could be made up of more valuable products of the hunt such as ostrich feathers, ivory, horns, and skins. Therefore the Cape sheep, whose inherent suitability to the Karoo had made the initial advance into the arid regions technically possible, continued in the second half of the eighteenth and the first decades of the nineteenth century to provide the major economic incentive to advance the frontier beyond the regions that could adequately supply the market for slaughter stock [56, p. 79].

As the population increased, settlement tended to encroach, wherever water supply permitted, upon areas hitherto occupied only as trekveld. In the east in the third decade of the nineteenth century, after the pacification and final elimination of the Bushmen in the Sneeuwbergen, many farmers began to transfer their stock regularly to summer grazing beyond the Orange River [104, p. 135]. As the century progressed graziers from the upper basins of the Sundays and Great Fish Rivers began to settle between the Sneeuwbergen and the Orange River in a region of sweet grass and Karoo bush described by a contemporary writer as 'amongst the prime sheep walks of the Colony' [18, p. 207]. From there they spread slowly westwards and north-westwards into the Upper Karoo and along the Orange River toward progressively drier country to where, in 1867, a poor farmer's children would be found playing with a 22-carat diamond among the brightly coloured pebbles that served as their only toys and, later, an obscure Griqua shepherd would pick from out of the dust the 'Star of South Africa'—an 82 $\frac{1}{2}$-carat gem that would set off the first explosion in an economic revolution that would transform the basis of the country's economy within a generation.

## A PRIMARY PRODUCER IN A WORLD OF EXPANDING INDUSTRIES (1800-)

But even before the drawn of the mining and railway era pastoral farming was already becoming more diversified and its bias was changing. Early in the

1. *Biltong* had long figured on the townsman's menu although less important there than in the rural diet, while ostrich eggs, because of their keeping qualities, were eagerly bought by ships' officers.

nineteenth century, when machines whose prototypes had been developed in Lancashire cotton mills were beginning to transform the Yorkshire woollen industry the invention of the Le Blanc process of soda manufacture and the large scale use of palm oil in place of tallow were laying the foundations of the British soap industry. The impact of this new competition upon the rustic Cape soap industry was accentuated by the shrinkage of the local market with the reduction of the South Atlantic squadron and of the Cape and St. Helena garrisons following the death of Napoleon. Henceforth, the rise of the Merseyside soap industry on the one hand and the Yorkshire woollen and worsted industry on the other were to impart an entirely new bias to South African sheep raising.

## RISE OF THE MERINO

This turn of events came at a most opportune time. First, in 1789 two rams and four ewes of the Escurial Merino breed, renowned for its fleece, the finest of the Spanish fine wools and long a jealously guarded monopoly of Spain, had been landed at Table Bay. By 1797 they and their descendents at the Cape numbered 38 and, although 29 were then shipped to become the first Merinos introduced into Australia and three were sent to England, six purebred Merinos, 4 rams and 2 ewes, remained in the Colony. Secondly, in 1795 the Colony was occupied by the British and, apart from a brief interlude under Batavian rule (1803-1806), was thereafter to become economically as well as politically closely related to Britain.

In the hands of enterprising colonists, the brothers, Sebastian V. and Jan G. van Reenen, and others who later acquired breeding stock from them and followed their example, the Escurial Merino strain was maintained and, in addition, an excellent dual-purpose near-Merino type was evolved by upgrading selected Cape sheep with purebred Merino rams through six or more generations. The result was not a tallow producer but a better slaughter animal than the Cape sheep and moreover a wool producer as well. It carried a 3-pound fleece of good quality, fine wool of 4-inch staple and the wethers at two years of age weighed 50-60 pounds, 20 pounds more than Cape wethers at the same age. Moreover, although equally susceptible to scab, then the scourge of all ovines in the country, it was reported to be less susceptible to ticks and *geilsiekte* than Cape sheep, among which losses from this last cause were estimated, in about 1800, to run as high as 20 per cent annually [109, p. 62]. However, as it is highly probable that the new sheep were herded with more care and on better grazing than the average Cape flock, a lower mortality from plant poisoning may not reflect any greater physiological immunity on the part of the Merinos and cross-bred Merinos themselves.

The adverse economic conditions in the Colony coerced others, more conservative, farmers to adopt the Merino, for it was a period when the increasing imports of the growing Colony could no longer be balanced by the sale of produce to the garrison and to passing ships. An additional source of overseas credit or exchange, such as an export trade in wool, was urgently needed. Flocks of high-grade crossbreeds were established in the Roggeveld in 1805 and nearly 120 selected rams were distributed there and in the Bokkeveld, Hantam, and adjacent areas on the Atlantic slope [78, p. 324-435]. Later the British administration, keenly aware of the high wool prices that prevailed during the Napoleonic Wars and recognizing the mutual benefits that the replacement of the Cape sheep by a fine-wool producing breed would confer on both the growing Yorkshire industry and the newly acquired colony, promoted the transition towards wool farming by importing Merino breeding stock : 10 rams and 25 ewes in 1815, 10 rams and 50 ewes in 1818, and others at intervals to 1826. Thereafter, business men, speculators, and farmers began to vie with each other in importing Merino stock in increasing numbers : many of the Saxon Electoral strain were brought in from Britain, from Saxony, and from Australia (1830-1850), followed by numbers of the larger French Rambouillet type (1860-1880), others of the heavy-fleeced Vermont type after 1890, and finally large numbers of Wanganella and Tasmanian Merinos (1910-1929).

After 1820, following the establishment of a considerable body of British settlers in the hinterland of Algoa Bay, woolled sheep rapidly displaced Cape sheep in the eastern part of the Colony. For this there were several reasons. Most of the new immigrants possessed no livestock on arrival. They were familiar with woolled sheep, but were unfamiliar with the Cape breed. They had no large nearby market for slaughter stock but through Algoa Bay saw prospects of an expanding overseas market for wool and, farther inland, found grazing progressively better suited to high-grade sheep. In the west, on the other hand, the long-established colonists occupied grazing less suited to Merinos than that in the east and possessed larger numbers of Cape sheep, a long-standing attachment to the breed, and a large market for slaughter stock in Cape Town and in the shipping that it serve. Many were naturally disinclined and many were unable to undertake the capital outlay entailed in replacing their stock with woolled sheep. Consequently, in the Karoo and in the arid section of the Atlantic slope, the Cape sheep long held its ground and, when it finally yielded, it was replaced not by a woolled sheep but by a new mutton breed evolved from a few fortuitous immigrants from the Middle East (Fig. 3 and 4).

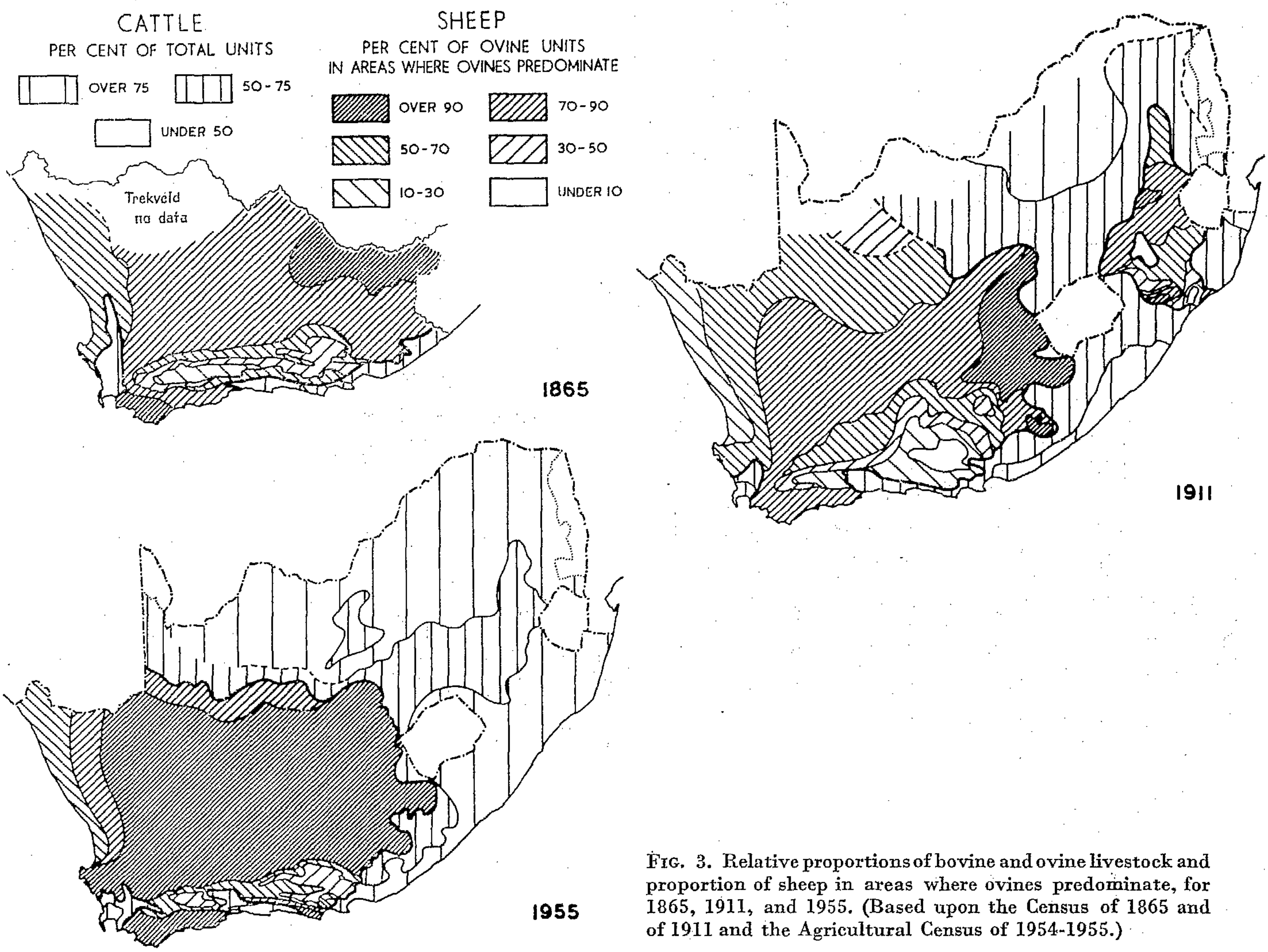


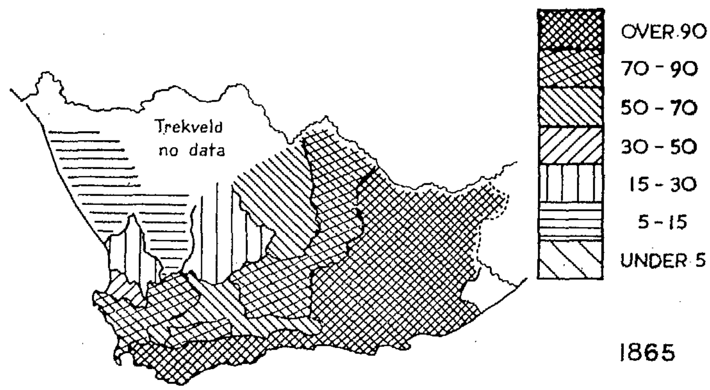

FIG. 3. Relative proportions of bovine and ovine livestock and proportion of sheep in areas where ovines predominate, for 1865, 1911, and 1955. (Based upon the Census of 1865 and of 1911 and the Agricultural Census of 1954-1955.)

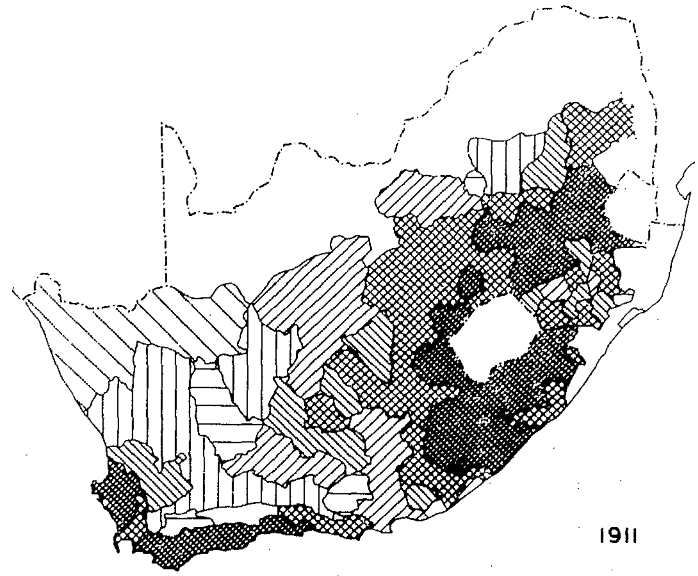
## SPREAD OF THE BLACKHEAD PERSIAN AND THE KARAKUL

The progenitors of the so-called Blackhead Persian were very nearly castaways on the rugged southern coast of Africa, but once safely ashore they prospered and, in the course of a few decades, their breed came to play a leading role in the economy of the Karoo. In 1868 a disabled ship entered Port Beaufort. On board were a few survivors of some fat-rumped Hedjaz sheep bought as provisions in the Persian Gulf. Three of the ewes and a ram were acquired by an enterprising farmer and taken to the Hex River Valley, the south-western gateway to the Great Karoo. They were superior to Cape sheep as a mutton breed and their progeny proved inherently good foragers equally suited to arid conditions. With their clean configuration and smooth hair they proved far less susceptible than Merinos to blowflies and *keds* and, unlike woolled sheep, could graze veld infested with *steekgras* (*Aristida* spp), *driedoring* (*Rhigozum trichotomum*), and similar awned grasses and thorny plants. Moreover they were relatively prolific and exceptionally hardy; they were not very susceptible to blue tongue and tolerated heartwater as merely a mild temporary indisposition.[1]

By the end of the century selective breeding had developed the Blackhead Persian as a distinctive South African breed, superior to any of its ancestral stock. It had become widely distributed in the arid regions and was in the process of replacing the Cape sheep in the west and the north-west and the Merino

1. Blue-tongue: a midge-borne virus infection similar to if not identical with horse-sickness in equines, frequently caused severe losses among sheep during warm wet weather. Heartwater (rickettsiosis), a tick-borne disease of bovines and ovines, was a veritable scourge of small stock, particularly in the south-eastern part of the Colony. There, for instance, in 1863-1864 an usually severe outbreak left few survivors of the formerly thriving Merino flocks along the valley of the Great Fish River [81, p. 325; 90, vol. 3, p. 430].



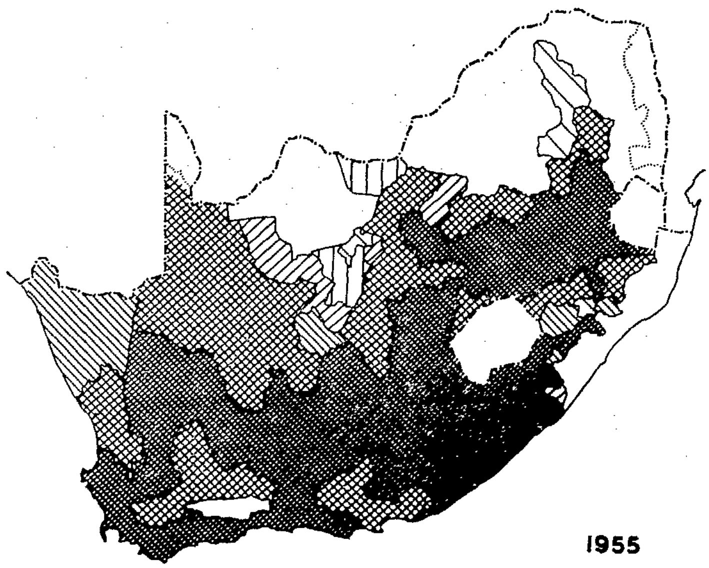




FIG. 4. Relative importance of woolled sheep, for 1865, 1911 and 1955. On the 1911 and 1955 maps unshaded areas represent districts where the number of sheep per square mile was less than that in Namaqualand, 15 and 24 respectively on 7 May 1911 and 31 August 1955. (Based upon the Census of 1865 and of 1911 and the Agricultural Census of 1954-1955.)

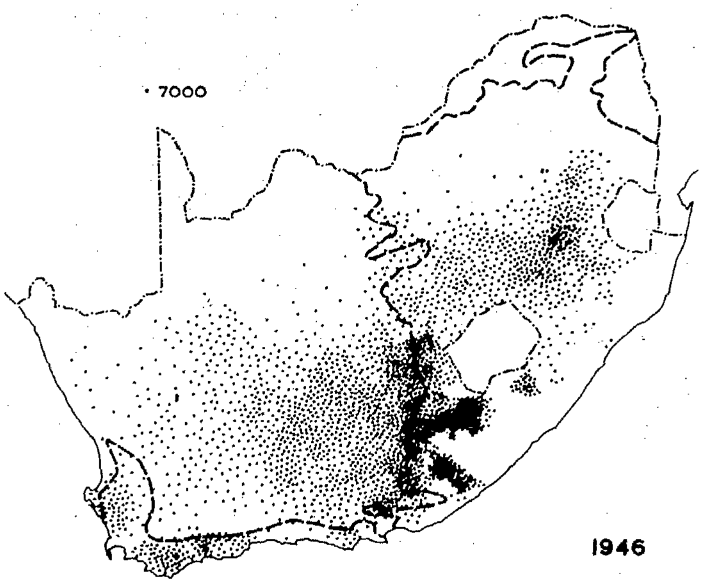



FIG. 5. Distribution of Merino sheep owned by Whites, 1946. (Based upon the Agricultural Census of 31 August 1946, in which Native-owned sheep are not differentiated according to breeds.)

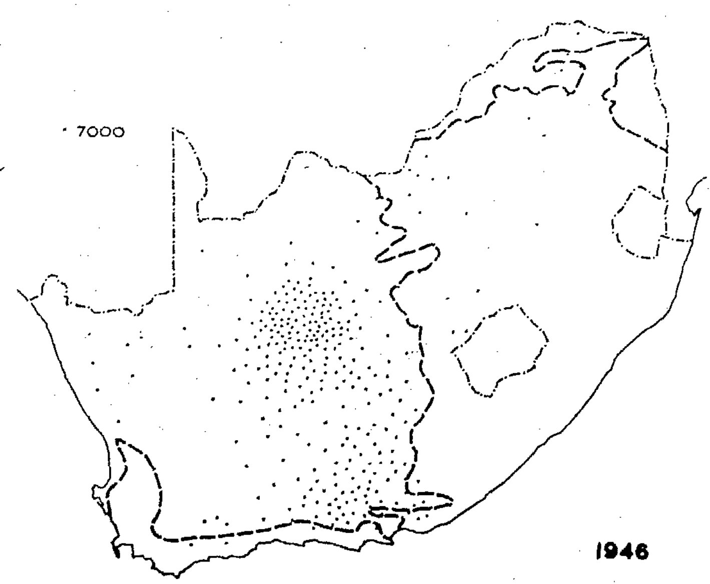



FIG. 6. Distribution of Blackhead Persian sheep owned by Whites, 1946. (Based upon the Agricultural Census of 31 August 1946.)

toward the east. In later years its resistance to heartwater and non-susceptibility to injury from steekgras were to carry it northward into the arid regions of the Transvaal but, unlike the Merino, it failed through susceptibility to cold and to internal parasites to spread eastwards into the more humid grasslands of the High Veld (Figs. 5 and 6). After 1930 the breed assumed a new role in the Karoo as the preferred basis for crossing with English rams to produce early-maturing fat lambs, e.g., the Dorper (Dorset Horn x Persian) [54], and after 1940 it became, in the absence of sufficient purebred stock, the basis on which many farmers in the north-western Karoo built up valuable flocks of grade Karakuls.

Karakuls are raised primarily for the pelts of the unborn and newly born lambs, the so-called 'Persian lamb' of the fur trade. As a mutton breed it is inferior in conformation to the Merino and the Blackhead Persian and its fleece is a mixture of coarse wool and hair that, until very recently, experienced little demand. But the high prices commanded by good quality pelts and the ability of the animals to thrive where Merinos would starve provide ample compensation. The breed was first introduced into southern Africa in 1909 when the German administration in South West Africa imported a small flock from Bokhara; other shipments followed, mainly in 1913 and 1914, and by 1915 the government flock comprised 80 rams and 360 ewes. Of these, 3 rams and 84 ewes were transferred in 1916 to the Grootfontein Agricultural School at Middelburg, Cape Province. In the Union, farmers showed little interest in the breed until after the drought of 1933-1935 and no rapid increase in its popularity took place until a decade later, after the end of World War II. Thereafter grade Karakuls, bred up by Karakul rams from Blackhead Persian and Africander ewes, rapidly assumed a leading role both in the more arid section of the Karoo and in the adjoining southern fringe of the Kalahari thorn-veld that is currently (under the impact of grazing) being invaded by Karoo species (Figs. 1 and 7).

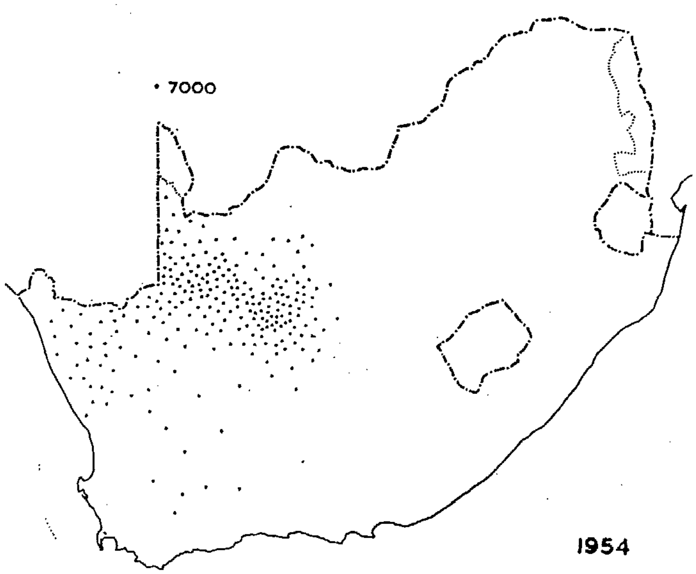


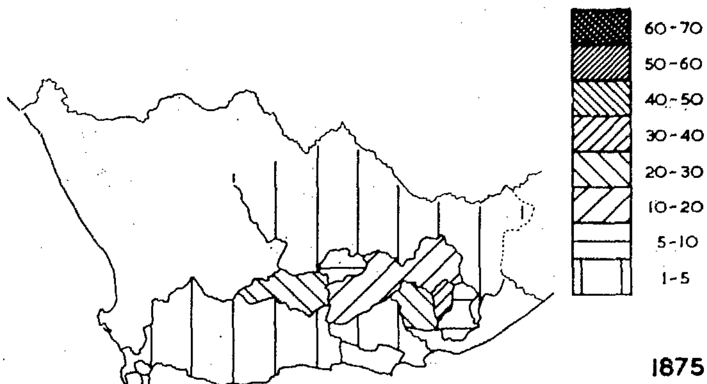

FIG. 7. Distribution of Karakul sheep owned by Whites in the peak year, 1954. (Based upon the Agricultural Census of 31 August 1954, in which Native-owned sheep are not differentiated according to breeds.)

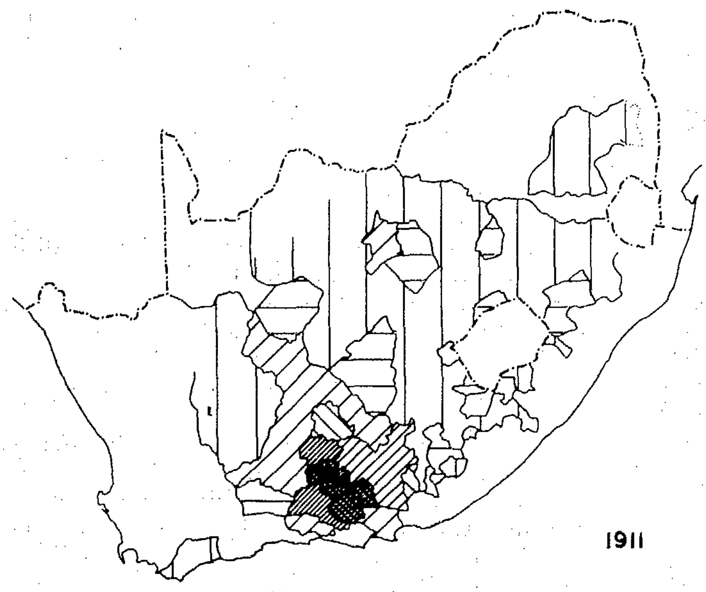
THE ROLE OF THE GOAT AND THE RISE AND DECLINE OF THE ANGORA

Goats were never important in the husbandry of the Hottentots but became almost ubiquitous in the Karoo in the colonial era. Their greater agility enabled them to thrive better than sheep on rugged terrain and to browse on small trees and bushes. Therefore, in the succulent bush of the Atlantic slope in the west and between the Cape Ranges in the south, goats, able to feed on much of the vegetation ignored by sheep or inaccessible to them, played a complementary role to sheep and, locally, displaced them altogether. Their sagacity also made goats indispensable in herding and moving sheep; in a land where sheep dogs were unknown, goats to lead the flocks were well-nigh indispensable, especially where regular seasonal migrations and nightly kraaling of sheep were general [58, p. 291]. Finally, being prolific and hardy (except in areas of the heartwater disease), goats became increasingly important as slaughter animals as the wild game diminished in numbers and the population increased, while their skins, the raw material for Cape kid, became an increasingly valuable export item.

A pair of Angora goats introduced in 1838, three years after the beginning of the mohair spinning industry in England [27], made possible the gradual development of some flocks of grade Angoras on a foundation of selected Cape goats [58, p. 293]. The first recorded export of mohair—870 pounds valued at £10—followed in 1857 [37, p. 415]. Thereafter, breeding stock were imported by various commercial firms,[1] eager to build up the limited trade potential of their hinterland, and by leading farmers. Less than 100, all from the Angora district, were brought in between 1856 and 1868 but thereafter about 2,700 from various parts of Asia Minor were imported before the Turkish Government in 1880 prohibited further exports. Adequate numbers had by then reached South Africa and the foundation of an Angora Breeders' Association in 1881, in response to the Turkish embargo, ensured the maintenance and improvement of the breeding stock [44].

1. For example, Messrs Mosenthal Bros. of Port Elizabeth who imported 30 rams and ewes in 1856.



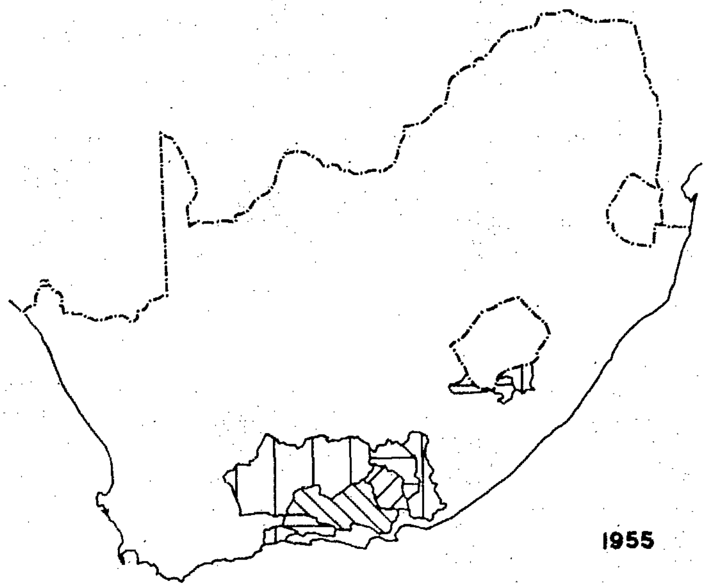




FIG. 8. Angora goats as a percentage of all bovines and ovines, expressed in terms of large-stock units, for 1875, 1911, and 1955. (Based upon the Census of 1875 and of 1911 and the Agricultural Census of 1954-1955.)

Most of the animals imported were acquired by farmers in the succulent scrub and neighbouring areas in the hinterland of Algoa Bay (Fig. 8). Much of this is rugged country where the animals were soon thriving on succulent browse such as *spekboom* (*Portulacaria afra*) and *bergpruim* (*Pappea capensis*)—slow-growing species that are unfortunately easily destroyed by heavy stocking [37, p. 418]. In their new habitat shearing proved necessary twice a year, in spring and autumn, instead of annually in spring as in Turkey. Consequently winter cold tended to limit their distribution, owing to the susceptibility of the delicate animals to chills after the autumn shearing. Nevertheless, in the more favoured areas the pure-bred Angora multiplied and, as mohair prices from 1880 onwards until World War I ranged consistently above those of Merino wool, in adjacent areas flocks of grade Angoras (with a greater degree of hardiness inherited from selected Cape goats) grew in numbers until in the peak year, 1912, there were more than four million reputed Angoras in the country (Fig. 8). Thereafter, under the impact of droughts, tariff barriers, increased competition, and a deteriorating market for mohair the numbers declined again and by 1950 had fallen to about 560,000.[1] The droughts of 1915-1916 and 1918-1919 were particularly severe in the chief Angora-raising districts; not only the flocks but the veld suffered grievously. After 1920, when the Union Government at the behest of the Angora breeders themselves removed the ban on the export of stud rams, Angora raising on the Edwards Plateau began its spectacular expansion. Aided by a tariff of 31 cents per pound of clean scoured hair imposed by the United States in 1922, Texas by 1926 had surpassed South Africa as the world's leading producer of mohair [28]. During the succeeding depression the Angora declined further in importance and even in the succulent scrub, which may be regarded as its stronghold, farmers have brought in Merinos in increasing numbers (see Figs. 5 and 8).

1. By 1955, in response to improved prices for mohair, numbers had increased to nearly 690,000.

### DOMESTICATION OF THE OSTRICH: AN IMPETUS TO IRRIGATION

To the familiar long-domesticated farm animals the arid regions of South Africa added a new one of their own—the ostrich. It had long been hunted for its plumes in all parts of the African steppes and savannas but about 1857 a few farmers in different parts of the Cape Colony began to capture and to tame wild ostrich chicks. In 1865 80 ostriches were enumerated in the census of farm stock and in 1869 the development of a satisfactory incubator placed ostrich rearing on a firm foundation [58, p. 298]. By 1875 there were nearly 22,000 domesticated ostriches and the number increased yearly until in 1913, the peak year, there were more than 750,000 (Fig. 9). After 1890 increasing attention was devoted to selective breeding in order to improve the quality of the feathers. In 1876 4 ostriches had been introduced from Tripoli and in 1912 132 specimens of the Sudanese ostrich were imported from Northern Nigeria to impart to the South African feathers some of the density and strength for which the North African plumes were noted [6]. Unfortunately, fashions changed soon after, a world war intervened, and the prime feather market vanished. By 1930 the number of birds had fallen to less than 33,000. Since then there has been a slow increase again to nearly 60,000 in 1955, but ostrich farming is now based more upon a market for feather dusters, ostrich-skin leather, and ostrich *biltong* than upon an eager demand for prime feathers (Fig. 9).

Climatic and grazing conditions concentrated most of the ostrich rearing in the Karoo. A relatively dry climate is reputedly essential for the production of quality feathers [31]. However, quality is also dependent upon an adequate protein-intake throughout the year—a condition more easily fulfilled on Karoo bush than on grassveld, but best fulfilled where the natural pastures can be supplemented or replaced by lucerne (alfalfa). Lucerne, moreover, was early recognized as excellent feed for the relatively delicate young birds [57, p. 65]. Consequently the Karoo and particularly the Little Karoo—which could most readily provide adequate water and extensive areas of irrigable land for lucerne—were the areas that benefited most from a form of land use that, in its heyday, was incredibly remunerative.

In its wake ostrich farming has left not only the ornate 'ostrich mansions', distinctive features of the Little Karoo, but also numerous small-scale irrigation works, many dependent upon the flood-waters of erratic rivers, that serve in the aggregate several thousand acres of lucerne. In the Little Karoo much of the lucerne is now grazed by Friesland cattle, the basis of a local cheese industry. Large quantities of lucerne hay are produced for sale off the farms and the dry climate and deep loamy pedocals favour the production of lucerne seed. As bees are essential for pollination, nearly one-fifth of the South African output of honey follows as a by-product. In the Great Karoo and elsewhere, lucerne lands established originally for ostriches have added to the stock-carrying capacity of farms and provide stacks of fodder and patches of green grazing that are invaluable reserves against drought.

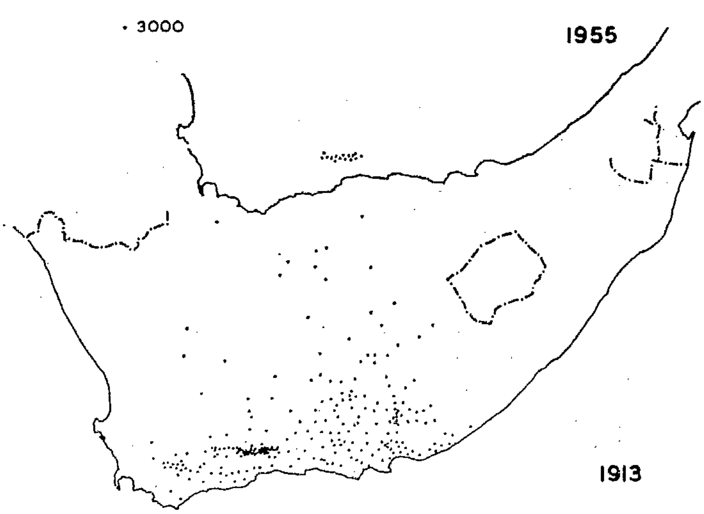



FIG. 9. Distribution of ostriches in 1913 and 1955. (Based upon figures in the *Official Year Book of the Union of South Africa*, no. 2, 1918, and the Agricultural Census of 31 August 1955.)

## THE THORNVELD AND BUSHVELD BEYOND THE ORANGE AND THE VAAL (THE EUROPEAN INTRUSION, 1860-)

The arid regions to the north of the Orange River, already set apart botanically as distinct from the Karoo, also stand apart historically and economically: they were colonized much later and under different economic circumstances and with a bias towards cattle raising rather than sheep farming (see Fig. 3). The thornveld and bushveld of the north, farther from the first-settled corner of the Colony, naturally did not become known to the colonists until the occupation of the Karoo was already well advanced. When the Kalahari thornveld, the nearest of the northern arid regions, eventually became known it appeared ill-suited to sheep. Therefore it attracted no seasonal graziers such as had already begun in 1820 to cross the river regularly into the more humid grassland farther east—but was left to the half-caste Griquas, to the Natives, and to the wild game until the days of the diamond diggers [104, p. 125]. The more distant bushveld in its turn positively repelled settlement: chronic strife among the Natives and endemic diseases made it unhealthy for man or beast, sheep or cattle. Until the discovery of the Lydenburg goldfields it, too, was left a wilderness.

The Kalahari thornveld extends over two contrasting types of terrain: sandveld and hardeveld. The country west of the Langebergen and Koranabergen and north of a line 10-50 miles north of the Orange River is mantled by aeolian sand several hundred feet in thickness (Fig. 1). Over great distances it is completely devoid of surface water although summer thunderstorms bring sufficient rain to support a good growth of grass, herbs and trees that formerly provided grazing and browsing for 'prodigious herds of . . . antelopes' and other game [49, p. 47]. East of the Langebergen the sand-cover becomes discontinuous and ends at the western edge of the *'Ngaap*, or Kaap Plateau. Towards the east the rainfall is a little less scanty and the hardeveld or hard-rock country, being lithologically more varied, is better endowed with surface waters, including a number of large springs that issue from the dolomite.

The sandveld in the mid-nineteenth century was occupied by a sparse population of semi-nomadic Bushmen and Bakalahari, the former entirely and the latter (the most primitive of the Bechuana) mainly dependent upon hunting and gathering. Its eastern and north-eastern fringe and the adjacent hardeveld were inhabited by various Bechuana tribes (refugees from the more militant Matabele) who supplemented the livelihood derived from their cattle, sheep, and goats by cultivating patches of sorghums, millets, and maize and by hunting and gathering. To the south-east and to the south, along the Orange River the hardeveld was occupied by the Koranas, a Hottentot group, and the Griquas, a people of mixed Khoisan and White ancestry. Both groups were immigrants displaced by the Whites from south of the Orange River. Like the Bechuana, they supplemented their pastoralism by hunting and, to a limited extent, by cultivation. Most of the Bechuana were settled in villages (some of considerable size) located where water was permanently available, as at the springs that issue from the dolomite at Kuruman. After 1801, under missionary influence, most of the Griquas and many of the Koranas had also settled either at springs, as at Klaarwater (Griquatown) and Danielskuil, or at places such as Rietfontein near the edge of an inlier in the Kalahari sands where the water table is exceptionally near the surface.

## TRADERS AND HUNTERS

In contrast to the regions south of the Orange River, the thornveld to the north did not initially attract White graziers; there the forerunners of White occupance were the missionaries, the traders, and the hunters. The concentrations of population centred on the springs and wells presented such excellent business prospects as to induce more than one of the itinerant traders (who had long been the most active element in the commerce of the interior) to take root [106, p. 99]. The teeming game presented a unique opportunity for other adventurers in the early 1870s to profit by the sale of venison and *biltong* to the tens of thousands encamped on the Vaal River and Kimberley diggings. Few of these hunters may have become settlers but, by exterminating most of the antelope—and thereby the lion and other carnivora that preyed upon them—the hunters prepared a way for the graziers who were to follow.

In such country it was a natural step for a settled trader to add cattle raising to his cattle-dealing ventures. Before 1880 one trader-cum-rancher was already regularly driving cattle in winter across the sandveld from Rietfontein to sell them at Vryburg, 300 miles away. Other settlers soon began to intrude into the eastern and south-eastern sectors of the hardeveld. The discovery of the diamond fields was followed in 1871 by the British annexation of Griqualand West and the partition of their former communal lands among the Griquas under individual freehold titles—titles which by fair means and foul passed rapidly into the hands of the colonists and newcomers who, bringing in increasing numbers of sheep and goats, probably initiated the deterioration of the thornveld[1] (see Fig. 1). Farther north, strife between Bechuanas and Koranas after 1880 gave others—farmers from the Transvaal and adventurers from the diamond fields—opportunities to filibuster and to acquire land grants and livestock from Native chiefs in return for their services.

## IMPACT OF DIAMOND MINING ON A PASTORAL FRONTIER

The diamond discoveries influenced, indirectly, the course of land utilization in South Africa in many ways. They brought in a tide of new immigrants of varied origins, aptitudes, and experiences, many of whom found employment in fields other than mining. They brought into being—in the mining camps—the first large consuming centres in the interior that created an unprecedented demand for transportation services for foodstuffs and equipment. This in turn created at first a great demand for draught oxen and an expanded field of employment in 'transport riding' that attracted many of the poorer farmers. But thousands of ox-wagons on the

1. *Vermeerbos* (*Geigeria passerinoides*), a common cause of plant poisoning among livestock in Griqualand West and one of a number of invading species characteristic of over-grazed and mismanaged veld, was present but relatively rare in 1880 [55, p. 491].

50-60-day trek from the coast could serve only as a temporary expedient, pending the construction of a railway. Soon one railway, multiplied by geographical and political circumstances, became three. In 1870, 500 miles of sparsely populated country extended between the existing railhead at Wellington and the Kimberley diggings. There was no free capital in the nearly bankrupt Colony and no overseas investors were eager to participate in a venture as doubtful as railway construction under such circumstances. Therefore the Colonial Government, with prospects of adequate revenue from the diamond mines, decided to exercise its option to take over the Cape Town-Wellington line and to embark on its extension to Kimberley. Thereupon, in the political arena, pressure groups were able to demand that Colonial funds should not be expended for the benefit of Cape Town alone but that railways should be constructed also from Algoa Bay and East London. In 1884, the year the railhead reached Kimberley, the discovery of gold on the Witwatersrand (proclaimed a public digging in 1886) created a new goal for railway extension, and subsequently a new source of capital for investment in agriculture as well as other fields [76, sections 1 and 6].

The railway net-work, facilitating access to inland markets and coastal ports, made possible more intensive and varied land use, and further stimulated the influx of new settlers and new ideas into a rural population that was intellectually in no way comparable with contemporary American and Australian farmers and which, after two centuries of social isolation, of intermarriage within very limited circles, and with neither formal education nor educated neighbours, could scarcely have been otherwise [52].

After an interlude, 1896-1902, during which rinderpest and a protracted guerilla war caused heavy losses of game and of livestock throughout most of the thornveld and the neighbouring humid regions, the influx of colonists and *uitlanders* (overseas immigrants) was resumed. While devotees of the Africander cattle began the task of breeding up their depleted herds [13, p. 103], large numbers of livestock, including grade Herefords and Shorthorns from Argentina, Queensland, and Texas and pedigree stock from Britain and Holland were imported into South Africa [85, p. 20].

In the thinly settled hardeveld traversed by the Kimberley-Mafeking railway, extensive areas of unalienated land were still available. Where blessed with water, these were taken up mainly for cattle ranching. There were a few tentative trials with other stock also (e.g., Angora goats, Merino sheep, and ostriches) and, where irrigation was possible, a few small patches of lucerne and deciduous fruit orchards were established. Farther west the sections of the sandveld not already pre-empted as Native Reserves, remote and lacking surface water, attracted few settlers, and—like Bushmanland—no *uitlanders* and practically no capital.

## FRONTIERS OF SETTLEMENT IN THE TWENTIETH CENTURY

The spread of settlement into the waterless areas of Bushmanland and into the Kalahari sandveld awaited the well-drill that made possible the tapping of deep-seated groundwater and the windmill pump that brought it so effortlessly to the surface. Scarcely known in South Africa in 1890, the windmill pump spread rapidly after the drought of 1903 and is now as characteristic and essential a cultural feature of the Karoo as it became of the Prairies and the Great Plains of North America.

### BUSHMANLAND: THE WELL-DRILLER OPENS THE VRYBULT

In Bushmanland, the central section of the Bult, the so-called 'Vrybult'—where, if groundwater is found it is rarely less than 100 feet and usually more than 200 feet below the surface—remained common trekveld as late as 1908. There, until the area had been surveyed and subdivided into farms, the land could be used only under annual grazing licences or through the purchase at public auction of leaseholds to specific areas for periods of from 1 to 21 years. Alienation awaited the government land surveyor and permanent settlement thereafter awaited the success of the well-driller whose operations in areas so devoid of local fuel and water and so far from a railway were gravely handicapped until the motor-driven replaced the steam-driven boring machine [95, p. 71]. The last farm on the Vrybult was allotted in 1938 but the well-driller still has far to go in his uncertain quest for water deep in the Dwyka tillite and hard Archaean granite [107, p. 210]. There are still farms of 70-100 square miles without water and those that have one permanent watering place in 30 square miles are fortunate indeed [106, p. 46].

### THE KALAHARI AND ITS BORDERLANDS: BEEF AND DAIRY RANCHES

In the Kalahari sandveld a few White settlers began to infiltrate among the Griquas south of Rietfontein in the 1890s. The Kalahari police established a camel-breeding station at Witdraai[1] and, after 1906, a few poor Whites with small flocks of Cape sheep

1. Camels were introduced in 1897 for research directed towards the prevention and cure of rinderpest, a disease to which they are immune. They were first used by police patrols from Vryburg in 1898 [4] and from Upington in 1903 [5].

and goats settled north-west of Kuruman beside wells that they dug in the dry bed of the Kuruman River.[1] They received few new neighbours or even visitors until 1915 brought troops and army lorries, raising the dust from the smooth dry bed of the Kuruman on their way to South West Africa. The first convoys were soon followed by well-drilling crews who established 10 boreholes at intervals from Boesmansputs to Witdraai. A settler was installed at each to prevent Bushmen interfering with the water supplies but, with the end of the South West African campaign, they and the Kuruman 'road' were soon forgotten. Farther north, toward the Molopo River, the State in 1911 began water-boring operations about 60 miles west of Vryburg. Their success greatly enhanced land values and the few neighbouring landowners were encouraged to follow suit [95, p. 70]. Thereafter it became the policy of the Department of Lands to establish boreholes before allocating any of the large area of Crown land remaining or re-allocating any farms that had reverted to the State because of lack of water [99, p. 9].

In the post-war years, renewed attention was given by the Union Government to land settlement in the Kalahari, particularly along the dry courses of the Molopo and Kuruman Rivers, and in the Bushveld of the northern and eastern Transvaal. But it was mainly the poor and land-hungry—who saw in the cheap land on the Union's last frontiers of settlement their own last opportunity of becoming landowners—who were attracted as settlers to the immense and remote Kalahari or to the arid sections of the bushveld, notorious for malaria in summer and for bilharzia at all seasons. Farms, such as the holdings of 35-45 square miles along the Kuruman, that were offered to settlers between 1929 and 1933 at prices of the order of £1,200 payable with one per cent per annum interest over 65 years, were taken up eagerly. Most of the settlers were small-stock farmers, many from Griqualand West, who recognized the grazing as better suited to cattle. Although the jackals, diseases, and intestinal parasites soon taught them that the Kalahari is no paradise for sheep, most of them could not at first afford to buy cattle in place of their suffering flocks. Furthermore, being typically 7-10 days' journey by donkey wagon from the nearest town, they could make only minimum profits from the sale of their produce (mainly low-grade wool, slaughter wethers, and soap made from butter which, especially in summer, could not have been brought so far to market before spoiling) [101, p. 7]. Many lacked the modest capital to install a windmill pump on the borehole that the government had sunk before allotting each farm. For years they baled water from depths of 200 feet or more with an 8- or 10-gallon 'byler' hoisted by a pair of donkeys or, with three or four men on a long-handled pump, raised water by man-power. On a hot summer day 2,000 sheep and 180 cattle needed as much water as four men, pumping continuously from before dawn to long after dusk, could raise. Where labour is as scarce as in the Kalahari, the whole family frequently had to abandon all other chores to sweat together at the pump. And the installation of a windmill pump alone did not ensure unfailing water for, apart from breakdowns, it might stand idle for lack of wind, especially during the hot dry days from October to January when long spells of windless weather are typical. A supplementary animal-powered pump, a 'horse-gear', was also needed and, in later years, the small diesel-operated pump was a welcome innovation. Other problems sprang from the gradual diminution in the flow of water (necessitating either the deepening of existing boreholes or the sinking of new ones) and from the characteristic location of boreholes near one extremity of the farm. This is strikingly demonstrated along the Kuruman. Everywhere in the Kalahari the depth, mineral-content, and potability (even for stock) of the groundwater away from the river courses are uncertain. Therefore each farm along the Kuruman was given a 'river frontage', about 3 miles, from which it extends back 12-15 miles. As the first boreholes were sunk near the river course and few successful ones have been sunk elsewhere, overgrazing at the 'water end' of each farm has followed almost inevitably while the 'dry end' remains little used [106, p. 129].

Though Nature was so parsimonious with water, the vegetation in its original state provided surprisingly good grazing. The grasses, mainly species of Eragrostis, Aristida, and Digitaria,[2] provide not only excellent grazing during the summer but mature into 'a palatable veld hay which retains a fairly high digestibility and nutritive value' (in contrast with the grasses of the humid High Veld, most of which deteriorate rapidly with maturity into 'hard fibrous stalks and leaves of poor digestibility and feeding value') [9, p. 33]. In good seasons a lush growth of succulent herbs enabled the animals to go for days without drinking—making possible at such times the grazing of areas several miles from the nearest drinking point—while plants like the *tsama* melons (*Citrullus vulgaris* var.) and the *gemsbokkomkommer* (*C. naudinianus*), that store quantities of water, carry over valuable reserves to the ensuing winter [106, p. 124]. Furthermore, the leaves and pods of many of the trees and shrubs, particularly the pods of the *haakdoring* or umbrella thorn (*Acacia heteracantha*) and the *kameeldoring* (*A. giraffae*) and the leaves of these trees and of

1. The daily flow of the spring at Kuruman, about 20 acre-feet, is all used for domestic purposes and irrigation within a few miles. Farther downstream the river carries water only after such exceptionally heavy rains as have occurred only twice within living memory, in 1894 and 1918 [111, vol. 1, p. 57].
2. *Eragrostis lehmanniana, E. atherstonei, Aristida uniplumis, A. barbicollis, A. diffusa, A. namaquensis, Digitaria eriantha*, and *D. smutsii*.

others such as the *witgat* (*Boscia albitrunca*), *rosyntjiebos* (*Grewia flava*), and *rooibos* (*Combretum apiculatum*) provide nutritious browse with a protein content that makes it an excellent supplement to the winter grazing as well as a valuable fodder reserve in times of drought [11, p. 238].

Nevertheless, cattle failed to thrive and *lamsiekte*, a fatal form of paralysis associated with pica became so prevalent in both hardeveld and sandveld areas as to leave many with no alternative to farming sheep (which are not subject to this sickness). In climatically marginal districts such as Bloemhof, Christiana, Schweizer-Reneke, and the eastern parts of Mafeking and Vryburg, wherever the uncertainty of the rainfall and the distance from the railway were not prohibitive, others turned from stock raising to grain farming, to maize and kaffir corn. Of the two crops maize was consistently preferred because kaffir corn, although more tolerant of drought, is subject to sporadic attacks of aphides, often experiences a poorer market, and is very vulnerable to birds, particularly the red-billed quelea (*Quelea quelea lathamii*) that is so widely distributed over the African savannas and is found in 'flocks of . . . hundreds of thousands and even millions—truly comparable with locusts, which they have replaced as the main plague of seed-growing farmers throughout Africa' [63, p. 434]. But, although cropping is more attractive as a short-term enterprise during periods of low wool prices, cultivation of the light soils so vulnerable to wind erosion has left a heritage of impoverished farms (many divided into sub-economic holdings), sand drifts, and eroded fields [22].

In 1919 the recognition of *lamsiekte* as an infection resulting from the ingestion of putrid matter by animals suffering from pica, particularly osteophagia, led to a rapid solution of the problem. The pica proved to be a symptom of inadequate phosphate in the animals' diet—traceable to the extremely low phosphate content of the soils [79]. Thereafter, regular doses of bonemeal (or, alternatively, phosphate licks) transformed the gaunt pica-crazed cattle into sleek healthy animals; continued research revealed *stywesiekte* (stiff-sickness), endemic in parts of Bechuanaland and the northern Transvaal, to be aphosphorosis —another manifestation of phosphate-deficiency — and demonstrated the importance of phosphorus as a crucial factor affecting the food consumption, growth, and milk-yield of cattle [80]. Therewith the name of the Vryburg *lamsiekte* research station, *Armoedsvlakte* (Poverty Plain), ceased to be so grimly appropriate; the way was opened for the advance of cattle ranching.

Its progress was naturally most rapid in the areas within 100 miles of the Kimberley-Mafeking railway. Cattle driven longer distances to railing points naturally suffered greater loss of condition (a problem which was aggravated as the spread of fencing restricted wayside grazing) but those from the sandveld suffered particularly because their hooves could not withstand a long trek over the hardeveld [17, p. 62]. Such obstacles to marketing cattle directed attention to alternatives that could be taken to town by donkey wagon, particularly to butter and to soap made from it. Therewith the 'half-dairy-half-beef system' that had already become popular near the railway began to spread westward. After the establishment in 1927 of road motor services radiating from Vryburg and Kuruman north westwards and westwards for distances of 150-200 miles, it spread so rapidly that by 1930 the South African Railways Road Motor Services were transporting annually nearly one million gallons of cream, most of it from this region [100, p. 85].

But the climate and the 'dairy ranching' system are not conducive to the production of high quality beef and dairy produce nor to good pasture management. The 'total digestible nutrients' per acre do not provide the level of nutrition essential for both early-maturing beef breeds and high-yielding milkers. Exotic breeds, whose hair covering, skin thickness, and general metabolism are ill-suited to high temperatures and bright sunshine, have little appetite for daytime grazing in summer, suffer more from thirst, and are adverse to foraging farther than they do in the cooler climate of Europe [12]. Therefore, being physiologically better suited to the climate and inherently good rustlers, the indigenous African stock —up-graded with superior bulls, predominantly

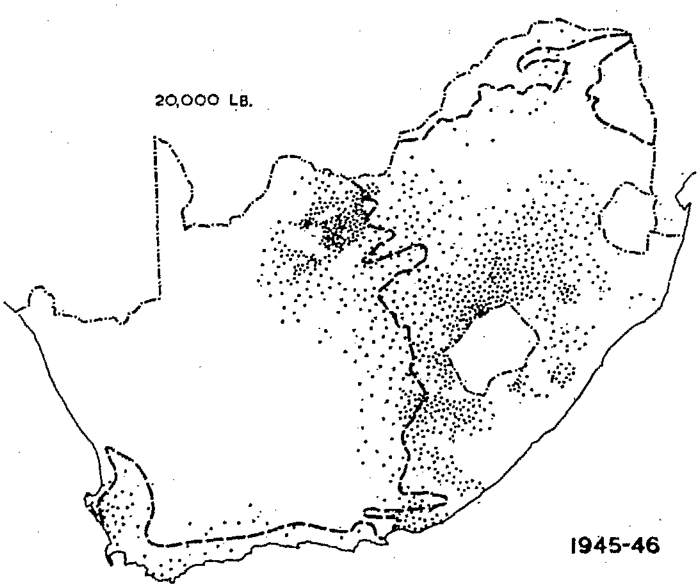



FIG. 10. Butterfat sold to creameries during the year ended 31 August 1946. *The heavy dashed line marks approximately the present limit of the arid regions.* (Based upon the Agricultural Census of 1945-1946.)

Africanders and, to a lesser extent, Shorthorns and Red Polls—have proved the most satisfactory foundation for the herds [59, p. 51]. However, up-grading under the most favourable circumstances is not possible beyond a certain level unless better breeding is accompanied by better feeding. But under the 'half-dairy-half-beef' system, calves, following Native custom, are usually kept kraaled during the day while the cows graze within a limited radius. Although 'few range cows on natural veld produce more milk than is required to raise their calves respectably' [65, p. 510], the calves here must share their limited birthright with the cream separator or the cheese factory—as generations have done since the 1920s (Fig. 10).

Consequently the undernourished survivors of paratyphoid and similar ailments (which are apt to be more prevalent among calves kept in kraals than among those allowed free range) mature slowly and at five years of age are typically 150-200 pounds lighter than those left with their dams until weaning [65, p. 510]. Nevertheless, the facility of dispatching cream and milk from the farm by public motor transport, the regular cheque from the creamery or cheese factory, and 'the idea . . . that the milk obtained is . . . something for nothing—a by-product' made dairy ranching the *métier* of many and left normal ranching with beef cattle to a minority of large operators. As long as the disposal of second-grade butter and cheese through controlled marketing channels presents no difficulty and 'the value of low grade beef in Johannesburg is . . . greater than anywhere else in the world',[1] dairy ranching would appear to be the most remunerative short-term use for much of the Kalahari thornveld. Its ultimate future, however, is threatened by overgrazing of the veld near the milking points and by the division of ranches into sub-economic units which engenders only further overstocking of veld that is frightfully susceptible to overgrazing, to bush encroachment, and to wind erosion [112].

The most assured long-term use, however, is that exemplified by the extensive 'beef ranches', units of upwards of 15 square miles. The steer is undeniably in closer harmony with the Kalahari than is the milch cow: its metabolism requires less water, its management less labour—both scarce commodities, less easily provided than the motor transport now available to move animals to market without loss of condition. The range of the beef animal is not restricted to the vicinity of the milking points, it can graze farther from water at all times, and, when *tsamas* and other succulent feed are abundant, it can go weeks without drinking. Consequently, the utilization of areas remote from water, the avoidance of permanent concentrations of stock in one locality, and better pasture management in general are possible on the beef ranch—and nowhere in the Union is the permanency of land use more dependent upon effective veld conservation.

### THE ARID BUSHVELD : GAME RESERVES AND TROPICAL CATTLE RANCHES

The arid sections of the bushveld include the plain of the Limpopo, mostly below, 3,000 feet, and the northern part of the Transvaal Low Veld, less than 2,000 feet above sea level, areas where, for at least half of the year, mean monthly maximum temperatures exceed 85° F. and mean monthly minima exceed 60° F. These and the adjoining regions have been sparsely occupied since 1500 and possibly longer by various Bantu groups who combined the cultivation of small plots of millets, sorghums, and vegetables with the herding of cattle, goats, and hairy sheep and the hunting of the ubiquitous and varied game. Endemic fevers, recurrent droughts and, particularly in the eighteenth and nineteenth centuries, anarchy ensured sparsity of population and feuds and wars fragmented and scattered the Native tribes. The first white visitors, 1836-1838 ,were not attracted to the Low Veld itself but were seeking a way to the sea. Their fate was not unusual : the Van Rensburg party was massacred on the Pafuri; the leader and most of the Trichardt party died of fever in Lourenço Marques.

A few intrepid Portuguese disregarded the malaria, blackwater fever, bilharzia, and other uncertainties of life in the Low Veld to profit at the expense of the nearextermination of the elephant but, until gold was discovered, 1868-1870, on the Olifants River and in the Murchison Range, few other white men came to share the wilderness. About the same time the progressive depletion of game on the High Veld began to impel Transvaal farmers farther afield for *biltong* and hides—into the bushveld where the great wealth and extraordinary variety of game could be exploited in winter with little risk from malaria. At the same time the quality of the grazing became better known. By 1880, cattle and sheep in increasing numbers were being moved regularly betweent he High Veld—where the 'sour veld' grazing in winter provides less than a maintenance ration of digestible nutrients,—and the 'mixed veld' and the 'sweet veld' of the lower country.

In the arid areas the veld was particularly 'sweet'. As in the Kalahari, Digitaria, Eragrostis, Panicum, and Aristida grasses[2] retain much of their nutritive value through the dry season and are supplemented by the leaves and pods of the *haakdoring* or *nsasane* (*Acacia heteracantha*), *witgat* (*Boscia albitrunca*), *rosyntjiebos* or *kruisbessie* (*Grewia flava*), *rooibos* (*Combretum apiculatum*) and of a large number of other trees and shrubs, such as the *mopani* (*Copai-*

1. Owing to the opportunity that has long existed for disposing of forequarters and other inferior cuts of low grade beef through contracts to the Witwatersrand gold mines (which maintain upwards of 300,000 Native miners on a high-protein diet) while distributing hindquarters and 'choice cuts' from the same carcases at considerably higher price levels through the retail trade ]14, p. 49].
2. Largely *Digitaria eriantha* var. *stolonifera*, *Eragrostis atherstonei*, *E. superba*, *E. denudata*, *Panicum maximum*, *P. coloratum*, *Aristida barbicollis*, and *A. uniplumis*.

*fera mopane*) and *knoppiesdoring* (*A. nigrescens*), that are unknown in the west.

The utilization of the Limpopo and Low Veld grazing was, however, restricted to areas that were not infested by tsetse flies (*Glossina morsitans* and *G. pallidipes*), vectors in the transmission of *nagana* or trypanosomiasis, a disease endemic among and tolerated without apparent harm by the indigenous game over wide areas of tropical Africa but usually fatal to exotic species of bovines, equines, and ovines. *Nagana* effectively limited both the range of the flocks and herds of the farmers and the range of the horses, ox wagons, and donkey wagons of the hunters; thereby it offered some asylum in the 'fly belt' to the game that suffered so heavily in the three decades of unrestricted slaughter that brought the nineteenth century to a close.

In this period much of the country was surveyed and subdivided into 8,000-acre farms that were allotted to Transvaal burghers. But, as the region was used mainly as a hunting ground by burghers who were free to hunt anywhere and had no desire whatever to settle in the fever belt, the land grants were of little practical value to them. 'Various Johannesburg land companies, hoping to discover a new field for mineral exploitation, were therefore able to acquire the farms at comparatively trifling cost.' [74, p. 185.] Though mineral wealth in most instances did not materialize, after 1902 some of the companies were able to draw considerable revenue from 'kaffir farming', i.e., the exaction of rent from Natives residing on their properties, and from the sale of farms in the land boom that followed the first world war.

The destruction of wild life was a matter of concern to President Kruger and the more enlightened of his colleagues as early as 1884 but sufficient support for its conservation was not forthcoming until the game had been critically reduced in numbers and some species had been exterminated. In 1898, after rinderpest had inflicted further grievous losses on most species other than the impala and when the buffalo and kudu in the Transvaal were on the verge of extinction [74, p. 64], a subhumid section of the Low Veld (between the Crocodile and Sabi Rivers) was at last proclaimed a game reserve—1,800 square miles under the nominal control of a sergeant of police stationed at Komatipoort [75, p. 10]. After the South African War the Sabi Game Reserve was extended into the arid country northwards to the Limpopo and, to deter poaching, was provided with a small staff of rangers, Bantu and White. Through the next twenty years its existence continued to be threatened by conflicting private interests and, in 1923, 2,500 square miles, including 'the best of the sable and roan antelope country, as well as that containing all the red, or Natal duiker, and nearly all of the mountain reedbuck' [75, p. 182] was de-proclaimed. In 1926, after a change of government, the remaining 8,000 square miles were finally proclaimed as the Kruger National Park (see fig. 1). Since then it has proved conspicuously successful, both as a game reserve and as a tourists' wonderland. The game have so increased as to necessitate, for certain species, a further control of numbers beyond that exercised by the lion and other carnivora. The increase indicates, indeed, that the most economic utilization of large areas of the African savannas might well be achieved through indigenous herbivores, so managed as to provide a regular meat supply on a sustained yield basis, rather than through such exotic animals as cattle, sheep, and goats that lack the inherent tolerance of and resistance to African pests and diseases. As a national park, within six hours' drive over excellent highways from Johannesburg and Pretoria, it provides thousands of holiday visitors and overseas tourists each year with a unique opportunity of seeing at close quarters a panorama of primeval Africa and much of the magnificent fauna that everywhere else on the continent, except in the few game reserves, is threatened with extinction within the next twenty years.

The remaining areas of the arid bushveld attracted few White settlers until after the first world war. Much of the land remained either in the hands of speculative companies or of the State, a few farms had been acquired as holiday or hunting resorts by non-residents, some relatively populous areas had been set aside as Native reserves, and the regular winter trekking of the High Veld stock into the Low Veld was declining. In the 1920s efforts were made to establish a number of large company-operated cattle ranches in the Limpopo region and farms were allotted to a number of ex-servicemen and other settlers who soon learned that new frontiers present new problems.

*Nagana* had not been a threat to farm animals since the tsetse fly had died out during the rinderpest epidemic at the end of the last century, but other problems remained. In areas where game were still numerous, wildebeest and zebra made the maintenance of fences impossible and, where water-holes were few and far between, aggravated the trampling of the veld around watering points. Furthermore, the game served as reservoirs of diseases and parasites, They carried foot-and-mouth disease, heartwater, horse-sickness, *snotsiekte*, and other endemic diseases to which they themselves were 'clinically' immune but which were a continual drain on the vitality and numbers of the stock with which they mingled [7] and, as the natural hosts of various kinds of ticks, their presence made it impossible to eradicate ticks by the regular dipping of the domestic stock alone. Stock dipping merely produced numbers of arsenic-contaminated ticks that poisoned the *renostervoëls* (oxpeckers) or tick-birds (*Buphaga erythrorhyncha* and *B. africana*) which Nature had provided for the control of these insects, and led to abnormally heavy tick-infestation of the game [74, p. 73]. When the indigenous herbivores were shot out as vermin or sold off as *biltong*, the lion and the leopard were left to go hungry or to prey on the farm stock. For their protection it became necessary to kraal all stock regularly at night, thereby promoting the spread of such diseases as ophthalmia, contagious abortion, and scours and leading inevitably to the overgrazing and trampling out of the veld around the kraals. Moreover, during the hotter months cattle have little appetite for daytime feeding but graze more freely at night, if at liberty. If kraaled overnight, the animals, released hungry in the morning, seemed to feed on anything, especially if it was wet with dew, and suffered correspondingly from eating poisonous plants they would normally avoid [65, p. 511].

Most of the large company operations and many of the individual settlers' ventures ended in bankruptcy. Few, if any, of the survivors achieved great prosperity and, as late as 1950-1951, an economic survey of 137 representative holdings in the Limpopo region revealed an average net farm income equivalent to only 5.2 per cent of the capital invested [29, p. 475]. Nevertheless, in 1946-1947 a Parliamentary Bill to set aside part of the region north of the Zoutpansberg as a national park, was strongly opposed by ranching and other private interests and, although passed in November 1947, it was repealed within two years.

Forty years of occupance in the older settled areas have partially tamed the wilderness, have removed or solved some of the problems that faced the pioneers, but have brought others in their train, notably the problem of bush encroachment. Formerly the game and Native stock used the sourveld in the first half of the growing period, when the grasses are palatable and nutritious, the mixed veld in the late summer, and the sweet veld in the dormant season only. This allowed each kind of veld sufficient rest to maintain it in full vigour despite the veld fires that swept the region almost every year. The depletion of the grass-cover resulting from year-round grazing on the same veld enabled bush seedlings to become established more easily and thereby initiated the progressive spread of bush at the expense of grass. Bushes gradually became more numerous, the supply of the nutritious pods that the cattle relished was thereby augmented, the number of seeds distributed with their manure was multiplied correspondingly, and, within a few years, bush encroachment was enormously accelerated. The weakened grasses could offer no effective competition even to germinating seedlings and, as the bushes grew, grass was shaded out by their crowns and crowded out by their roots until large areas that had been open plains in 1920 had become so densely bushed by 1940 as to be virtually useless [38]. Some such areas were abandoned; others, where the bush was less advanced, were reclaimed with difficulty and can be maintained only by regular manual and chemical counter-measures to control the bush [110].

The economic development of the region has been directed mainly toward the breeding and rearing of tropical beef cattle. Unlike the Kalahari it is ill-suited to the commercial production of industrial milk or butterfat because of the high environmental temperatures which are conducive to tropical undernourishment in the cattle, the generally lower carrying capacity of the grazing (in which trees and shrubs are more numerous), and the prevalence of heartwater (rickettsiosis), gallsickness (anaplasmosis), and redwater (babesiosis) which necessitate continuous control measures such as dipping and spraying (9, p. 80]. Although the nutritive value of the veld is highest in mid-summer, the growth of the animals is retarded until late summer or early autumn when temperatures subside to levels at which cattle can 'metabolize properly sufficient food for normal existence' [10, p. 378]. Exotic breeds, particularly, suffer tropical degeneration and impaired fertility and are very susceptible to the endemic diseases; the Red Poll appears more heat-tolerant than the others but also degenerates. The Africander and the cattle derived from stock brought in from tropical Africa by the southward migration of the Bantu in the pre-colonial era have proved the most suitable and the bulk of the herds are made up of such African stock up-graded by superior Africander bulls [59, p. 12].

Most of the farms have been subdivided, many to less than a quarter of their original size, and, in their efforts to extract a livelihood from holdings typically of less than 7 square miles, farmers have felt compelled to attempt to grow maize, kaffir corn, groundnuts, and others crops—utilizing 100 acres on an average farm—to supplement their income from cattle raising. But the rainfall is low and variable, the soils are predominantly light and very vulnerable to erosion, and any short-term profits that have been made in favourable seasons have been neutralized by financial losses in other seasons and soil losses in every year [29, p. 472].

## PERENNIAL IRRIGATION AND ITS NATURAL LIMITATIONS

Irrigation exerted only a very limited and localized influence on the development of the arid regions of the Union: its application was stringently curtailed by relief, by soil, and by climate. The larger rivers occupy relatively narrow valleys entrenched well below the surface of the plateaux they traverse. The gradients of the two longest, the Orange and the Vaal, are of the order of 3 feet per mile (in contrast with 5 inches per mile on the Nile below Wadi Halfa) and the little alluvial land in their valleys occurs typically in discontinuous 'shreds and patches'. Over nine-tenths of the country the mean annual precipitation is less than

30 inches and the evaporation from a free surface is between 50 and 110 inches [45, p. 32]. The average run-off has been estimated as approximately 6 per cent of the precipitation, a total of perhaps 30 million acre-feet—equivalent to about half of the discharge of the Tennessee River whose catchment area is less than one-tenth as large as the Union [93, p. 4]. Only part of this meagre and highly irregular run-off is carried by rivers that traverse or originate in the arid regions, and only part of their flow could ever be effectively utilized for irrigation. Sites physically suitable for diversion weirs and storage dams are few; even fewer are well located in relation to potentially irrigable land and adequate stream-flow. Groundwater resources are limited in volume and distribution. Between 20 and 30 per cent of the underground waters are too highly mineralized even for stock-watering purposes [72, p. 172] and in only a few localities is the groundwater of a quality suitable for irrigation and available in quantities sufficient to serve more than a few acres. Finally, soil erosion, resulting from ignorance, negligence and apathy in land use—especially during the last hundred years—has enormously increased the silt-content of many streams and accentuated the naturally highly irregular character of their discharge. Thereby the capacity of any storage dam established to impound their waters is steadily reduced while the need for such storage and flood control increases yearly. Such, in outline, are the physical conditions that underlie the history of irrigation in South Africa.

The earliest irrigation works were undertaken not in the arid regions but in the original settlement at Table Bay where water was diverted from the Vars Rivier to irrigate vegetable gardens established there by the Vereenigde Oost Indische Compagnie in 1652. In the arid regions, apart from the west where occasional winter rains made possible a modest though variable wheat harvest in favoured localities in most years, pioneer land use was purely pastoral. Irrigation does not appear to have been attempted until towards the end of the eighteenth century. The earliest record relates to 'at least one furrow leading out of the Hex River' about 1787 and others are reputed to have been led from the Sundays River to provide water for crops and domestic use at Graaff-Reinet about the same time [46, p. 3]. Elsewhere the Griquas and the missionaries seem to have been the pioneer irrigators : the Griquas on the Orange River before 1800 and later at Klaarwater (Griquatown), members of the Moravian Brethren at Genadendal on the Rivier Zonder End (in a marginal semi-arid area) in 1792 [46, p. 3], and members of the London Missionary Society among the Bechuana at Lattakoo (Maruping) on the Kuruman River about 1820 [68, p. xxv].

With closer settlement, crop production under irrigation from springs and streams gradually became more widespread. It is said to have been fairly general by about 1830 along the Olifants River in the Little Karoo and along some tributaries of the Great Fish River farther to the east [108, p. 21]. In the Upper Karoo and the Great Karoo the Colonial Government after 1864 embarked on the construction of a few water storage works, largely as poor relief measures : to provide, in their construction, work for unemployed Whites and, subsequently, opportunities for poor Whites[1] to settle and (it was hoped) to achieve economic independence as farmers raising crops under irrigation. The most notable of these was on the Sak River where in 1876 the village of Brandvlei was laid out and assigned rights to water. However, even as late as 1912, water never reached the village although in some years floodwaters impounded (in the manner of ancient Egypt) in basins or *zaaidamme* on the floodplain farther upstream made possible the cultivation of a few thousand acres of wheat [94, p. 13]—until the increasing alkali-content of the soil forced it out of cultivation. Greater success was achieved at Olivenhouts Drift (Upington) by the Griquas who, with few resources other than the inspiration of a Rhenish missionary, had constructed a canal, 6 feet wide and 14 miles long, and by 1885 were leading water from the Orange River to irrigate a considerable area of alluvial land along the north bank [53, p. 95].

The greatest development of irrigation in the nineteenth century, however, did not draw upon the waters of the largest perennial river, but took place farther south where the floodwaters of intermittent streams were distributed over alluvial fans and flats by innumerable small diversion works. With the rise of ostrich farming such schemes, each involving no great capital outlay by the riparian owners co-operating in its construction, spread a green rash of lucerne pastures over the Little Karoo and adjacent regions. Although these works made no provision for water storage, on the whole they proved satisfactory enough : lucerne, when well-established on the deep alluvial pedocals, could tolerate long intervals between waterings and the ostrich, whenever the lucerne paddocks needed resting, was content to return to its native veld. 'Provided one or two crops of lucerne were produced during the year, ostrich farmers were not seriously put out, and the flood irrigation system based upon the scanty and erratic flow of Karoo rivers satisfied the needs—more or less'. [96, p. 2.] Later, following the introduction of the well-boring machine and the windmill pump, it became possible to irrigate small areas of lucerne and to provide some supplementary fodder on many

1. Graziers impoverished by drought losses were among the 'foundation members' of the poor White class. Later, thousands who had found employment as 'transport riders' after the opening of the diamond mines and gold mines were also relegated to the same class when the railway replaced the ox-wagon as the medium of inland transport. Finally, the collapse of the ostrich-feather market brought other recruits who likewise were unaccustomed to diligent labour and possessed little knowledge of arable farming [34, p. 82].

far-scattered farms by tapping groundwater, such as that impounded behind the numerous dolerite dikes that transect the nearly horizontal sedimentary rocks of the Karoo. The purchase of well-boring machines by farmers was first subsidized by the Cape Government in 1896 [2, p. 366] and the spread of the windmill pump was undoubtedly hastened by the drought of 1903 [16].

Thus, until about 1913, most of the irrigation development was based on the ostrich feather industry but thereafter the collapse of the feather market, the drought of 1913-1915, and the first world war made it obvious to all that ostrich farming must give place to the production of staple agricultural products. For these, irregular flood irrigation would not suffice; 'a supply of water must be assured during the critical seasons of the year' and such a supply could be provided only 'by the conservation of water in large reservoirs' [96, p. 2].

This became the key-note of the irrigation policy in the postwar years. The era of flood irrigation had prepared the way by giving rise to a number of irrigation boards[1] and a generation of farmers experienced in co-operative irrigation. The legal experience of that era had also borne fruit in legislation (Act No. 8 of 1912) that for the first time made legal provision for the impounding and storage of floodwater and for the protection of water storage works, once established, against the interception or diversion of floodwaters that would normally be tributary to them and to which they had been granted exclusive or prescribed proportional rights [46, p. 71; 35, p. 36].

The provision of the large storage works needed to supply perennial water to former flood-irrigation schemes and to new irrigation areas elsewhere was, in the Union as in most other countries, not attractive to private investment but was regarded, at least by the farmers concerned, as the duty of the State. Therefore, in the parliamentary lobby, irrigation schemes became the fair game of pressure groups. The relief of unemployment, particularly among poor Whites in areas drought-stricken in the years 1929-1933, and other political considerations vied with—and in some instances outweighed—physical and economic conditions in determining policy and decisions that the Irrigation Department was required to implement [50, p. 12].

Most of the first reservoirs to be completed (1918-1925) were in former ostrich-farming and flood-irrigation areas: in the Little Karoo and on the Sundays and Great Fish Rivers. But these areas were not alone in their need of irrigation. Wherever a long dry season is normal and precipitation is uncertain, irrigation is a prerequisite for intensive agriculture. Consequently there was a demand for irrigation in the subhumid areas also—a demand that could be most easily met where the water-gaps cut through the Magaliesberg and the other cuestas of the Bankenveld by the headstreams of the Marico, Crocodile, and Olifants Rivers offered a series of excellent dam sites near the large urban centres of the southern Transvaal. There the Hartebeestpoort Dam (136,000 acre-feet) was completed in 1924 and other reservoirs followed in the years 1929-1943.[2] Farther to the east, where the mild frostless winters and hot summers of the Low Veld permit the production of out-of-season vegetables and subtropical fruit, the steep *kloofs* of the Drakensberg offer no comparable storage sites but the less variable flow of the headstreams of the Letaba and other rivers makes storage less necessary. There in the same two decades small diversion works and pumps were installed to irrigate several thousand acres, mainly near the railway.

Meanwhile, the dams[3] built in the basins of the Sundays and Great Fish Rivers suffered rapid silting. Their headstreams originate in the region where, during the preceding 80 years or less, the former continuous grass cover had been removed by grazing and replaced by invading Karoo bushes—leaving the deep loamy soils, particularly in the dales and valleys, exposed to catastrophic erosion and charging the run-off with a burden of silt that, within eleven years, reduced the aggregate capacity of the four new reservoirs (initially nearly 280,000 acre-feet) by more than 28 per cent and the capacity of that on the Tarka, the worst affected, by nearly 40 per cent [41]. The name of Vlekpoort, one of the worst eroded areas in its catchment-basin, became a byword for erosion-wrought devastation. Expropriation and the application of costly soil conservation measures by the State became imperative if any of the residual storage downstream was to be preserved. For such action, however, the State had no legal power. With the perpetual quitrent system of land tenure forced upon reluctant farmers in 1813, the State had signed away its original ownership of the land and, in subsequent legislation, had conveyed and confirmed it, for better or worse, into private hands, competent or incompetent, worthy or otherwise. Erosion and silting accordingly continued uncontrolled until the passage of the Forest and Veld Conservation Act (No. 13 of 1941) gave authority for State intervention. Meanwhile the height of the dam at Lake Arthur on the Tarka River was increased in 1939-1940 in an attempt to restore some of the lost capacity. Later, after soil conservation measures initiated by the State had reduced the silt content of the run-off, a new dam to provide another 62,000 acre-feet of storage capacity was built at Commando

1. In the Cape Colony these were constituted under Act No. 8 of 1877 which made provision for State loans to finance irrigation works [46, p. 35].
2. 1929, Olifantsnek, 13,000 acre-feet; 1933, Bospoort, 3,000; 1934, Rust der Winter, 23,000; 1935, Buffelspoort, 4,000, Klein Marico 4,000; 1938, Loskop, 167,000; 1943, Lindleyspoort, 10,000.
3. At Grass Ridge on the Great Fish River (originally 63,200 acre-feet), at Lake Arthur on the Tarka River (57,400 acre-feet), and at Lake Mentz and Van Rhynevelds Pass on the Sundays River (94,600 and 64,300 acre-feet respectively).

Drift, 25 miles farther upstream. Similarly, on the Sundays River it was necessary to increase the height of the dam at Lake Mentz, first in 1936 and again in later years. By 1951 this had been raised to 24 feet above the original crest-level. Nevertheless, the storage is still inadequate in drought years to safeguard the citrus groves that after the completion of Lake Mentz in 1923 had so rapidly displaced most of the lucerne in the lower valley—barely 50 miles from Port Elizabeth and the regular refrigerated shipping services that link it to European markets.

Along the Vaal and the Orange the development of important irrigation works was retarded by the physical character of the valleys themselves and by the vast extent of their drainage basins which made the preliminary reconnaissance surveys correspondingly protracted. The surveys unfortunately revealed no extensive stretches of level land suitable for irrigation along the Vaal and only narrow, discontinuous areas, many liable to submergence at high floods, along the Orange; there were only two extensive irrigable areas in tributary valleys that would not require preposterously long canals to water them by gravity from either of the main rivers. But both of these valleys—those of the Rhenoster and the Harts—are in the basin of the Vaal which, if it is to serve also the rapidly increasing needs of the urban centres, industries, and mines of the southern Transvaal and of the Orange Free State goldfields, can provide sufficient irrigation water for only one. Furthermore, although the Vaal and the Orange are perennial rivers with mean annual discharges of the order of 3 million and 5 million acre-feet respectively, neither possesses any large natural storage in its upper catchment area : forests, lakes, and permanent snowfields are completely lacking. Therefore storage works are essential if large volumes of domestic and industrial water are to be guaranteed and irrigation water is to be available during the critical spring season when the rivers are normally at their lowest.

To meet these needs in the Vaal basin, the Vaalbank Dam was constructed in 1934-1937, just below the Vaal-Wilge confluence. Its original capacity of 873,000 acre-feet was increased to nearly 1.7 million acre-feet—more than 80 per cent of the mean annual run-off at this point, when the dam was raised in 1952-1954. In the Harts Valley a system of canals was completed by 1947 to serve more than 70,000 acres, and it was extended during the next ten years to water more than 80,000 acres (including nearly 11,000 acres in the Taung Native Reserve and some land along the Vaal towards Barkly West), devoted mainly to wheat, groundnuts, and lucerne hay for sale.

Two smaller schemes, subsequently initiated along the left bank tributaries, are noteworthy: on the Riet River a rock-fill dam was constructed in 1936-1938 to impound nearly 300,000 acre-feet and to serve 15,000 acres;[1] and on the Vet and Sand Rivers work was begun in 1946 on two dams of 190,000 and 170,000 acre-feet capacity, to serve jointly an area of 25,000 acres. Unfortunately, the latter scheme was held up by a dispute over mineral rights that enforced the suspension of construction until 1955 and delayed the completion of the twin dams until 1960.

Along the Orange River the aggregate area of land suitable for irrigation is probably not more than 80,000 acres—an area that could not effectively utilize more than one-tenth of the annual flow of the river, suitably regulated [50, p. 6]. More than half of this potential area lies between the Buchuberg Barrage (constructed as an unemployment relief work during the drought of 1929-1931) and the Aughrabies Falls, an area whose development was pioneered by the Griquas in the nineteenth century and which is now fully developed. There lucerne hay has long been the most valuable crop and cotton in the last ten years has displaced sultanas from the second place. The remainder of the irrigable land along the Orange is scattered in small patches, some already served by diversion works and pumps and others as yet undeveloped (Fig. 11).

To the farmers of the Sundays and Great Fish River valleys, the vision of nine-tenths of the waters of the Union's largest river, silt-laden though it is, being predestined to pour as wasted water 'down the drain' is too tantalizing to be accepted as a

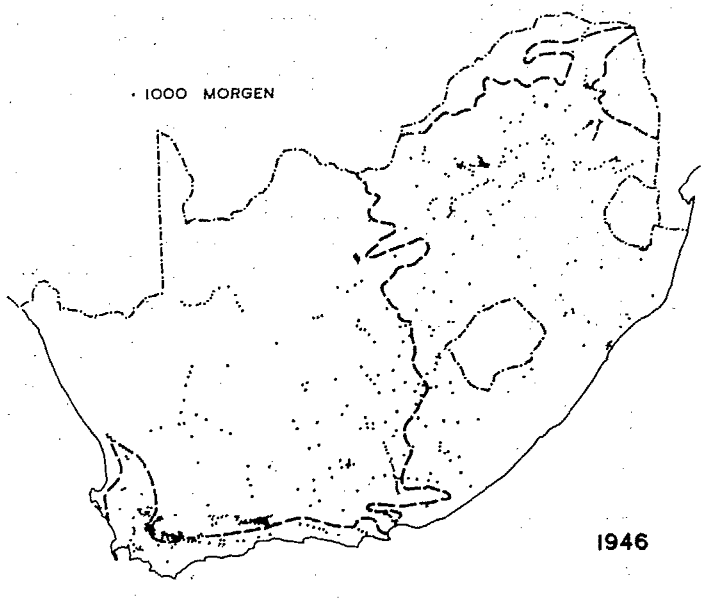



FIG. 11. Distribution of irrigated land, 1946. The heavy dashed line marks approximately the present limit of the arid regions. (Redrawn from map IV, 72, in the *Atlas of the Union of South Africa* [76].)

1. The capacity is unnecessarily large to control the run-off but the height of the embankment was planned so as to make possible the use of a col as a natural spillway.

Providential disposition. They have seen large areas of developed land abandoned in the Great Fish River basin and in drought years have seen citrus and other crops wilt in the Sundays Valley for lack of water. They dream of a barrage at Doornpoort near Venterstad to divert a million acre-feet a year from the Orange by a 5-mile canal and a 50-mile tunnel into the upper basin of the Great Fish River and, by branch canals, into the Sundays basin also. It does not yet belong to the history of irrigation, no parliament has yet been undaunted by the cost, but as a project its political history promises to be long and eventful.

The continued expansion of the area under irrigation[1] during the last 40 years, despite meagre water resources that are generally difficult and expensive to harness, is symptomatic of the general trend towards intensification of land use everywhere [76, section 4].

## INTENSIFICATION OF PASTORAL LAND USE

### FENCING, 'CAMPING', AND THE DECLINE OF SEASONAL 'TREKKING'

In the arid regions in general the most obvious and important change that has occurred has been the fencing of formerly open grazing land. The fencing and sub-division of farms into paddocks or 'camps', each provided with a drinking place, made pasture management possible. Judicious management could, in turn, increase by at least 30 per cent the carrying capacity of Karoo farms during normal years and increase considerably their capacity to support stock during drought years [86, p. 429].

Already in 1897 fencing as a measure to restrict the movement of animals and the spread of rinderpest was being encouraged by the free conveyance of fencing wire over the Cape Government Railways. In the same year some of the more progressive farmers in the Albany district, on the south-eastern margin of the arid regions, began to fence against vermin [3, p. 484]. However, fencing spread slowly, retarded by conservative attitudes, by lack of capital, and by the disruptions of normal economic life caused by the South African War.

From about 1910 onwards the more enterprising farmers in the Great Karoo and in the Upper Karoo, particularly in the districts of Beaufort West, Carnarvon, Fraserburg, and Victoria West, began to fence and to 'camp' their farms on a large scale [107, p. 281]. From 1912 the Fencing Act made fencing compulsory when proclaimed necessary for the prevention of the spread of stock diseases, required neighbouring owners to contribute equitably towards the costs of all boundary fences, and made provision for loans towards fencing costs to be made available from the Land Bank. In 1922 an amendment extending these last two chapters of the Act to cover also vermin-proof (jackal-proof) fencing initiated a more widespread movement. By the 1930s the manifold advantages of fencing were becoming generally recognized, even in the wide open spaces of Bushmanland.

The greatest advantages accrued where jackal-proof fencing was erected. This at one stroke eliminated the need that had long existed almost everywhere in the Karoo for both continuous herding during the day and regular kraaling at night. Thereby, at a saving of labour, the animals were left free to decide themselves when to graze and when to rest. They were not crowded each night in a kraal that harboured every parasite and contagion in its dry-stone walls and in the excreta of generations.[2] In summer they were at liberty to graze naturally in the coolest hours and to rest during the heat of the day. In winter, at nightfall or at the approach of a storm, there was no occasion to drive them hard at the risk of overheating on the trail and of subsequent chills in the kraal, for each was free to seek its own shelter in its own time. Consequently the quality of the mutton and wool and the carrying capacity of the veld were correspondingly improved.

Periodic resting of the veld, such as became possible when a farm was subdivided into camps, enhanced its carrying capacity further. In most regions the need for seasonal movements to other pastures began to fall away and with the spread of fencing the obstacles thereto began to multiply. Custom had, of course, established recognized rights of way, 'trekpaths', for the movement of stock. Along these ill-defined and unfenced ways, especially in Namaqualand, Bushmanland, and neighbouring regions, where law and custom permitted free grazing up to 400 yards on either side of the trekpath, the landless grazier or *trekboer* of the colonial era had survived into the twentieth century. But when farm boundaries were fenced, adjoining landowners reduced the trekpaths to mere *gorrels* (throats), 100 yards wide and in many instances even narrower. After the passage of a few flocks along these constricted ways, little remained, save poisonous and unpalatable plants. Thus in some areas trekking was figuratively strangled out of existence.

Fencing, by impeding free contact between flocks on the veld, also played its part, together with the compulsory dipping measures intensified after 1925, in the virtual elimination of scab (*Psoroptes communis*

1. In 1950 the total area of irrigated land in the Union, as recorded in the report of the Agricultural Census, was approximately 1,250,000 acres of which 160,000 acres watered from boreholes and a little less than half lay in the arid regions as here defined.
2. The sale of this 'Karroo manure', particularly to horticulturalists and viticulturalists in the south-western Cape Province, was for some years a notable source of supplementary income on many farms.

var. *ovis*) from White farming areas.[1] It is perhaps no coincidence that scab persisted longest in the north-west, the region that was last and least fenced, although it must be admitted that there the difficulties of control were multiplied by the vast extent and sparse population of the region that enabled many to avoid the stock inspectors, by local conditions that still make regular seasonal trekking necessary for some, by long droughts that still too often make emergency trekking necessary for many or leave the stock in too poor a condition to dip, and by the sparsity of dipping tanks, the scarcity of water to fill them, and the mineral content of the water that, in some instances, impaired the efficacy of the dip [39]. Scab control regulations in their turn supplemented fencing in discouraging trekking as regulations prohibiting the movement of scab-infested stock were enforced in ever-widening circles, beginning in the vicinity of 'clean' districts, until in 1937 even in the north-west it became necessary to obtain a permit from a government inspector before moving stock.

Consequently, seasonal trekking persists today in only a few places. In the north-west it has been maintained by the great seasonal fluctuation in the carrying capacity of the veld on the Atlantic slope. After 1913 it was facilitated by the sinking of boreholes in the formerly waterless 60-70-mile wide western margin of Bushmanland and after 1927 was stimulated for some years by the opportunities it afforded for the illicit acquisition of Namaqualand diamonds. Furthermore, the change from the dry grass of the Bult, low in phosphates, to the succulent and highly nutritious winter grazing of Namaqualand greatly benefits stock from Bushmanland, while in summer it is equally advantageous for Namaqualand stock to be removed from their home farms where the grazing is then so poor and stock poisoning from toxic plants is frequent.

In the south-west sheep still move down from the Cold Bokkeveld and the Roggeveld to lamb in winter in the Doorn Karoo, though in smaller numbers than formerly. The Bokkeveld sheep are virtually expelled by the lack of winter feed in the dormant bush and 'sour' grass on their home farms and profit much from a spell on the Karoo grazing with its higher lime and phosphate content. Their removal, attended in the past by some inevitable loss of condition and in many years by serious losses from grazing toxic plants along the trekpaths, has been facilitated by the general use of motor trucks since 1937. This in turn has made it possible to set the lambing season earlier, so that lambs can be dropped on the home farms in April, transferred with their dams to succulent grazing after the first rains in the Karoo, and soon after their return in spring can carry 6-7 pounds of wool each on to the shearing floor in October or November. From the Roggeveld trekking is not so necessary; rotational grazing in jackal-proof camps and the introduction of lambing sheds have made it possible for many Roggeveld flocks to remain on the home farms throughout the year. Nevertheless, where the distances are small, as between adjoining farms on the crest and at the foot of the escarpment, the benefits that trekking can bring to the stock and to the veld outweigh any disadvantages.

## THE CONTROL OF LOCUSTS AND VERMIN

Another notable development has been the attainment of a substantial measure of control over the locust. The springbok, that drought formerly expelled from time to time from the Upper Karoo in such immense herds, were more than brought under control by the hunter soon after the last appearance of the *trekbokke* in 1896. In their turn the locusts that as late as 1934 invaded almost the whole of the Union, apart from the western and southern littoral and the south-western Karoo [25], appear to have been largely brought under control by the regular observation of potential outbreak centres within and the early reporting of invasions from outside the Union and by the efficacy of gamma-benzenehexachloride as an insecticide for use against them, both from aircraft and from ground-operated dusting and spraying equipment. First used on an experimental scale in 1946-1947, BHC proved deadly to locusts but is apparently tasteless and harmless to grazing animals [87, p. 967-968 and p. 1059; 88, p. 49].

The leopard remains only in the more mountainous and broken country. Although its elimination permitted the jackal (*Thos mesomelas*) to increase in numbers and to become for many years a far greater pest to sheep farmers, the jackal in turn has been largely brought under control by fencing, hunting, and trapping. The campaign against it, promoted by the payment of a bounty on every jackal destroyed, provided incidentally a measure of distress-relief in some drought years when residents of the western districts of the Upper Karoo 'turned in many instances to the destruction of vermin as a means of livelihood' (e.g. in 1922-1923 when magistrates there paid out more than £16,000 in rewards) [98, p. 37]. The donkey that, abandoned and breeding wild in the north-west, was reputedly destroying the grazing in some areas after the first world war [98, p. 28; 97, p. 56] has also been largely eliminated.

Such developments have made the Karoo a less exacting habitat for sheep. They made it possible for sheep to increase to a peak figure of nearly 50 millions in 1930 (before the devastating droughts of 1931-1933) and enabled the wool-producing Merino

1. Its eradication from Native reserves has proved extremely difficult and such areas remain reservoirs of infection, particularly in the Transvaal and Natal.

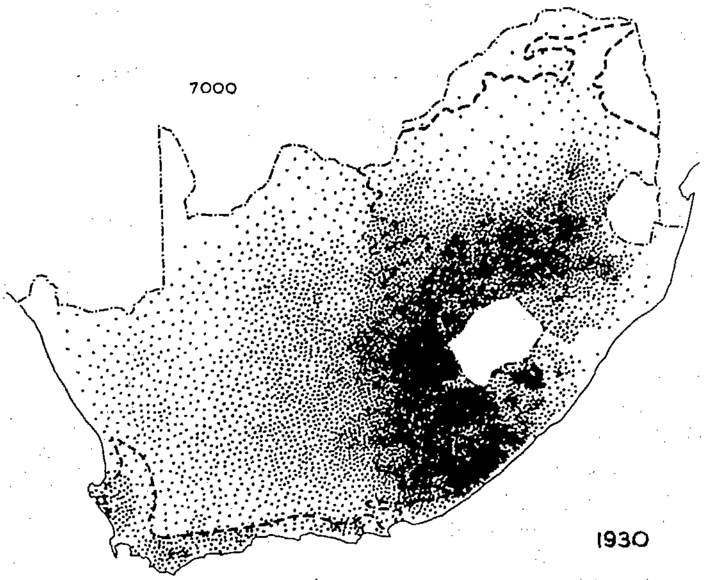



FIG. 12. Distribution of sheep owned by all races in the peak year, 1930. The heavy dashed line marks approximately the present limit of the arid regions. (Based upon the Agricultural Census of 31 August 1930.)

and, in favoured areas, wool-and-mutton cross breeds (e.g. Merino x Dorset Horn or Hampshire Down) to displace the Blackhead Persian and the Africander from most of the central and even much of the western Karoo (Fig. 12).

Nevertheless the future of the Karoo and, indeed, of all the arid regions remains uncertain, perpetually threatened by the curse of recurrent droughts (Fig. 13) and the not dissociated problem of veld deterioration that results mainly from injudicious land use and, to a minor degree, from the unfortunate introduction of alien weeds.

## THE CAMPAIGN AGAINST PRICKLY PEAR AND JOINTED CACTUS

Exotic weeds, notably prickly pear (*Opuntia megacantha*) and jointed cactus (*O. aurantiaca*), have proved more difficult to control and have been locally more destructive to grazing than either the donkey in the 1920s or the dassie (*Procavia capensis*), which in recent years has become a threat to the grazing in some areas where the jackal has been exterminated [63, p. 254]. The prickly pear, indigenous to Central America and Brazil whence it spread to Spain and Portugal and so to India, was introduced into the south-western Cape Colony by ships of the Vereenigde Oost-Indische Compagnie [102, p. 5]. There, as in Mexico, it was used successfully as a hedge plant but, following its introduction after 1750 into the drainage basins of the Sundays and Great Fish Rivers and the adjacent summer-rainfall regions, it spread rapidly. Jointed cactus or tiger pear, indigenous to Argentina and Uruguay, was introduced between 1850 and 1860 as an ornamental plant—unfortunately into 'a locality where conditions were most suitable for its propagation'—the sparsely populated, thorny, succulent scrub of the Great Fish basin. There it spread, unhindered by man and assisted by animals and stormwater, until in the 1930s it was branded the most noxious weed in South Africa [103, p. 495].

By 1935 the prickly pear almost completely occupied over two million acres of farm land in the eastern Cape Province and thousands of acres scattered along the semi-arid to subhumid marginal zone from the Great Fish River to the Limpopo. Encroaching insidiously and continuously on grazing land and causing the death of thousands of animals annually, it had become a national menace [62]. Farmers who had fought it with arsenious sprays and by manual means demanded State action [60, p. 339]. In 1934 the Department of Agriculture accordingly embarked upon a campaign to infest the weed growth with colonies of the Central American moth *Cactoblastis cactorum*, that had proved so effective in reducing infestation in Australia and which, in experiments in the Union in 1925 and 1933, had proved unlikely to damage any South African crops or veld succulents [61, p. 14]. Unfortunately, the cactoblastis proved less effective as a control under

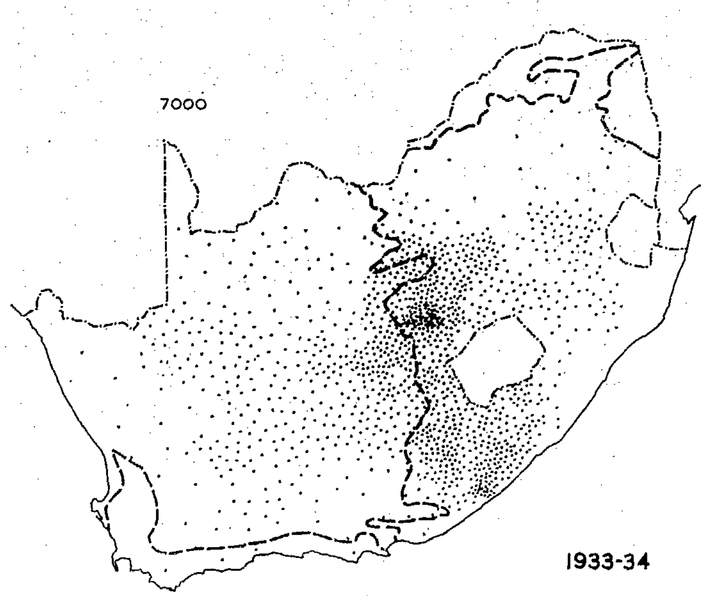



FIG. 13. Distribution of sheep lost through drought, diseases, vermin and other causes in the year ended 30 June 1934—a year of severe losses. The heavy dashed line marks approximately the present limit of the arid regions. (Based upon records in the Office of the Director of Veterinary Services, Pretoria.)

South African conditions. Its numbers increased less than half as rapidly as in Australia and even in the more favoured areas 'it was 4 years before any appreciable amount of . . . *O. megacantha* had become . . . heavily infested' [61, p. 68]. In the higher parts of the Karoo, winter cold proved a serious deterrent. Where the common prickly pear, *O. megacantha*, occurred with *O. tardospina* the moths were attracted to deposit most of their eggs on the latter whose highly mucilaginous sap proved fatal to most of the larvae. Hailstorms also destroyed large numbers of eggs; baboons and apes devoured the larvae, rodents ate the pupae; a protozoön disease, *Nosema cactoblastis* Fantham, unknown in Australia, caused considerable losses in the subhumid marginal areas; an insect parasite, *Brachymeria*, destroyed many pupae in the cocoons; and several species of ants attacked cactoblastis in all stages except the adult moth [61, p. 75].

By 1941 it was obvious that, although cactoblastis attacks weakened the prickly pear, the moth was not competent to eradicate it. Other media of biological control were sought and found in the commercial cochineal insect, *Dactylopius coccus*, and the common cochineal of Mexico and the south-western United States, *D. opuntiae*, introduced from Australia in 1937. The latter in the first few years following its release in 1938 proved too zealous. It defoliated not only large areas of the noxious opuntias but also some plantations of the 'spineless cactus' (other than the Monterey variety) which, after its introduction from California in 1909 [47], had been established on Karoo farms to provide fodder reserves for use during droughts. But by 1944 coccinellid predators, notably the African *Exochomus flavipes* and the Australian *Cryptolaemus montrouzieri*, introduced in 1900 to control grape and pineapple mealy bugs, had begun to make serious inroads into many colonies of *Dactylopius opuntiae*. The Cryptolaemus had not solved the mealy bug problems of either the Bathurst pineapple growers or the Constantia viti-culturalists, but it had proved conspicuously successful in the control of the citrus mealy bug. Consequently almost as soon as cochineal colonies were established in the abundant prickly pear of the Sundays River Valley they were attacked not only by the indigenous Exochomus but also by the Cryptolaemus that had been so carefully bred for years on one of the local citrus estates. By 1939 both beetles had so increased in numbers that, while citrus farmers were relieved of any further need to breed Cryptolaemus, the cochineal had been deprived of much of its efficacy as a means of controlling prickly pear [61, p. 113]. In the subhumid and especially in the coastal areas where the higher humidity and more moderate temperatures favour both the increase of the coccinellid predators and the regrowth of opuntia, cochineal was soon rendered useless; in the semi-arid areas, however, experiments between 1938 and 1943 showed that, where opuntia well-infested with cochineal was felled leaving no stumps, the cochineal was sufficiently protected from the weather and from the predators to continue to increase until the weed was eradicated [61, p. 133]. These measures were employed in a vigorous programme inaugurated in 1946 by the Department of Agriculture and by farmers operating under a subsidy scheme. It proved so successful that, of the 4 million acres originally infested, by 1950 only 200,000 acres remained—almost all in subhumid areas where the cochineal is ineffective [88, p. 442].

Biological control was urgently needed for the jointed cactus also. Between 1924 and 1934, despite an 'eradication campaign' conducted under a Provincial Ordinance (which provided for the equal sharing of costs between the provincial government, the local divisional councils, and the landowners) the estimated area infested by the weed increased from 100,000 to more than 400,000 acres. Thereupon, under Act No. 54 of 1934, the Union government assumed responsibility for cleaning the weed from infested areas, operating the campaign also as a small-scale unemployment relief scheme for Bantu, Whites, and Coloureds [26, p. 344].

In 1932, however, small numbers of a new South American cochineal, *Dactylopius confusus*, apparently specific to only two of the opuntias occurring in South Africa, *O. aurantiaca* (jointed cactus) and *O. tardospina*, were introduced. In 1935, when sufficient numbers had been bred, it was distributed in infested areas and soon proved so promising that the Department of Agriculture in 1938 discontinued the costly chemical and mechanical measures employed hitherto and concentrated entirely upon propagating and distributing the new cochineal. By 1941 it 'had accomplished almost complete destruction of the primary growth over the cactus-infested areas' but, unfortunately, it did not kill the roots and scattered regrowth from surviving tubers followed throughout practically all of the area originally infested. The re-establishment of the cactus was made possible not only by the dying out of the cochineal for lack of sufficient host plants after the success of its initial onslaught, but by the appearance of enemies of the new cochineal: rodents, ants, the same coccinellid predators that had earlier reduced *D. opuntiae* colonies on prickly pear, and a new fungus disease, *Empusa lecanii* [61, p. 156]. Therefore, although the cochineal has reappeared in some areas as soon as the secondary growth of jointed cactus has become sufficiently dense, hopes of controlling the weed must rest again upon manual and chemical methods of control. Among the last, the hormone weedkiller 2,4,5,T, which has been issued free of cost by the Department of Agriculture to farmers since 1957, may offer the greatest hope of success although the complete elimination of all sources of re-infestation by such means is almost impossible in sparsely populated and mountainous terrain.

## DROUGHTS, DESICCATION, AND VELD DETERIORATION— THE DECLINE OF AN 'AFRICAN EDEN'

Droughts of irregular duration and erratic occurrence have always been part of the climatic pattern but there is a widespread belief that they have become more frequent within living memory. However, personal reminiscences are notoriously unreliable as weather records and observational data from the four oldest rainfall stations in the arid regions, extending back to between 1861 and 1870,[1] show little evidence of any change. On the other hand 'there is ample evidence to support the view that serious desiccation is taking place in many parts of South Africa' [41, p. 136].

The causes of this desiccation are cultural rather than climatic. The replacement of the rich, varied, and mobile indigenous fauna by a far less mobile and nowadays largely sedentary fauna composed principally of one, two, or at most three kinds of exotic farm animals has completely changed the ecological conditions affecting the vegetation.

The veld was formerly the habitat of a prodigious variety of grazing and browsing animals, each species with its own particular feeding habits and preferences, to some extent complementary to those of others. Some animals, such as the *trekbokke*, grazed the veld intensively on certain occasions and in certain localities but for only short periods. Others, equally mobile but less numerous, their numbers adequately controlled by the lion and other carnivora, appear rarely to have subjected the veld to excessive grazing. The Hottentot and the Bantu added an insignificant minority of cattle, sheep, and goats, but the European colonist, over a period varying from a few decades in the north-eastern Low Veld to more than two centuries in the south-western Karoo, gradually exterminated most of the native fauna and substituted in its place one or more of these three kinds of farm animals.

Around the kraals, into which these domestic animals were regularly herded at night for protection from carnivores, and around the watering places, the veld was soon overgrazed and trampled out, run-off began to transform stock-trails into gulleys, and in light soils wind-erosion was initiated. As the population and the numbers of farm stock increased, some areas became overstocked. As long as trekking persisted the veld was relieved, at least seasonally, of grazing pressure—even though it was rarely rested at the optimum season for plant reproduction. With the decline of trekking, seasonal resting of the veld became less general and the pressure upon it was prolonged, except where fencing, the subdivision of farms into camps, and the provision of sufficient watering places was accompanied by a satisfactory system of rotational grazing—a condition rarely fulfilled and one that could be fulfilled only fortuitously in the absence of careful research into pasture management. For, despite the predominantly pastoral bias of South African farming, sufficient funds and sufficient staff have never been devoted to the intensive scientific study of the pastures upon which it is so fundamentally dependent.

In 1923 the Drought Investigation Committee in its final report recorded that grazing pressure was aggravated further by the then (and still) almost universal tendency of farmers to stock their holdings on the basis of the estimated or over-estimated carrying capacity in a good year and by the general failure to reserve fodder for use in times of scarcity [92, p. 8]. Furthermore, to avoid costs of transport and of hiring other grazing in times of drought, it was (and still is) usual to keep animals on the impoverished veld—in the hope of rain—long after antelope and zebra would have moved elsewhere.

Such prolonged selective grazing by one or two classes of animals, more or less frequent local overgrazing, and repeated punishment of drought-stricken pastures have impoverished the plant cover over wide areas. Palatable and nutritious plants have become fewer while toxic and unpalatable species have become more abundant. The grass (particularly the perennial grasses formerly widespread in the Karoo [40, p. 726])—of such manifold value as pasture, as 'the greatest conserver of soil moisture, and as the most important builder of soil fertility' —suffered most of all [91, p. 8]. Thereby, in a chain reaction, run-off and soil erosion have been promoted, the depth and water-retaining capacity of the soil have been reduced, precipitation has been rendered progressively less effective in providing for plant growth and in maintaining the flow of springs and wells, and the depleted veld has become less drought-resistant. As a result culturally-induced changes have created an illusion of general climatic deterioration. However the climatic change is not all illusory. Over enormous areas formerly well-vegetated surfaces are now more exposed, often completely exposed, to insolation. There, at the soil level where germination occurs, higher maximum temperatures and greater evapotranspiration losses represent a real and significant deterioration in the microclimate of the seed bed.

Today there is little or no vegetation in South Africa that is in its original condition but it is the arid regions and a broad marginal zone adjoining them that have suffered the most catastrophic

1. Graaff-Reinet, 1861; Clanwilliam, 1868; Worcester, 1869; and Somerset East, 1870.

changes. 'The most . . . alarming is the spread of Karoo at the expense of sweet grassveld' [1, p. 14], an eastward advance of as much as 150 miles in places in the last hundred years affecting an area of nearly 25,000 square miles [84, p. 521] (see Fig. 1). This 'False Karoo' appears to be primarily the result of overgrazing, although the depredations of locusts and harvester termites have been contributory factors. Once depleted beyond the critical stage the grass cover becomes vulnerable to harvester termites (*Hodotermes* spp. and *Microhodotermes* spp.), which thereafter practically eliminate the remaining grass [19, p. 263; 20, p. 243]. The invading, widely spaced Karoo bushes are incompetent to protect and conserve the grassveld soils and, consequently, over thousands of square miles the soil erosion has made the vegetation change irreversible.

The savanna grassland, or Kalahari Thornveld, of Griqualand West is suffering a similar Karoo invasion that appears to have followed in the wake of the colonial sheep farmers who first entered the region in significant numbers in the 1880s. They found the veld dominated by tall grasses but, by deliberate overgrazing, succeeded in 'taming' the veld, i.e. degrading the grass cover sufficiently to make it better suited to sheep. They welcomed the gradual appearance of Karoo bushes but were unable to foresee or to forestall the effects of continued selective grazing that further depleted the indigenous grass, reduced the numbers of the more palatable of the invading Karoo bushes and promoted the spread of poisonous plants such as *vermeerbos* (*Geigeria passerinoides*); it also appears in recent years to have accelerated the Karoo invasion [20, p. 62].

Parallel changes are to be seen in the extension eastwards over much of the Upper Karoo of the more arid Karoo facies, dominated by *blomkoolganna* (*Salsola tuberculata*), *driedoring* (*Rhigozum trichotomum*), and such desert grasses as *Aristida obtusa*, and, in the west, in the appearance in Bushmanland and Namaqualand of extensive patches of near-desert vegetation, characterized by a sparse growth of mesembryanthemums and other dwarf succulents. In the marginal zone to the east the threat of changes to come is perhaps to be seen in the developing thickets of *Acacia karroo* that dot the grassveld of the western Transvaal and Orange Free State and in the pioneers of the more arid Karoo species that are already to be found near the humid limit of the False Karoo.

In the savanna thornveld and bushveld other changes have followed the destruction of the delicate balance that formerly existed between grass and bush. In the north-western Cape Province and the northern Transvaal alike, most of this damage has been inflicted during the present century, mainly since 1920. Already in 1943 it was estimated that more than 35,000 square miles in the arid bushveld and adjoining regions of the

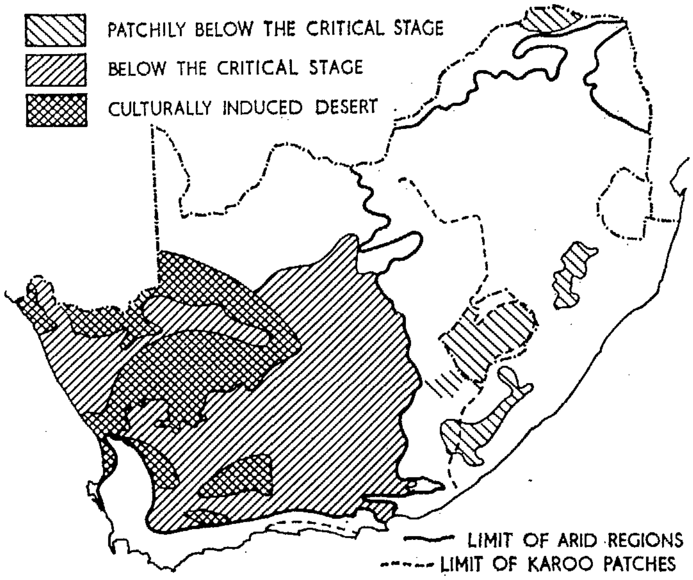



FIG. 14. The advance of the desert. The heavy dashed line marks approximately the present limit of the arid regions. In the deterioration of the vegetation, the critical stage is reached when the plant cover, particularly the grasses, is just able to protect the soil against erosion. Deterioration beyond this stage leads rapidly to soil depletion that makes impossible the restoration of a plant cover comparable with the original veld (even if grazing is suspended entirely) and that, if not arrested, ultimately reduces the veld to a condition that economically if not botanically is scarcely distinguishable from desert [1, pages 14]. (Redrawn from J. P. H. Acocks' *State of vegetation in* A. D. *1950*.)

Transvaal had either become so densely overgrown by bush as to have suffered a marked decrease in carrying capacity or were seriously threatened by bush that was 'invading grassveld at an ever increasing rate' [38, p. 725]. In 1956 it was estimated that 26,000 square miles in the Kalahari thornveld north and west of Kimberley were similarly affected [110, p. 732].

Throughout the Karoo and the southern margin of the thornveld and in part of the northern Transvaal bushveld the deterioration of the plant cover and the concomitant soil erosion have proceeded beyond the critical stage when prolonged resting might have permitted recovery and restoration of the original vegetation (Fig. 14). Over thousands of square miles it has gone so far beyond the point of no return that the appalling spectacle of 'denudation, impoverishment and weed-infestation' [91, p. 7] recalls as no idle rhetoric the grim foreboding of the Drought Commission Report: '*The logical outcome of it all is "The Great South African Desert" uninhabitable by Man.*' [92, p. 3.]

Droughts continue to take their toll of the farm stock and of the veld in many ways. Since 1925 annual losses of livestock (in which deaths directly or indirectly caused by drought usually predominate) have been equivalent to about 4 per cent of both large and small stock in good years but in bad years have been of the order of 10 per cent of the cattle and 20 per cent of the sheep[1] (see Fig. 13). These are percentages for the Union as a whole; for individual districts they range far higher. Special railway rates (less than one-tenth of normal rates) and modern motor transport, including in 1959 the use of a large number of military vehicles, have facilitated the watering and supplementary feeding of stock in, and their removal from, drought-stricken areas. Thereby livestock losses have been minimized but at a price to be measured by the extent to which millions of 'guest-sheep', transferred to High Veld pastures that were already fully stocked, have hastened the preparation of the grassveld for the further advance of the Karoo.

Thus the veld, virtually the only source of economic wealth in South Africa before the exploitation of its minerals, has become also a diminishing resource. Measures designed to relieve the more acute symptoms of its deterioration have, unfortunately, in many instances effectively hastened the process until regions that were formerly the source of the country's greatest wealth have become the seat of its gravest problems.

For more than a century after the first White colonists settled in the interior, the arid regions were the economic heart of South Africa. The humid eastern regions were not drawn into its economic life until the advance of the White settlers had carried their pastoral economy north of the Orange and across the Drakensberg in the 1840s. Arable farming, despite the more favourable climate there, remained relatively unimportant until the discovery of diamonds, gold, and coal in the decades 1870-1890 had brought an influx of immigrants and laid the foundations of the first large inland towns. Even then, farming remained predominantly pastoral to a degree that left the country a net importer of foodstuffs until the first world war.

But the environment that had confronted the pioneers with a wealth of game was equally rich in insect life and micro-organisms that came to plague the domestic stock and to take toll of the crops of their descendants. It was therefore natural, in the post-railway era of education, rapid communication, and scientific progress, that farmers should seek help from the State in meeting the manifold problems and adversities that beset them. In 1893, three years before the rinderpest epidemic swept in from the north, the South African Republic appointed its first government veterinarian,[2] in 1895 the Cape Colony appointed its first government entomologist,[3] and in 1898 the first government agricultural school was opened at Elsenburg, near Stellenbosch.

Since 1910 the policy of the Union Government has been consistently sympathetic to, and in large measure dictated by, the politically dominant rural electorate. Results of its support are to be seen in the long programme of veterinary research that has brought world renown to the Onderstepoort Veterinary Research Institute, in the State agricultural colleges and experimental stations and their manifold work in agricultural education and research, particularly in agronomy and animal husbandry, and in the facilities and services provided by the Department of Water Affairs (formerly Irrigation) and the Department of Geological Survey to assist farmers in the development of groundwater resources.

Measures to assist farmers in meeting other immediate problems and to encourage other desirable developments in farming methods were also, perhaps, justifiable in the early years in a country of poor soils, scanty and uncertain rains, and many pests. In times of drought the State railways transported fodder consigned to and livestock removed from drought-stricken areas at sub-economic rates and, from time to time, the legislature wooed the rural voter with other measures ranging from small unemployment relief schemes to large uneconomic irrigation works.

But recourse to the State for aid, which may have been genuinely necessary in the earlier years to rehabilitate the farm economy in some areas after the South African War and to hasten the attainment of a higher level of agricultural and pastoral production during and immediately after the first world war, has now become traditional. The rural population has been nursed on a wide variety of bounties, subsidies and loans; these have been offered for the destruction of vermin, the building of sheds and silos for grain and fodder, the construction of dams for irrigation and for watering stock, earthworks and structures to combat soil erosion, the digging of wells and sinking of boreholes, the eradication of prickly pear, jointed cactus, and other noxious weeds, the erection and relocation of fences, and similar purposes.

State aid, direct and indirect, is now demanded as a right. Thereby the ecological factors that would have directed each farming enterprise towards a closer harmony with environmental conditions have been muted.

In the depression years of the 1930s protective tariffs were raised and marketing controls were imposed on such staple commodities as maize, wheat and dairy produce, and, from 1931 to 1937, wool and mohair producers were given direct subsidies as compensation for low world prices. After 1937 the Marketing Act

1. More than 1,250,000 cattle in the census year 1945-1946 and nearly 9,400,000 sheep in 1933-1934.
2. Arnold Theiler, 1867-1936, subsequently Director of the Onderstepoort Veterinary Research Institute from its establishment in 1908 and a leading figure in African veterinary science, particularly the investigation of livestock diseases.
3. C. P. Lounsbury, whose pioneer studies demonstrated the importance of ticks as vectors in the spread of heartwater and other stock diseases.

provided for a whole series of Control Boards each constituted with a majority of producers and endowed with wide powers to control the prices, distributors' profits, and marketing system of a particular agricultural product or class of produce. By the insidious multiplication of such controls over the years, interest has become increasingly focused upon the profit motive in farming instead of upon the achievement of a sound system of land utilization in harmony with the climate, the soil, and the natural plant cover on every farm. The policy of each board is now to protect the profits of the producers of its particular commodity—with little heed to the policy of any other boards or of any division of the Department of Agriculture and regardless of the production methods that may be employed. Thus, in climatically semi-arid areas, the cultivation of maize has been made profitable, at least for a period, and the production of butter and cheese has been made remunerative under conditions inconceivable to a Danish dairyman. Farming suffers in a welter of independent and often conflicting policies while the basic knowledge that should be available, at least in the Department of Agriculture, for over-all planning and policy-formulation is equally fragmentary and incomplete. For, while distinguished research has been directed to the study of livestock parasites and diseases, livestock breeding, insect pests, fertilizer requirements, and other conditions affecting the growth of particular crops, no commensurate expenditure of talent and public funds has been devoted to the study of the most fundamental field of all, the ecology of the natural plant cover and the restoration, maintenance, and better utilization of the natural vegetation, the grass cover and the Karoo bush, without which vaccines and price controls, insecticides and subsidies will be of little avail and without which the unstable margins of the arid lands will continue to crumble as the desert advances into the Karoo and the Karoo continues to invade the thornveld and the High Veld grasslands.

# Part II: SOUTH WEST AFRICA

*by*

RICHARD F. LOGAN

*Associate Professor of Geography, University of California, Los Angeles, USA*

South West Africa affords an opportunity to study the utilization of desert lands under two extremely contrasting types of culture. Some areas are occupied by relatively primitive African tribes, while adjacent tracts are utilized by pastoralists of European ancestry, employing the latest results of modern science and technology.

South West Africa is a Mandated Territory of the League of Nations administered by the Union of South Africa. It is situated on the western side of southern Africa between 17° and 28° south latitude. Most of the Territory lies atop a portion of the great central plateau of southern Africa—a region of low relief at elevations ranging from 3,000 to 6,000 feet above sea level. On the west the plateau is separated from the sloping coastal platform by an abrupt escarpment. The coastal platform is monotonously smooth in the north with bare rock or gypsiferous gravels at the surface, but in the south solid rock is buried beneath a vast sea of sand dunes.[1]

From the climatic point of view the most essential feature is the decrease in precipitation from more than 20 inches per annum in the north-east to less than one-half inch along the south-west coast. Except in the extreme south (where the influence of the frontal storms passing the Cape Province in winter are sometimes felt), precipitation is almost entirely from summer convectional storms associated with invasions of maritime tropical air from the Indian Ocean; the winters are extremely dry.

Since the purpose of this book is to study the land utilization of *desert* regions, we will pay no further attention to the more moist areas. Hence we will omit from our discussion the north-eastern portion of the Territory plus an extension of it southward into the

1. This paper makes no attempt to discuss mining as an aspect of desert land use. However, it should be mentioned here that all of the southern portion of the coastal platform is closed to public entry because of the presence there of alluvial diamond deposits; and that much of the governmental support of agricultural improvement has been made possible by the revenues derived from the mining of these precious stones.

high uplands of the Windhoek district near the geographical centre of the country. If the 13-inch isohyet[1] is used as the criterion, the boundary between the arid and semi-arid extends from the Bechuanaland border westwards along the twenty-third parallel to the intersection with the meridian of 17° east; and from that point north-westwards parallel to and about 100 miles distant from the coastline.

This alignment is curious in that it removes from discussion a sizeable portion of the famous Kalahari Desert. This area has been termed 'desert' because of the absence of surface water—a result of its sandy soil rather than an absence of rainfall. Actually the deep sand makes an excellent reservoir for the storage of rainfall, with the result that portions of this 'desert' are an open woodland of camelthorn trees. Adjacent areas which lack the sandy cover, possess scattered surface waters, but have only low shrub vegetation and appear more desertic than the 'desert' itself.

Four vegetation type occupy the major part[2] of the arid portion of South West Africa. In the winter rainfall area of the extreme south-west (south of latitude 26° and west of longitude 17°), widely spaced succulent-leafed and succulent-stemmed dwarf shrubs dominate the scene. Over most of the plateau and along the inner edge of the coastal platform, sweeping expanses of grassy steppes alternate with wide stretches of bush steppe, the type being determined by either edaphic conditions or the nature of previous grazing. Most of the central and seaward portions of the coastal platform (constituting the heart of the Namib Desert), as well as certain valley flats (*vloere*) atop the plateaux, are almost totally devoid of vegetation.

The general appearance, the speciation, and the carrying capacity of all these associations vary greatly from year to year as a result of extremely great variations in the amounts of precipitation. As in most arid areas, the annual average precipitation is merely a mathematical mean which seldom occurs in actuality; rather the situation alternates irregularly between short-lived disastrous floods, years of better than average rainfall, and periods of protracted droughts.

Despite the scantiness of its vegetation and the unreliability of its precipitation, the area formerly supported a surprisingly dense and varied native fauna. Some herbivorous animals (such as springbok, gemsbok, wildebeeste and zebra) travelled in vast herds, often numbering thousands, while others (such as kudu, steenbok, duiker, klipspringer and ostrich) lived solitarily or in small bands. There was also a great variety of smaller animals, particularly the burrowing rodents. Preying upon all of these were innumerable carnivores such as lions, leopards, cheetahs, hyenas and jackals. Occasionally drifting into the area from the adjacent regions of heavier vegetation, or dependent permanently upon the riparian vegetation of the major stream beds, were some of the larger herbivores—rhinoceros, elephants, giraffes. Today most of these animals are to be found in the area although in considerably depleted numbers.

## HISTORICAL DEVELOPMENT

From the land use point of view, three periods can be recognized in the historical development of South West Africa: the period of aboriginal occupance; the era of German settlement and the early days of the mandate; and the period of postwar expansion.

### ABORIGINAL USE

From time immemorial all of the area under consideration was visited from time to time by wandering bands of Bushmen—a diminutive grey—or copper-skinned people with short kinky hair growing in peppercorns (tufts of hair surrounded by bare scalp). Still in the hunting and gathering stage of economic development, these very primitive people made almost total use of the resources of their environment, from the larger animals down to insects, lizards, and the seeds and bulbs of many plants. The recurrent drought years with their accompanying shortages of both vegetable and animal food served as a check to population growth, resulting in a very sparse population.

Widely scattered over the same territory, with an equally sparse population, were the Nama or Hottentot group. While these people were primitive pastoralists, grazing flocks of all-purpose goats and sheep, they also engaged extensively in hunting and gathering. Since they were prevented from engaging in agriculture by the lack of available water, they depended upon certain tubers and bulbs *(veldkos)* for an important part of the vegetable side of their diet.

These groups had a very serious effect upon the vegetation of the area. In their search for game, the Bushmen started fires which ran unchecked over vast areas. In the particularly favoured areas, for example about the water holes, the goats of the Namas so completely destroyed everything that such areas came to look like miniature deserts with all of the palatable species being removed and only the most undesirable ones being able to survive.

Neither of the above-mentioned groups are Negro. The Nama are short people with greyish or coppery skin, hair much like that of the Bushmen, faces with many Mongoloid characteristics and a tendency towards pronounced steatopygy (the storage of fat in the buttocks during periods of plentiful food). The only Negro or partly Negro group in the area was the

1. This conforms approximately with Koeppen's BW—BS boundary.
2. In addition to these areally-important types there are certain specialized associations of restricted extent, such as riparian, coastal salt marsh and mountain ravine associations.

Berg Damara (often called Klip Kaffirs). These primitive, weak people either lived in remote areas of rugged mountains or attached themselves voluntarily as servants to the Hottentots and even to the Bushmen exchanging their independence for security and protection.

At the time of the coming of the white man, the true Negro (Bantu) were in the process of invading the area from the north-east. The tall dignified black-skinned Herero had reached the borders of the desert country in the north-west and found it undesirable to press farther in that direction because of the increasing aridity. Their southward advance was stemmed by the Hottentots and others before reaching the area under consideration. However, since they were dependent almost totally upon their herds of cattle, the increasing aridity southwards would probably have halted their advance in any case.

Throughout the nineteenth century, the southern part of South West Africa was repeatedly invaded by mixed blood groups from the Cape Colony farther to the south. These people, basically Hottentots with an admixture of Dutch and Malay (the type usually termed 'Coloured') came northwards as individuals, in family groups or even as whole tribes. Although they possessed a smattering of European civilization, they adopted the Hottentot way of life almost *in toto*, becoming sheep and goat raisers and engaging in hunting and gathering. The main difference was one of degree : a more intensive use of the land with still stronger alteration of the vegetation.

Aside from occasional missionaries, traders, and miners, there were no white settlers in South West Africa until 1890, and no agriculture was practised in the country on any appreciable scale.

## GERMAN SETTLMENT

In 1890 the German Government began a large-scale colonization undertaking in South West Africa, operating largely through the medium of the Deutsche Kolonialgesellschaft, a company formed for the express purpose of exploiting all the resources of the country. During the succeeding 25 years this colonization went forward most successfully. A port was developed, railways constructed, towns and cities built, the native tribes pacified, and a large part of the country developed into European-owned farms.[1]

Agriculture in the arid zone was limited to narrow patches of floodplain along the lower course of the Swakop River, where the raising of a variety of crops on a very small scale was carried out under irrigation. By and large, however, the Germans were forced, due to insufficient water for irrigation or insufficient rainfall for normal agriculture or even dry farming, to engage in pastoral activities. Extensive tracts of land were awarded to settlers by the government. A very dispersed form of settlement developed, with each individual German family living on its own tract of land at a considerable distance from the nearest neighbour. With the exception of Swakopmund and Windhoek, the Territorial capital, most of the towns remained as very small agricultural and administrative service centres.

Because native labour was so plentiful, the German farmers came to depend heavily upon it. Its presence made possible the handling of large flocks or herds on large tracts of land. Despite a great reduction in the number of natives and coloureds as a result of a brutal war waged against them by the Whites early in the present century, there has never been a real shortage of native labour.

In spite of the great differences in the two environments, the Germans built their herds out of the breeds of livestock with which they were already familiar in Europe—particularly German, Swiss and Austrian breeds of cattle such as Brown Swiss, Pinzgauer and Simmenthaler. They made no use of the native breeds herded by the Hereros and other local tribes. The European animals were surprisingly successful in the more moist areas for the production of milk and a butter and cheese export trade soon developed. But they were not successful in the drier portions of the southern part of the Territory. There, no commercial raising of cattle was successfully developed, although a few animals were kept for a supply of milk and meat for the house.

In the drier south, the early German settlers were dependent upon the sheep and goat at first, and carried on a principally subsistence economy. In 1907 the Karakul sheep (which had been imported from Central Asia by a breeding station in Germany) were introduced into South West Africa. They proved to be ideally adapted to both the climatic and vegetative situations and developed rapidly throughout the western and southern parts of the Territory, becoming eventually the mainstay of the economy of that portion of the country.

After World War I, a number of English farmers, largely from the Union of South Africa, acquired land in South West Africa, chiefly in the more moist areas. They introduced a number of British strains of cattle, notably Hereford and Shorthorn, together with some Red Poll, Aberdeen Angus, North Devon and Sussex. A few farmers settled in the southern part of the Territory.

Until the end of World War II the country remained, from a land use point of view, just the same as it had during the German régime. The lengthy depression of the 1930s and a series of droughts discouraged expansion.

1. In South West Africa the term 'farm' designates any type of rural landholding. Since in South West Africa such areas are devoted to pastoral activities rather than to cultivation of the soil, the American term 'ranch' would perhaps be more appropriate. Throughout the remainder of this article, however, the writer will conform to local usage and employ the term 'farm'.

### POSTWAR EXPANSION

During the period since the termination of World War II there has been a rapid immigration of Afrikaners[1] from the Union of South Africa and this, combined with a natural increase of population within the Territory, has created a very strong demand for more farms. To satisfy this demand the government has awarded a great many new farms, opening to settlement territories which the Germans had considered unsuitable for normal use. Today nearly all of the usable land is assigned either to native tribal use, to game reserves, or to white farmers, and the actual frontier has practically disappeared.

## PRESENT SITUATION

The Karakul are still the most important element in the economy of the arid portions of the Territory. Because of the peculiar nature of the Karakul industry, the animals are ideally suited to the environment and are able to do well in areas where no other form of pastoral economy could possibly exist. Karakul are successfully raised in areas where the average precipitation is as low as two inches per annum, and where the browse is extremely sparse.

Karakul, or Persian lamb pelts, are obtained by killing and skinning the newborn Karakul lamb in its first 24 to 36 hours of life—and herein lies the secret of the ability of the industry to survive under such adverse conditions. Because the young are slaughtered at birth, the postnatal drain on the ewe's vitality associated with the nursing of the lamb is avoided. Furthermore, there is no necessity for fattening either the ewe or the lamb for market, for the pelts are normally the sole marketable commodity. Thus it is only necessary that the ewe manages to find enough forage to enable her to survive and to bear her young regularly. This is possible in areas where the raising of sheep as slaughter stock would be impossible.

Typical Karakul farms range from 20,000 to 60,000 acres in extent, with the largest tending to occur in the driest areas—in the extreme south and along the Namib border at the foot of the western escarpment. Carrying capacities range from 15 to 20 acres per animal, and flocks average between 1,500 and 2,000 animals per farm.

Since the nature of the curl (upon which the quality of the pelt is based) is determined by the ram rather than the ewe, the quality of the ram is of prime importance. The ratio of rams to ewes averages about 1: 50, but because the breeding takes place on the open range it varies considerably with the nature of the terrain. Under normal conditions a lamb yield of about 125 per cent is expected, since some ewes have lambs twice a year. The oestrus cycle in ewes is initiated by the vitamin A content of the grass feed. If good rains occur in late spring (November) conception also occurs early (January), lambing takes place in June, and enough green feed may still be present to induce oestrus again in part of the ewe flock. In such cases a second lambing season occurs in November. In years with late summer rains there is only one lambing season.

Sheep in flocks of approximately two hundred are herded by a native who drives them out to their feeding areas by day and holds them in a corral at night. The animals are driven to water daily when the feed is dry, but when the grass is green they may stay out for several days at a time.

During the lambing season, newborn animals are picked up by the herders and deposited in crude stone corrals from which they are taken by truck daily to the farmstead. There they are skinned, and the pelts are dried on burlap stretched over frames in the shade. Pelts are sold either to independent buyers, usually with their headquarters in Windhoek, or through one of the co-operative enterprises which play an important role in the economy of the Territory.

The mature breeding animals are sheared two or three times a year and the rather coarse, fairly straight wool is sacked for shipping.

In recent years the raising of beef cattle has become increasingly important on many of these arid zone Karakul farms. While this is a good plan in that it relieves the farmer from total dependence on the single luxury item of Karakul it must be noted that most of these areas are suited to cattle raising only in the years of heavier rainfall and the effects of drought years may be greatly increased by this shift in emphasis.

The modern trend is largely toward the Afrikander—a breed developed in South Africa from cattle introduced from Central Africa by the Bantu tribes, and very well adapted to arid environments. In the last several years, experiments have been made with Brahman stock imported from the United States.

In addition to the white owner and his family, between 50 and 100 non-whites of several types live on the typical Karakul-cattle farms. Most farmers employ, by contract with the South West Africa Native Labour Association, one or several Ovambo males who act as herders and general handy men. These Bantu tribesmen from the extreme northern part of the Territory volunteer to work for wages on the white farms for a term of 12 or 18 months, at the end of which they return to their homeland. They come alone, leaving their families in Ovamboland.

Most of the native residents on the farms of the south and west are Namas and Berg Damaras—the original occupants of the area. The men usually work as herders and handy men, and a few of the women as herders and house servants, but for every native

1. People of Dutch or Huguenot ancestry, speaking the modified Dutch (*Afrikaans*) of South Africa.

actually employed on a farm, there are usually between six and twelve family members and other relatives who are dependent upon the wage earner for support.

The farmer pays each worker a fixed wage, supplemented by large rations of food and almost obligatory gifts of cloth and clothing. The natives construct their own dwellings (*pondoks*) of whatever material may come to hand. In addition, each native family is allowed to graze a flock of 40 to 50 goats and sheep on the land of the white farmer without charge. In most cases the natives have been on their present farm for years, if not for generations.

Today a considerable degreee of mechanization has taken place on most of these farms. Nearly all the farms are reached by roads traversable by standard cars, are illuminated by gasoline-operated power plants, have running water, gasoline pumps and windmills. Many are served by telephones, and most have home radios. The network of the Road Motor Services of the South African Railway System reaches many parts of the area and provides mail, freight and passenger service, and a means by which live animals, pelts and wool may be sent to market.

In spite of the many obvious advantages of this type of operation, the South West African Karakul raiser is faced with some very serious problems. His economy is based upon a very unreliable luxury market subject to the whims of fashion and the danger of a worldwide depression.

A second, serious, deep-seated problem is that of overgrazing and the accompanying deterioration of the range. This is no new matter; as we have seen, in prehistoric times these areas were overgrazed by the vast herds of game animals and the flocks of the natives. With the great fluctuations of the carrying capacity of the area owing to the variability of rainfall, it becomes very difficult for any farmer to stock his land effectively. There is always a tendency toward overstocking, particularly in the good years, with resultant overgrazing during drought periods. In some of the drier parts of South West Africa the more palatable perennial grasses have been replaced by less desirable annuals, and elsewhere by very pronounced bush encroachment, particularly of unpalatable species. In the early days of settlement drought conditions could be overcome by 'trekking', that is, by the movement of flocks or herds from drought-stricken areas to other parts of the Territory in which both rainfall and forage were sufficient. However, today (as many farmers learned to their dismay in the drought of 1958-1959) virtually all of the Territory is farmed, fenced and well stocked with animals. Hence it becomes extremely difficult to find spare grazing areas and trekking has, of necessity, been much reduced.

The wild game existing on the farms poses another problem. According to South West African law the game on a particular parcel of land is the property of the owner, to be disposed of as he sees fit. In some areas this has resulted in the virtual extermination of game, but in many cases the farmer is proud to possess wild animals on his property, with the exception of the carnivorous predators. On the other hand, the game competes directly with his domestic herds and flocks for feed, and in times of drought the competition becomes very strong.

## ROLE OF THE ADMINISTRATION

The Government of the Territory (always referred to as the 'South West Africa Administration') has done much in the past two decades to assist the individual farmer in overcoming these problems. Its Agricultural Department is charged with the administration of the Soil Conservation Act, which actually aims at the conservation of far more than soil and covers water, vegetation, and the general productivity of the country. Under its terms the administration assumes part of the cost of certain farm improvements: the fencing necessary to permit the practice of rotational and deferred grazing, and to aid in the elimination of predatory jackals; the drilling of wells; and the construction of tanks, windmills, and water storage reservoirs. In addition, the Agricultural Department carries on a series of advisory services in a most enlightened manner. Practical advice is given to farmers in matters of range improvement and dam construction, eradication of undesirable plants, on veterinary and animal breeding problems and home economics. The administration also makes available to farmers a series of financial loans, where necessary, for either disaster relief or farm improvement.

The administration at present operates three experimental farms and plans to establish at least two more in the near future. It operates an agricultural college, giving both a two-year programme and a series of short courses for adult farmers, and it gives financial assistance to local students studying science and agriculture in universities in the Union.

## NATIVES RESERVES

Approximately one-fourth of South West Africa is allocated to Native Reserves—areas in which the natives live under their tribal laws and customs, and from which white men are excluded not only from the ownership of property, but even from entry without special permission from the authorities. Contrary to the popular belief, the Native Reserves are not in the worst areas of the country. Rather, most of the reserves are not even in the arid or semi-arid region, and hence are not discussed here. The Ovambo, Okavango, Bushman, Waterberg, Aminuis, and Ovitoto Reserves are all in areas of considerable precipitation and good vegetation, and the first four are in areas where agriculture is possible. Much of the best land in the Territory is in the Native Reserves. The only reserves which fall within the arid region are the Bondelswart, Barseba and Tses Reservations in the south, and the Otjimbingue and Okambahe Reserves adjacent to the Namib. Within these areas the natives herd large flocks of sheep and goats primarily for subsistence use. While the reserves are not overpopulated, they are drastically overstocked and extreme overgrazing is the result. Inasmuch as the natives are semi-autonomous within their own reserves, they have the right to accept or reject many types of measures offered them by the administration, and in some cases have summarily rejected attempts of the administration to extend provisions of the Soil Conservation Act and similar legislation to their reserve. Attempts at stock-improvement measures have met with only moderate success.

### UNOCCUPIED AREAS

Large tracts of South West Africa still remain unoccupied, and in the hands of the administration. A large portion of the Namib Desert is closed to public entry and is totally unutilized, inasmuch as it is being held as a potential future diamond prospecting area. Several other areas have been set aside since the days of the German occupation as game reserves. In addition a large area of land lying along the fringe of the Namib has not as yet been assigned to graziers for permanent occupance. It is most important that this land remain unoccupied inasmuch as it is capable of supporting herds only in occasional better-than-normal rainfall years. Already land has been assigned to private ownership much too far into the desert edges with disastrous results both to the land and its occupants during droughts. The South West African Government must realize that the day of the frontier has passed and that there is no more land to be given out for permanent occupancy, and that future development can come only from the improvement of the already-settled areas. It is most fortunate that the administration has, for the most part, been forward-looking, and has been 'investing' funds derived from diverse tax sources in extensive agricultural-pastoral improvements.

## BIBLIOGRAPHY

### PART I


1. ACOCKS, J. P. H. *Veld types of South Africa.* Pretoria, Government Printer, 1953. (*Botanical Survey of South Africa Memoir*, no. 28.)
2. ANONYMOUS. Diamond water drill. *Agricultural Journal of the Cape of Good Hope*, vol. 9, 1896. p. 366.
3. ——. Vermin-proof fences. Ibid, vol. 12, 1898. p. 484.
4. ——. Camels in South Africa. Ibid, vol. 13, 1898. p. 32-35.
5. ——. Camels at the Cape. Ibid, vol. 24, 1904. p. 732-735.
6. ——. The crossing of North African and South African ostriches. *Journal of the Department of Agriculture*, vol. 1, 1920. p. 737-740.
7. BIGALKE, R.; DE KOCK, G. The conservation and control of wild life in South Africa. *African Regional Scientific Conference*, Johannesburg, 1949. (Communication no. C(j)4.)
8. BONSMA, F. N. *Studies on Africander Cattle.* (*Publications of the University of Pretoria*, Series I : *Agriculture*, no. 39.) 1938.
9. ——; JOUBERT, D. M. *Factors influencing the regionalisation of livestock production in South Africa.* Pretoria, Government Printer, 1957. (*Department of Science bulletin*, no. 380.)
10. BONSMA, J. C. Influence of climatological factors on cattle. *Farming in South Africa*, vol. 15, 1940. p. 373-385.
11. ——. Useful bushveld trees and shrubs. Ibid, vol. 17, 1942. p. 226-239.
12. ——. *Ecological animal husbandry research and its application in maintaining a permanent pastoral industry.* Pretoria, Government Printer, 1949. (*Department of Agriculture Science bulletin*, no. 307.)
13. ——; JOUBERT, D. M. The Africander breed. *Farming in South Africa*, vol. 27, 1952. p. 99-104 and p. 126.
14. BOSMAN, A. M. *Cattle farming in South Africa.* Johannesburg, Central News Agency, 1932.
15. BOTHA, C. GRAHAM. Early Cape land tenure. *Cape Law Journal*, vol. 36, 1919. p. 149-160 and p. 225-233.
16. BRADFIELD, E. R. The Great Drought. *Agricultural Journal of the Cape of Good Hope*, vol. 23, 1903. p. 666-669.
17. BRINK, D. *Noord-Kaapland, die geografiese faktore wat sy ontwikkeling bepaal.* 1950. (*Annale van die Universiteit van Stellenbosch*, Jaargang 25, Reeks B.)
18. BROWN, J. C. *Hydrology of South Africa.* Kirkcaldy, Crawford, 1875.
19. COATON, W. G. H. The harvester termite. *Farming in South Africa*, vol. 23, 1948. p. 259-267.
20. ——. Veld reclamation and harvester termite control. Ibid, vol. 29, 1954. p. 243-248.
21. CURSON, H. H.; THORNTON, R. W. A contribution to the study of African native cattle. *Onderstepoort Journal of Veterinary Science and Animal Industry*, vol. 7, 1936. p. 613-739.
22. DEGENAAR, S. A. Will the western Transvaal disappear with the wind? *Farming in South Africa*, vol. 25, 1950. p. 72-76.
23. DE KIEWIET, C. W. *A history of South Africa.* London, Oxford University Press, 1941.

24. De Kock, M. H. *Selected subjects in the economic history of South Africa.* Cape Town, Juta, 1924.
25. Du Plessis, C. Outbreaks of the brown and red locusts in the Union during the 1934-1935 season. *Farming in South Africa*, vol. 11, 1936. p. 10-14.
26. Du Toit, E. The jointed cactus eradication campaign. Ibid, vol. 10, 1935. p. 344.
27. Du Toit, F. J. The future of mohair. Ibid, vol. 8, 1933. p. 419 and p. 433.
28. ——; Stoker, H. M. The mohair industry. Ibid, vol. 8, 1933, p. 59.
29. Du Toit, S. J. Economic survey of cattle farms in two agro-economic cattle-grazing areas. Ibid, vol. 27, 1952. p. 469-475.
30. Epstein, H. Animal husbandry of the Hottentots. *Onderstepoort Journal of Veterinary Science and Animal Industry*, vol. 9, 1937. p. 631-665.
31. Evans, O. Ostrich farming in the Cape Province. In : Somerset Payne (ed.). *Cape Colony.* London, Foreign and Colonial Compiling and Publishing Co., 1911. p. 53-56.
32. Faure, J. C. Some recent advances in research on locust problems. *South African Journal of Science*, vol. 33, 1937. p. 797-811.
33. ——. *The life history of the red locust.* Pretoria, Government Printer, 1935. (*Department of Agriculture bulletin*, no. 144.)
34. Glanville, E. The problem of rural White unemployment. *South African Journal of Industries*, vol. 8, 1925. p. 82-89.
35. Hall, C; Fagan, H. *Water rights in South Africa.* Cape Town, Juta, 1933.
36. Henrici, M. Namaqualands' sheep pastures. *Farming in South Africa*, vol. 7, 1932. p. 5-8.
37. Hobson, E. R. The Angora goat in South Africa. *Journal of the Department of Agriculture*, vol. 3, 1921. p. 415-424.
38. Irvine, L. O. F. Bushveld encroachment in the northern Transvaal. *Farming in South Africa*, vol. 18, 1943. p. 725-729.
39. Juritz, D. F. The use of hard or saline waters for sheep dipping. *Journal of the Department of Agriculture*, vol. 1, 1920. p. 40-44.
40. Klintworth, H. Desert encroachment over the Karoo. *Farming in South Africa*, vol. 23, 1948. p. 723-727.
41. Kokot, D. F. Irrigation possibilities in the Union of South Africa. *Proceedings of the South African Society of Civil Engineers*, vol. 40, 1942. p. 166-219.
42. ——. *An investigation into the evidence bearing on recent climatic changes over southern Africa.* Pretoria, Government Printer, 1948. (*Irrigation Department Memoir.*)
43. Kolbe, P. *Naauwkeurige en Uitvoerige Beschrijving van de Kaap de Goede Hoop.* Amsterdam, Lakeman, 1727. 2 vols.
44. Lee, C. G. The mohair industry. In: Somerset Payne (ed.). *Cape Colony.* London, Foreign and Colonial Compiling and Publishing Co., 1911. p. 310-331.
45. Levinkind, L. Gross evaporation from standard tanks in the Union of South Africa. *South African Geographical Journal*, vol. 22, 1940. p. 27-34.
46. Lewis, A. D. *Water law: its development in the Union of South Africa.* Cape Town, Juta, 1933.
47. Lewis, J. Note on Burbank's spineless prickly pear. *Agricultural Journal of the Union of South Africa*, vol. 3, 1912. p. 227-228.
48. Lichtenstein, H. *Travels in Southern Africa in the years 1803, 1804, 1805, and 1806.* London, Colburn, 1812. 2 vols. (Translated from the original German by Anne Plumptre.)
49. Livingstone, D. *Missionary travels and researches in South Africa.* London, John Murray, 1857.
50. Mackenzie, L. A. *The Irrigation Department: its functions, operation, and policy.* Memorandum presented by the Director of Irrigation to the Soil Conservation Board, Pretoria, August 1947. (Mimeographed.)
51. ——. *Memorandum on the water resources of the Union of South Africa . . . to the inaugural meeting of the Natural Resources Development Council.* December 1947. (Mimeographed.)
52. Macowan, P. *Reports of select committees.* Ninth Parliament of the Colony of the Cape of Good Hope, Session 1894, A.5-'94. p. 19-20.
53. Marais, J. S. *The Cape coloured people, 1652-1937.* London, Longmans, 1938.
54. Meyer, W. D. The development of mutton sheep in the Union. *Farming in South Africa*, vol. 25, 1950. p. 205, and p. 208.
55. Morris, J. J. The vermeerbos problem in Griqualand West. Ibid, vol. 20, 1945. p. 489-494.
56. Neumark, S. D. *Economic influences on the South African frontier, 1652-1836.* Palo Alto, Stanford University Press, 1957.
57. Noble, J. *Descriptive handbook of the Cape Colony.* London, Stanford, 1875.
58. ——. *Illustrated official handbook of the Cape and South Africa.* Cape Town, Juta & Co., 1893.
59. Oberholzer, S. F. *An economic investigation of the farming system in two extensive cattle-farming regions of the Union of South Africa.* Pretoria, 1957. (*Department of Agriculture bulletin*, no. 350.)
60. Pettey, F. W. Cactoblastis and its progress in South Africa. *Farming in South Africa*, vol. 10, 1935. p. 339 and p. 356.
61. ——. *The biological control of prickly pears in South Africa.* Pretoria, Government Printer, 1948. (*Department of Agriculture Science bulletin*, no. 271.)
62. Phillips, E. P. *et al.* Opuntias in South Africa. *Farming in South Africa*, vol. 15, 1940. p. 119-128.
63. Roberts, Austin, *The birds of South Africa.* Revised by G. R. McLachlan and R. Liversidge. Johannesburg, Central News Agency, 1957.
64. ——. *The mammals of South Africa.* Revised edition edited by R. Bigalke, V. Fitz Simons and D. E. Malan. Johannesburg, Central News Agency, 1951.
65. Romyn, A. E. Ranching in the Transvaal. *Journal of the Department of Agriculture*, vol. 8, 1924. p. 508-517.
66. Schapera, I. *The Khoisan Peoples of South Africa.* London, Routledge, 1930.
67. ——. The native inhabitants. *Cambridge history of the British Empire.* Vol. 8. London, Cambridge University Press, 1936. p. 20-50.
68. —— (ed.). *Apprenticeship at Kuruman, being the journals and letters of Robert and Mary Moffat, 1820-1828.* London, Chatto and Windus, 1951.
69. Schulze, B. R. The climates of South Africa according to the classifications of Köppen and Thornthwaite. *South African Geographical Journal*, vol. 29, 1947. p. 32-42.

70. Schulze, B. R. The climate of South Africa according to Thornthwaite's rational classification. Ibid, vol. 40, 1958. p. 31-53.
71. Sclater, W. L. *The mammals of South Africa*, London, Porter, 1900-1901. 2 vols.
72. Stander, G. J. Waterbewaring en doeltreffende beplanning vir die maksimum-exploitasie van Suid-Afrika se natuurlike hulpbronne. *Tydskrif vir Wetenskap en Kuns*, vol. 14, 1954. p. 162-177.
73. Starke, J. S. Development of the non-woolled sheep. *Farming in South Africa*, vol. 27, 1952. 87-91 and p. 108.
74. Stevenson-Hamilton, J. *The Low Veld: its wild life and its people.* London, Cassell, 1929.
75. ——. *South African Eden: from Sabi Game Reserve to Kruger National Park.* London, Cassell, 1937.
76. Talbot, A. M.; Talbot, W. J. *Atlas of the Union of South Africa*, Pretoria, Government Printer. (In the press.)
77. Talbot, W. J. Kapstadt als Weltstadt. In : *Zum Problem der Weltstadt.* Berlin, de Gruyter, 1959. p. 56-82.
78. Theal, G. M. *Belangrijke Historische Documenten over Zuid-Afrika.* Vol. 3. London, Clowes (for Union of South Africa Government), 1911. p. 324-435.
79. Theiler, Sir Arnold. The cause and prevention of lamziekte. *Journal of the Department of Agriculture*, vol. 1, 1920. p. 211-244.
80. ——. Phosphorus in the livestock industry. Ibid, vol. 8, 1924, p. 460-504.
81. Thom, H. B. *Die Geskiedenis van die Skaapboerdery in Suid-Afrika.* Amsterdam, Swets & Zeitlinger, 1936.
82. Thompson, G. *Travels and adventures in Southern Africa.* 2nd edition. London, Henry Colburn, 1827. 2 vols. p. 268-274.
83. Thunberg, C. P. *Travels in Europe, Africa, and Asia.* London, E. and C. Rivington, 1795. 4 vols.
84. Tidmarsh, C. E. Conservation problems of the Karoo. *Farming in South Africa*, vol. 23, 1948. p. 519-530.
85. Transvaal Department of Agriculture. *Annual report, 1903-1904.* Pretoria, Government Printer, 1905.
86. Union of South Africa. *Report of the Desert Encroachment Committee.* Pretoria, Government Printer, U. G. 59/1951.
87. ——. *Final report of the Drought Investigation Committee.* Cape Town, Government Printer, U. G. 49/1923.
88. ——. Department of Agriculture, *Annual report for the year ended 30th June 1923.* Pretoria, Government Printer, U. G. 9/1924. p. 371-483.
89. ——. Annual report for the year ended 31 August 1947. *Farming in South Africa*, vol. 22, 1947. p. 919-1176.
90. ——. Annual report for the year ended 31 August 1950. Ibid, vol. 25, 1950. p. 379-503.
91. ——. Annual report for the year ended 31 August 1953. Ibid, vol. 29, 1954. p. 3-124.
92. ——. *Handbook for farmers in South Africa.* 1957. 3 vols.
93. ——. Department of Irrigation. *Irrigation in South Africa.* Pretoria, 1947. (Mimeographed.)
94. ——. *Report of the Director of Irrigation for the year ending 31st December 1911.* Cape Town, Government Printer, U. G. 39/1912.
95. ——. *Report of the Director of Irrigation for 1912-1913.* Cape Town, Government Printer, U. G. 2/1914.
96. ——. *Report of the Director of Irrigation for the period 1st April 1918 to 31st March 1919.* Cape Town, Government Printer, U. G. 28/1920.
97. ——. Department of Justice. *Annual report for the year 1922-1923.* Pretoria, Government Printer, U. G. 9/1924.
98. ——. *Annual report for the year 1922-1923.* Pretoria, Government Printer, U. G. 9/1924.
99. ——. Department of Lands. *Annual report for the year 1912.* Pretoria, Government Printer, U. G. 62/1913.
100. ——. South African Railways and Harbours. *Report of the General Manager of Railways and Harbours for the year ended 31st March 1930.* Pretoria, Government Printer, U. G. 45/1930.
101. ——. *Report of the Road Motor Competition Commission* Pretoria, Government Printer, U. G. 8/1930.
102. Van der Merwe, C. R. *Prickly pear and its eradication.* 1931, Pretoria, Government Printer. (*Department of Agriculture Science bulletin*, no. 93.)
103. ——. Jointed cactus and its eradication. *Farming in South Africa*, vol. 6, 1931-1932. p. 495-497; vol. 7, 1932. p. 21-23.
104. Van der Merwe, P. J. *Die Noordwaarste Beweging van die Boere voor die Groot Trek, 1770-1842.* Den Haag, Van Stockum, 1937.
105. ——. *Die Trekboer in die Geskiedenis van die Kaap-Kolonie.* Cape Town, Nasionale Pers, 1938.
106. ——. *Pioniers van die Dorsland.* Cape Town, Nasionale Pers, 1941.
107. ——. *Trek.* Cape Town, Nasionale Pers, 1945.
108. Van Reenen, R. J. Development of irrigation in the Union of South Africa. *South African Journal of Science*, vol. 22, 1925. p. 20-41.
109. Van Ryneveld, W. S. *Aanmerkingen over die verbetering van het vee aan de Kaap de Goede Hoop, inzonderheid over de conversie der Kaap in Spaansche of wolgevende schapen, Kaapstad.* Van Riebeeck-Vereniging, 1942.
110. Van der Schyff, H. P. Bush encroachment in South Africa. *Handbook for farmers in South Africa.* Vol. 3. 1957. p. 732-741.
111. Wellington, J. H. *Southern Africa.* London, Cambridge University Press, 1955. 2 vols.
112. Whitlock, L. F. Future development of the Kalahari. *Farming in South Africa*, vol. 25, 1950, p. 82-84.

PART II

113. Hintrager, Oskar. *Sudwestafrika in der Deutschen Zeit.* Munich, R. Oldenbourg, 1956.
114. Vedder, Heinrich. *South West Africa in early times.* Oxford, 1938.
115. Walter, Heinrich. *Grundlagen der Weidewirtschaft in Sudwestafrika.* Stuttgart, Ulmer, 1954.
116. Wellington, John M. *Southern Africa : a geographical study.* Cambridge, University Press, 1955. 2 vols.

# THE PROBLEM OF ARID AUSTRALIA

*by*

Sir Samuel Wadham

*Professor Emeritus of Agriculture, University of Melbourne*

## PRELIMINARY NOTE

In this account of the factors which have been important in the evolution of systems of land use in Australia, no attempt has been made to define the boundaries of arid and semi-arid zones with any precision. Numerous contributors to other arid zone publications have discussed the use of various physical constants and formulae for this purpose, e.g., Griffiths Davies [10].[1] The pioneer work on Australian climatology by Griffith Taylor [35] is still significant.

Prescott [25] showed the correspondence between the actual boundaries of *desert* formations in Australia and their theoretical limits as estimated by various physical methods. The map (Fig. 1) shows Prescott's desert area and, at the moister extreme, also indicates the approximate boundaries of the area in which, on the average, the arid period of the year is not more than three months [9]. Between this boundary line and the desert are the arid and sub-arid regions. No attempt will be made to separate or subdivide them. They pass uninterruptedly into each other, for there is no major geographical feature to cause any abrupt change in the climate; such ranges as occur are not large enough to do more than cause a small disturbance in the isohyets and the isotherms.

This intermediate region between the desert and the subhumid zones has been the chief scene in which the various developments to be described have taken place. In it, and especially in the parts of it near the coast, techniques have been evolved that have gradually led to more efficient use of many parts of the arid zone, and some that have affected the outlook of man toward the desert. This centripetal evolution of methods is inevitable, because the risks of drought and discouragement increase with the aridity; naturally therefore, men have tried new ideas with greater courage and better chances of success where the climate is less harsh.

## LAND USE BEFORE 1788

Before the arrival of the first British colonizing fleet in 1788, the aboriginal inhabitants had had no continuing contact with other centres of human development from which they might have acquired bad habits in regard to the use of land. At that time they are said to have numbered about 300,000, most of whom lived along the northern, eastern and south-eastern coasts which are fairly well watered. Inland in the drier areas the population was sparse.

They lived mostly on fish, which they speared, oysters which they chipped off the rocks in estuaries, such marsupials and birds as they could knock down with boomerang or spear. They also ate lizards and snakes, wild honey, ants and the grubs of many insects, notably the large 'Witchetty Grub' (*Zeuzera eucalypti*). They had digging sticks with which they extracted the roots of certain plants, e.g., yams and bulrushes, and they collected the seeds of various grasses, the sporocarps of *Pilularia* and the sclerotial masses of certain fungi. These vegetable products were ground up under large stones and eaten as a paste. They used fire for roasting, but had not acquired the art of boiling water. They made no attempt at cultivating plants, and they had no domestic animal except possibly the dog.

The families or tribes which inhabited the drier areas each had its own range of hunting country, and a considerable folklore about the probability of food animals being present in certain regions. But they were essentially nomadic because there were relatively few opportunities of securing food in any one part of their range. The only shelters they constructed consisted of light *mia-mias* of cut or broken branches sufficient to keep off the heaviest rain. Their attempts to ensure a supply of water did not extend beyond enlarging a water hole. There would

1. The figures in brackets refer to the bibliography at the end of the chapter.

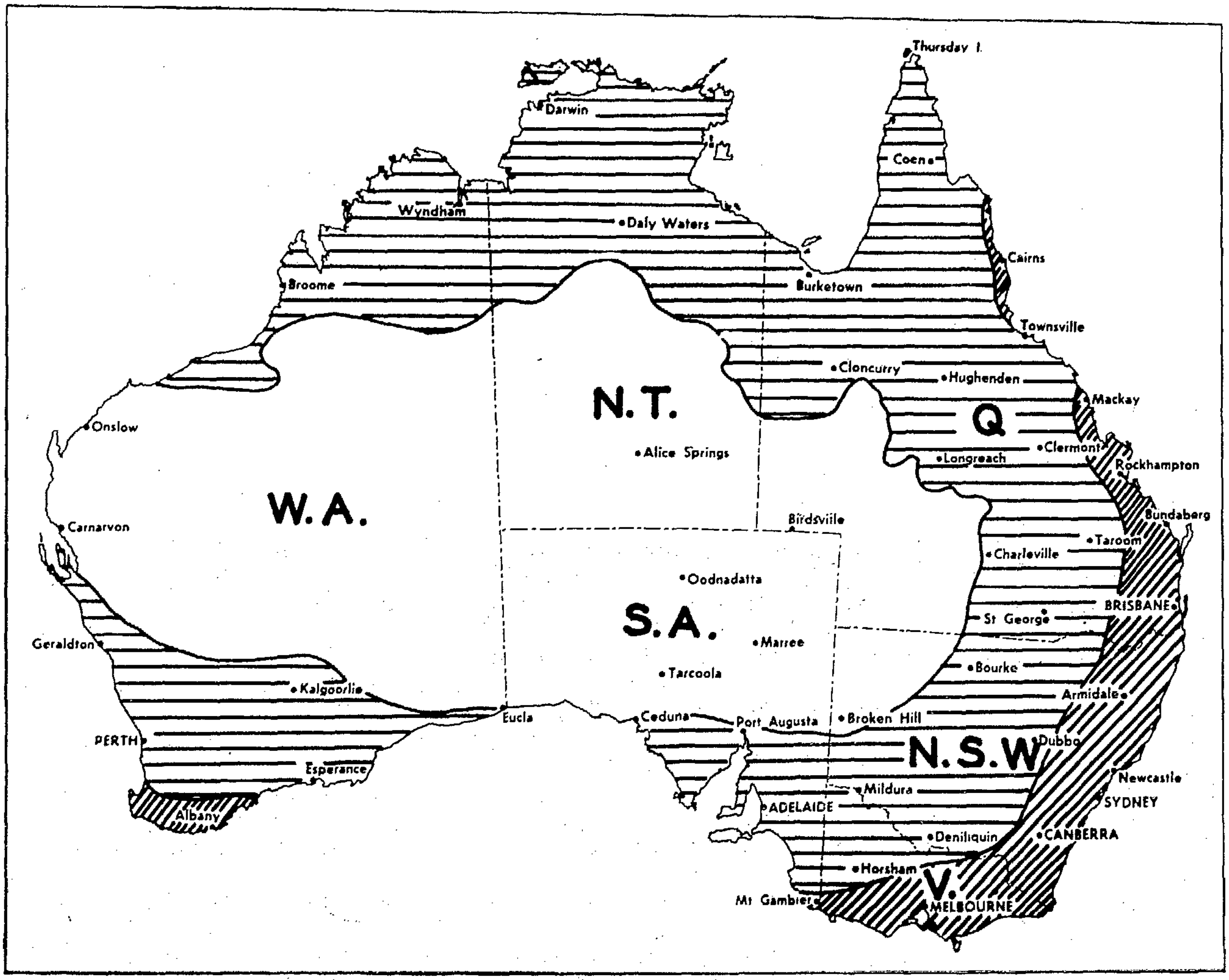



FIG. 1. Showing the boundaries of the States, the approximate boundaries of 'the region of desert formations' (Prescott) and the zone of the subhumid areas (not more than 3 months of aridity annually).

have been no point in making any more permanent construction, because their continued stay in any district depended largely on their being able to find game, and this would not be increased by the mere enlargement of a water hole.

In some districts bush fires doubtless occurred as a result of lightning which sometimes accompanies dry thunderstorms. The results of these were probably sufficiently damaging to instil into the tribal tradition a wholescome regard for fire danger—especially in a community where the authority of the old men was paramount.

The aborigines therefore did little or no harm to their country, either by destroying the native vegetation, diverting the channels of the water courses, or tearing up its soils; nor is it reasonable to suggest that they were responsible for major conflagrations which had some influence on the vegetation. Such serious degradation of the soils and plant cover as may have occurred are due to the natural processes of denudation and soil development, or to man's activities since 1788, or both.

In this respect Australia differs from the other large land masses of the world, in the arid parts of which man has apparently been the disturbing factor, at least since prehistoric times when some of his wandering tribes began to occupy in sedentary fashion these more difficult regions.

## THE PHASE OF PRIMARY OCCUPATION

### EARLY DEVELOPMENTS

The permanent occupation of land in Australia by Europeans began in 1788, when a convoy of naval vessels and convict ships arrived near Sydney. The primary objective of the new settlement was the construction of a place for convicts from Britain. It was expected that they would be able to grow their own food in due course, but trade was not a primary objective.

The struggles of this small group to maintain themselves on the poor soils of the coastal strip with its high but fickle rainfall are not within the compass of this book. The general attitude of the governors of the colony was against exploration over the steep, forested ranges which separate the coastal strip north and south of Sydney from the then unknown hinterland. Actually, the first known crossing was not made until 1813. The widespread invasion of the drier interior began about 1820, after the potentiality of the country for producing fine wool had been demonstrated on the coastal strip.

By this time the high prices obtained in Britain for Australian wool stimulated great interest in the possibility of using the country as an area for running sheep [23]. Men, and sometimes whole families, migrated from Britain, where an economic depression was grinding the farmers to despair, with the idea of becoming landowner-pastoralists in the new country [7]. By 1820 only half the population were convicts.

A general wave of exploration towards the interior from the Sydney settlement began, and Tasmania, which had been occupied for strategic reasons in 1803, shared in the expansion of the sheep industry. Landings on the mainland were made from Tasmania at Portland (1834), and Melbourne (1835); a new colony was started by an expedition from Britain at Adelaide (1836-1837). To the north, Moreton Bay, which later became Brisbane, was started as a penal

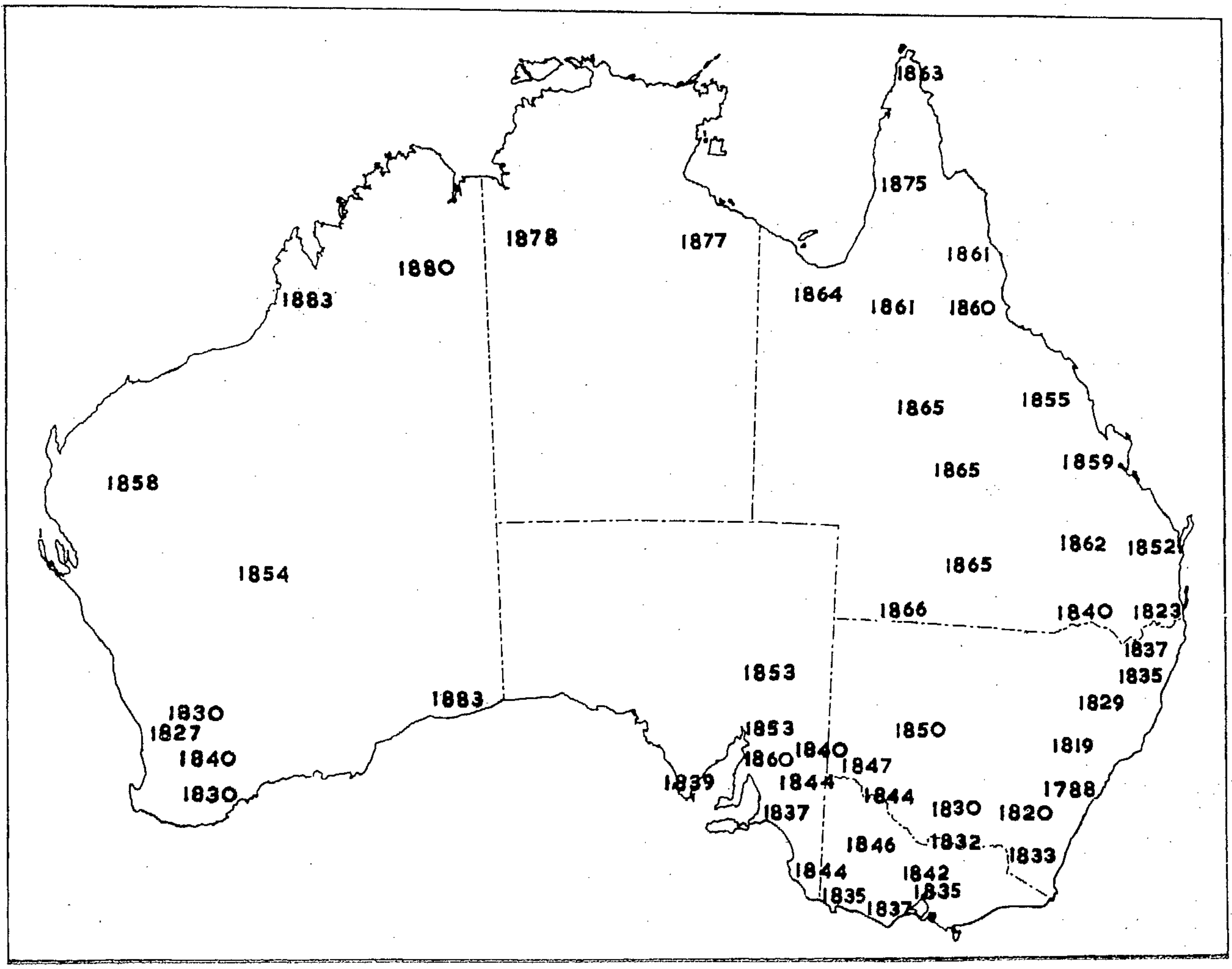



FIG. 2. The approximate dates of first settlement in many districts.

settlement in 1823, but made little progress on the poor coastal country. However, when the better land on the Darling Downs was opened in about 1840, occupation developed rapidly. On the west side of the continent the confusion of land policies was some obstacle to settlement after the initial landings in 1827 [29]. However, the great difficulty was the extreme poverty of most of the soils between the coast and the range behind. Even when this range had been crossed, the land beyond was only fertile in a few places and pastoral success was not really achieved until the arid Murchison country was reached in about 1854. In the far south-west settlement took place at various points, but here again conditions were difficult [33]. It is interesting to reflect that these many failures in the west were basically due to the low phosphorus-content of the soils, which was not realized till the end of the century, and also in many cases to the lack of trace elements, first demonstrated in the 1920s.

Water was the limiting factor in this early pastoral occupation. The main lines of advance of the pastoralists were down the rivers and water courses of the inland. Most of the lakes of the interior were too saline to be of value, but along the foothills the creeks, which only run after rain, often provided soaks and other spots where water could be obtained by digging. Gradually the occupied areas were extended until, apart from the waterless regions, the only sheepless parts were those were the vegetation was too thick, or the terrain too rough, or the places where sheep failed to thrive owing to maladies which were then obscure. Cattle runs where established in some of these localities, because the herds can make their way over rough country or through scrub, and during the cooler season they will often graze land as far distant from watering points as ten miles, in contrast with a sheep's radius of about three miles. Cattle were, however, economically far inferior to sheep because, apart from their use as draught animals, hides and tallow were then their most valuable products, the only markets for beef being those supplying the populations of the seaports, and the towns which sprang up at the gold-diggings after 1851.

This primary occupation of the country was naturally a gradual process. Figure 2 gives the approximate dates of the first settlement for many districts. Two new factors influenced the effectiveness of the system towards the end of the nineteenth century: the increased use of artesian bores and the onset of the rabbits.

The widespread development of water supplies from the artesian basins began about 1880, and enabled much greater use to be made of many areas in the arid zones, especially in Queensland. Today there are more than 8,000 bores, some of which go to great depths although the average is only about 500 feet. [13, 32]. The free-flowing bores provide considerable quantities of semi-saline water which is distributed through adjacent grazing areas by bore drains ploughed out along the contours. Boring for artesian water revealed 'sub-artesian' (i.e., low pressure) supplies in some localities; these require the installation of pumps, which are usually driven by the familiar windmills. The effect of these supplies of water from the ground was to enable more stock to be carried and to increase the intensity of the stocking; this sometimes led to pasture deterioration, especially round the troughs.

The second new development was the arrival of the rabbit as a grazing competitor with the stock of the pastoralists. They were originally introduced as food animals, but after some years of multiplication they became completely out of hand in the 1880s. The damage which they did to grazing plants of all kinds, together with droughts and low prices for wool, caused the economic depression of 1891 to 1903.

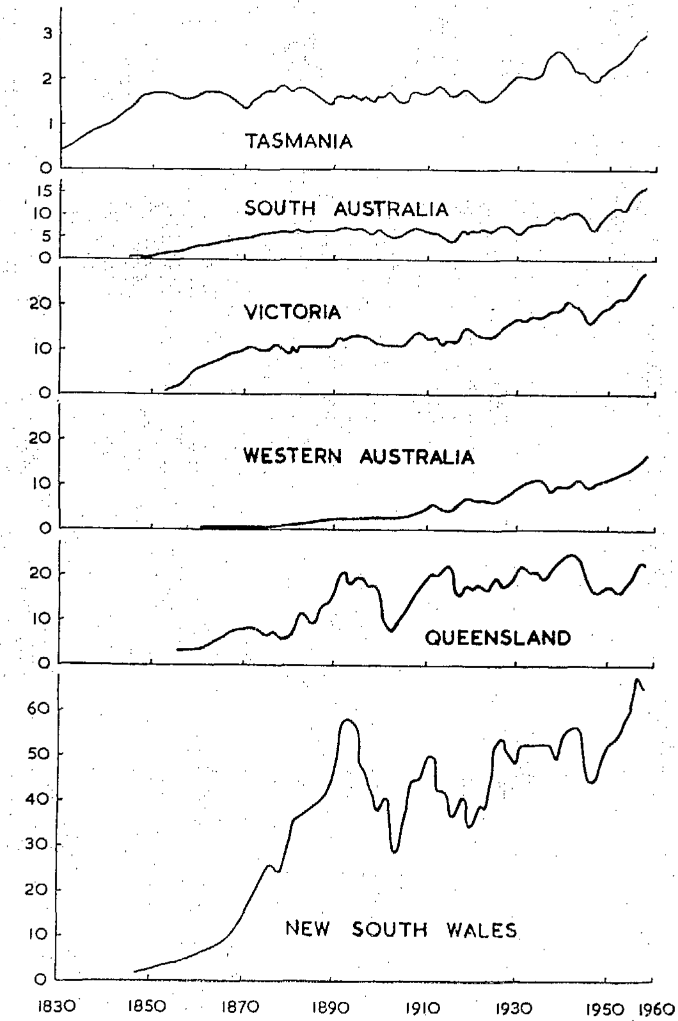



FIG. 3 Trends in sheep populations in each State. Vertical scale in Tasmania is 10x of the others.

The graphs (Fig. 3) show the trends in the sheep populations in each of the States and indicate the end of the expansion of primary exploitation. In each case there is a general trend which reaches a peak, after which there is a decline in numbers, and a period of oscillation followed sooner or later by a further increase, which can usually be associated with improved methods of farming and grazing in the sub-arid zone. Thus, in Tasmania the sound sheep country was soon occupied, and the population became more or less constant after 1859. In New South Wales, Queensland, South Australia and Victoria, the peaks occurred between 1891 and 1893, when a series of circumstances described later undermined the industry. This was the end of primary exploitation in these States. The second phase of expansion began at varying dates : Tasmania 1924, Victoria 1926, South Australia 1933, New South Wales and Queensland 1956. In Western Australia development of the sheep industry progressed fairly steadily until 1935, when a long drought set the pastoralists back and further progress was not made until 1951.

Apart from these changes in the general trends, the graphs show considerable fluctuations which were usually caused by droughts, although economic instability at times caused great hardship to those who had bought runs and their sheep at high prices, and then found that the price of wool declined owing to temporary oversupply of the markets in Europe. But in general, European populations were increasing and required more clothes, while wars occasionally led to a sharp rise in the demand and caused a temporary boom in trade.

### LEGAL AND ADMINISTRATIVE PROBLEMS OF THE EARLY OCCUPATION

The occupation of the country in this sparse manner was largely the result of the natural conditions, but the policy of the administration had a significant influence. The first occupation of the land during the great pastoral advances of 1830-1860 was only legal under the same conditions as squatting on common land in Britain. The sheep and cattle men seldom owned the runs they used. They 'occupied' them. Incessant wrangles went on between the pastoralists and the various Governors who were charged with the task of carrying out the policy of the authority in London. Up till 1842 that policy was framed and frequently amended by successive Colonial Secretaries of State. After that date Parliament took control of the matter. This policy itself changed markedly as the settlement evolved from a convict dump, through a stage of self-supporting farming to a large and vigorous community.

Foremost among the reasons for the later policy of the administration in this matter of landownership, was the determination to maintain the basic principle that the Crown (i.e., the government in London) actually owned the land from the time when Governor Phillip formally proclaimed the occupation of the continent in 1788. This may seem a somewhat slight concept, but behind it were economic considerations. The administration and management of the colony entailed considerable expense, and the authorities well knew that as development proceeded, much larger expenditures would be necessary in maintaining the administration and in providing buildings and constructing roads and bridges, until such time as authorities could be set up with power to raise money from local sources. As far as possible the Colony should provide this money for basic expenditure, and the sale of 'Crown Land' was one method of acquiring it.

A second reason for refusing to recognize the squatters' claim to own their land lay in the social prestige which generally went with the ownership of broad acres in Britain, and presumably, the same position could easily develop in Australia, and in fact, for a time this was an official objective. But the social structure in Britain at that time was a 'three-decker' system of landowners, tenant-farmers and labourers, and it did not follow that a similar system would work advantageously in a new country which lacked tradition. After the arrival of large populations during the gold rushes of the 1850s, many of the new labourers saw no reason why they also should not have some land of their own. At any time, if the administration was weak, a body of large landowners could easily become defiant of authority, as indeed had happened in 1807, when officer-landowners under Macarthur had virtually deposed Bligh, the Governor at that time. So the administration set itself against giving ownership to the squatters, against the establishment of large estates and in favour of smaller settler-owned farms; but this last objective was difficult because a man needed a much larger area of grazing land to provide a living in Australia than in Britain and, moreover, the conformation of the ground and the fertility of the soils in this new country were very varied.

Governors had the right to make grants of land to retired officers, and also to time-expired convicts. The authorities in London also granted pre-emptive rights of selection to individuals in Britain who intended to settle. But the main body of men responsible for the great phase of pastoral expansion after 1830 did not wait for title deeds; they swept across the country and squatted on the best tract they could find which was so far unoccupied. Naturally, there were many disputes in a country without roads or any fixed points of survey.

But if the land was to be used effectively, fences, water facilities and buildings were necessary. Such fixed improvements required labour and money, and it would be foolish to construct them without some security of tenure of the holding. Naturally, therefore, the squatters soon pressed their claims to ownership of the land which they occupied, and the administration was quite unwilling to agree. The argument was intense and extended beyond the bounds of Australia. Materially the squatters were in a weak position. The only channels of trade through which their product, wool, and their supplies of necessities had to pass, were the centres of the administration. Few parts of the country were capable of providing a reasonable existence without the use of imported materials and equipment. Finally, law and order are a first essential to all forms of farming, and to sheep grazing in particular, and the administration alone could organize a police force, give it the necessary authority, and co-ordinate its activities.

The government secured its position in regard to the Crown's right to the land, the system of grants was gradually dropped, and payment for the alienation of land became normal after 1824. The government also maintained its principle of the restriction of the size of the holding to which a man had any right by virtue of occupation; but in practice it gave way to some extent. Numerous methods were tried to solve the problem, because, from 1820 at least, the governors realized that the whole wealth and progress of the Colony depended on the export income, of which the squatters provided by far the most important part. The first step was the temporary legal recognition of the squatters' position by *Occupation Licences* based on the number of stock carried. Then, in 1844, came two measures which aroused violent controversy. The first was the *Occupation Regulations*, under which the area of land that could be occupied under a licence was limited to 20 square miles, or an area sufficient to carry 4,000 sheep—whichever was the smaller. The second was the *Purchase Regulations*, which gave the squatter security of tenure for five years under his lease if he bought 320 acres of land, and at the end of the period the right to a further extension if he made a second purchase. This raised enormous controversy because, although the squatters were ready to buy the first quantum, which would contain the chief improvements such as the homestead with its watering facilities, the yards and any other buildings, they were not so interested in making further purchases of land which might not be so essential or so valuable.

The argument about the Purchase Regulations was intense, and there is little point in considering it in detail here, especially as soon after 1850 the States of Queensland and Victoria were separated from the jurisdiction of New South Wales, and in each State development took a somewhat different course.

In New South Wales modifications of the Purchase Regulations were introduced which enabled the squatters to consolidate their position for the time being, and then in 1861 an Act was passed which allowed 'free selection' of from 40 to 320 acres by anyone who was prepared to live on the block for a year and pay for it in three years. The limitation of the area one man could select was overcome by the squatters who employed persons as dummies, and who arranged for them to select the strategic patches of their holdings and then, as soon as the required period was over, transfer the land legally to the squatter. In this way the other parts of the property were often rendered unmanageable for farming. In Victoria the same sequence of events occurred, and under Acts of the new State Parliament purchase was permitted. In the better rainfall regions the best areas were rapidly alienated although areas of dense forest or poor soil remained unsettled until dairying made the clearing of the former worthwhile after 1890, and until scientific knowledge showed the way to use the latter.

In the more arid regions of New South Wales grazing lease-holds for 21 years or less remained the customary tenure. At the end of a lease the government had the right to resume half the property for subdivision, the previous lessee being compensated for those improvements on the resumed part which were valuable to the incoming tenant in the operation of the property on a grazing basis.

In South Australia the original settlement of 1836 was planned in a more orderly fashion. The squatters never dominated the development. The Wakefield Scheme, under which migrant-labourers from Britain worked on farms for wages until they had accumulated enough money to buy land and start on their own, was theoretically simple. The settlers' payments for their land were used to recoup the government for the expense of bringing out more migrants. In the end, however, the British Government had to face a deficit of £1,000,000 because the settlers could not earn enough to buy their land. The government early determined to give long-term opportunities to the farmers only in areas which were unsuitable for agriculture. Goyder, the surveyor, in 1865 put down a line on the map separating arable and pastoral land using the natural vegetation as an indicator. This line has not always been respected by legislators, but subsequent events have shown its value as a rough method.

In Western Australia the situation was very different. Numerous coastal settlements failed to find much country which was useful in its virgin state for grazing or farming. In general, success was only achieved on the market garden scale by the use of far larger quantities of farmyard manure than could be obtained for broad-acre farming. Only at the end of the century when the need for superphosphate became more generally appreciated, could much progress be made. As already explained, the graziers' prospects were rather brighter when the Murchison District was opened. The nutritional quality of the herbage and shrubs was better; this area, however, is well inside the arid zone and the carrying capacity only one sheep to 30-50 acres (12-20 hectares). The districts farther north—the Ashburton, De Grey and Gascoyne—are no better. Under these circumstances, which forced themselves on the notice of the administration through the unhappy experiences of many would-be graziers, a generous attitude developed towards leaseholders and the acreages they were allotted.

In Queensland the pastoral surge flowed over areas which were merely a northern extension of those of New South Wales. In the southern sections some rain often falls in the winter, but over the State as a whole most of the rain falls in the summer. At first water a great problem, and although some belts of good pasturage occur others are less fertile. The higher temperatures made living conditions more arduous, and a large proportion of the land remained as grazing or pastoral leaseholds which were run by managers for absentee owners living in Sydney, Melbourne or Britain. The result was a long continued conflict between the State Parliament and the grazing interests. Revolutionary ideas of land ownership were common, and the political policy was to reduce the size of each grazing property as opportunity offered, either at the end of the term of a lease or for other alleged reasons. At times this conflict was strong enough to threaten the welfare of graziers, until sanity returned with the recognition that they provided a large part of the export and of the taxable income of the State.

The Northern Territory proved by far the most difficult area to develop. The earliest attempts were in 1824-1829 at Melville Island and Port Essington, where for years small military outposts were maintained. Ambitious schemes were made for the cultivation of tropical crops by settlers who were to come from various places. The schemes remained as schemes, because there was no evidence that the crops would grow. Pastoral occupation took place on the Queensland border in the 1860s but a scheme for settlement by a land company failed in 1866. At one stage an approach was made to the Government of Japan to send colonists. The basic fact is that none of these schemes, except pastoral occupation in certain localities was founded on an accurate knowledge of the soils or an efficient assessment of the climate and its irregularities.

The transfer of control of this territory from South Australia to the Commonwealth in 1908 eventually resulted in somewhat greater security of tenure for the grazing leaseholders, but apart from the cultivation of a few acres of peanuts on special soils, little progress in agriculture was made. In 1955 American capital came in to develop a large irrigation scheme near Darwin, but its sponsors soon found that the process was not as simple as they originally thought.

These few points from the administrative and political history of the various States are only of importance in this present chapter in so far as they show the factors responsible for the present position. Weaker administrations might have accepted principles which would have undermined all control of land use. Under such circumstances the pastoral industries would have gained complete dominance. On the other hand, it is undoubted that the policy of subdivision was at times carried too far; at times considerable financial injustice was done to individuals in regard to compensation for improvements when properties were resumed by the Crown for subdivision.

From 1860 onwards the various States were trying to deal with the problem of settling would-be farmers, as opposed to graziers, on the land. This matter became urgent after the gold rushes had brought a large population from overseas, many of whom, when they tired of searching for elusive gold, wanted to turn to farming as a way of life. In South Australia the idea of 'close settlement' for agriculture was present from the start. In Victoria, where the area of reasonably well-watered land suitable for grazing was greater, the problem was more acute because the graziers had early occupied so much of this area. Where they had not done so land was made available under various Acts during the 1860s, each of which successively made it easier for the settler, ending up with the promise of a free title to 600 acres if payments of one shilling per acre were made for the following 20 years. Even these easy terms were found to be unavailing, because the chief commodity the land would produce was wool, and the area a man could develop and farm would not at that stage carry enough sheep to give him a reasonable livelihood (300 sheep cutting 4 pounds of wool each at one shilling a pound would yield £60 gross income); there was no local market for meat except near the cities.

Rather unwillingly, the Land Administrations in all the States were gradually forced to realize that closer settlement on areas which were too small usually meant either no settlement at all or an impoverished countryside, or the gradual re-acquisition of the best of the subdivided blocks by the adjacent pastoralists. However, this did not at once deter parliaments from trying all sorts of schemes for putting people on the land—homestead blocks for men who would earn most of their living by other means, special schemes for forestry workers etc.—but very few met with any success. Some of this experimentation originated from the writings of European theorists, who were struck by the sad state of social development in the cities as a result of the industrial revolution; others had ideas of the idyllic existence which was supposed to have been characteristic of village life—and especially in England before the Acts of Enclosure changed the basic structure of agriculture.

The principle which ultimately evolved and was nearest to solving the problem was that of the 'home maintenance area'. Under it, subdivision should not proceed beyond farms of a size sufficient to give the landowner a return roughly comparable with the basic wage of the cities, provided that he farmed the land effectively. This concept was laid down by a Royal Commission after World War I as a basis for the readjustment of the size of the farms of soldier settlers. Naturally, it can only be logical during periods of stable prices for both the requisites and the products of the farm. In Victoria in 1928, an area sufficient to maintain 1,000 wool sheep was regarded as sufficient in the districts of good rainfall. This was certainly too small four years later, when the index of wool price had fallen from 126 to 64, while in 1950-1951, when the same index had risen to 1,098 it meant affluence. Five hundred kilometres farther north in New South Wales, the proper number of sheep on a home maintenance grazing property in the arid areas was set at 3,000 in the 1930s. This frequently required holdings of over 50,000 acres (20,000 hectares). Mere acreage figures mean little in describing the size of efficient farm units in the arid country, and even the figures for stocking capacity must vary with the location and special features of the district. The same authority which fixed 3,000 as the correct number of sheep for that district in the south-west of New South Wales, also fixed 1,500 in another grazing area where 3,000 acres (1,200 hectares) sufficed for a home maintenance area holding.

The decades of struggle between the administrations and those occupying or settling on the land have considerable interest. The success of those working on the land in getting a recognition of the need for reasonable acreages as a basis of land settlement has been remarkable. Possibly the fact that at most periods of Australian development—the 'depressions' of the 1890s and the 1930s excepted—it has been possible to find work in the cities, has meant that families have abandoned their blocks if unsuccessful. Possibly the somewhat stark conditions on farms, the periodic severe droughts of the unlovely townships prevented the settler in many districts from developing that attachment to his land which is characteristic of small-scale farmers in some other countries. Possibly also, the independent attitude towards life inherent in many migrants to Australia may have been significant. Some were gold-seekers, some left their country for their country's good, others were adventuresome spirits lured by stories of the freedom of the bush that were characteristic of many early writers about Australia. Whatever the reason, the problem of farms which are uneconomic because of their small size is not common in the arid and semi-arid zones of Australia, although it also occurs in some of the districts of better rainfall.

## LABOUR AND LIVING CONDITIONS (1788-1900)

During this period of primary occupation the relations between wage earners and employers on the farms gradually changed. During the early expansion, 1825-1850, the objective of every free man was the independent ownership of a flock, and the occupancy of a tract of land. Few wanted to work for wages when there was a chance of independence. The chief supply of labour was derived from the time-expired men of the convict population, or from those with tickets-of-leave, although a few free labourers arrived in the country, often in the service of migrant family groups from England. Practically every pastoralist needed workers; the runs were at first unfenced and the sheep had to be shepherded; buildings, sheep washes, yards, bridges and dams had to be constructed, and as occupancy gave way to settlement with security for capital investment, the need increased. During the 1840s attempts were made to recruit labour from China and the islands of the Pacific, but those few who came had no knowledge of sheep and were not prepared for the isolation of the shepherd's life in his bark hut in some remote part of the run.

Shearing at this stage was commonly carried out by the owners, with assistance from neighbours and anyone else who could be engaged. Transport to the ports involved long journeys over rough tracks with wagons drawn by bullocks, or faster but less dependable horses; later camels were imported for use in the arid regions and cartage contractors soon began to work from the coastal towns. Life was not easy, and crises were continuous.

The gold discoveries of the 1850s made matters worse, because many employees left their jobs and tried their luck at the diggings. However, gold attracted many migrants from overseas, and when their hopes of rapid wealth had proved groundless some were prepared to work on the land for wages. This period—1855 to 1890—saw steady developments in ringbarking trees and felling some of them, slashing the regrowth and the scrub, making fences from the cut trees whilst the construction of surface dams improved the facilities for watering. Houses and other buildings were improved.

Sheep scab was frequent and caused many losses, while blowfly attacks occurred in many seasons. For these maladies the use of dips became common, but the mixtures used were often based on hearsay of experience rather than on experimental demonstration.

The practice of shearing by itinerant shearers became general, but neither side showed much consideration for the other in the arguments which frequently arose. The shearers' quarters were often extremely rough, and the wages relatively low when the arduous nature of the work and the need to travel from shed to shed for months on end are considered. Conversely, the general trend of the price of wool was downwards, and the shearers themselves were often dissolute and undependable. The labour difficulties were worst in Queensland, where many stations were managed for absentee owners and conditions were more arduous than in some other parts. A general pastoral strike occurred in 1889, at a time when the pastoralists were becoming desperate owing to bad seasons and low prices. Although the shearers could scarcely claim to have 'won' the strike, its occurrence emphasized the need for regulation of the industry in regard to both wages and conditions.

## THE SITUATION IN THE 1890s

This decade is a convenient halting point in any survey of development of rural Australia, and especially of the more arid regions. Up to that time, the grazing industries were by far the most important factors in the use of land; they were now to face a major setback. They had made remarkable progress, despite numerous difficulties. The continent had been explored. In most areas, except the driest deserts, attempts had been made to use the land, and the barriers of the Western and Simpson's Deserts, and of the central semi-desert were recognized. The Western Desert had been crossed by stock in some seasons. Parts of the Kimberleys in the far north-west had been occupied, but many other attempts at using various regions of the country had not been so successful. The Victorians, who in 1864 moved sheep by boat to Camden Haven near Broome, with the idea of settling a large empty tract, met with disaster; their sheep died because for long periods the herbage was too low in nutritive qualities to maintain livestock. Many unsuccessful attempts were made to use land near Darwin. But these are only isolated instances of many cases of settlement failure due to the poor quality of various tracts of country, especially in coastal areas where the rainfall is moderately high.

During the general process of development in the occupied areas, individuals failed in hundreds owing to various catastrophes, among which droughts were the most frequent; others had bought properties at prices which were too high; others failed financially because the price they received for their wool fell faster than the prices they had to pay for essentials. At times governments took action without understanding its effects. Thus in 1859, after a run of good seasons the leases in the arid grazing areas of South Australia were reappraised. Despite protests, the 'anti-squatter' government raised the rents, public opinion being violently against the graziers. As a result, in four years 15,156 square miles (4 million hectares) of runs were abandoned. This was followed by a drought, and in a year 235,000 out of 270,000 sheep died [29, p. 254]. The life of the pastoralist was invariably arduous, and not always one of profit.

However, all these setbacks were trivial when compared with the catastrophe which began in 1891; during it the whole existence of the sheep industry was threatened and, consequently, the economic structure of Australia itself began to disintegrate. Costs had been rising, and many pastoralists had endeavoured to meet the fall in their incomes by increasing the number of sheep and cattle they carried. The recorded figure for the sheep population in 1891 is 106,421,068. In addition rabbits, originally liberated as food animals, increased enormously in numbers and began to exert a serious effect on the pasturage of grazing shrubs. Most people saw that they were doing damage to the herbage, but the importance of their selectivity in picking out the youngest leaves and shoots of plants was scarcely realized at that time. By the late 1880s they had spread in great numbers to the sparse grazing lands of the south-eastern arid and semi-arid regions.

This dual increase in grazing pressure—sheep plus rabbits—which had built up gradually, became of great significance in 1891, 1892 and 1893—all years of subnormal rainfall in the eastern half of the continent. To aggravate the position, the Australian average of prices for greasy wool fell to sixpence per pound in 1892 and 1895. Wool was Australia's chief export, so this alone would have meant financial stringency for the whole community. In addition a world-wide financial crisis developed, and naturally it affected countries such as Australia whose economic position was weak. Most of the banks in Australia suspended payment; many business houses became insolvent; credit was scarce and no money was available for restocking runs depleted by the drought, or for re-opening those which had been abandoned. These difficulties and the low prices affected the confidence of the wool industry, which was again shaken by a further run of droughty seasons in 1901-1902.

When recovery began in 1903 the sheep population was recorded as 53,675,210—about half the figure it had reached twelve years earlier (see Fig. 3). The losses were greatest in the more arid areas: Queensland flocks declined by 60 per cent; those of New South Wales and South Australia by 53 per cent and 35 per cent respectively. This was the end of the phase of simple pastoral exploitation. As Fig. 3 shows, recovery was gradual and subject to other droughts, e.g., 1914 and 1943-1944, but the arid areas have never carried as many sheep as in 1891. The concentration of sheep numbers has moved further toward the semi-arid and even the high rainfall country. The exception to this statement is Western Australia, which was relatively unaffected by the calamity which struck the eastern States in 1891. In that State a parallel collapse, again owing to drought, occurred in 1935-1937, and again subsequent events have shown a transfer of sheep population from the arid to the semi-arid regions.

Whilst the sheepmen were suffering these reverses in the 1890s, developments were taking place in four other directions which were important in the future of land use.

First was the steady development of wheat growing on the outer margin of the southern semi-arid zone. Cropping had been carried on for local requirements in small areas throughout the subhumid pastoral districts, although its greatest development was to the north of Adelaide, on flattish land not far from the seaboard, because from there the grain could be lifted by wagons to the ports and shipped cheaply to Melbourne, Sydney and Perth. With the opening of export markets, and with the construction of railways across the ranges to the plains beyond, large potential wheat districts in the semi-arid regions were opened. The possibility of attaining personal independence was attractive, and men were taking up land for development as wheat farms with avidity as soon as the railways had advanced near enough to make it reasonable. All through the 1870s and 1880s new districts were being opened. The acreage under wheat increased from 3.2 million (1.3 million hectares) in 1890-1891 to 6.2 million (2.5 million hectares) in 1904-1905.

Secondly, although experiments on refrigeration and especially on its installation in the holds of ships had been going on for years, it was not until the 1880s that they met with success, and it became practicable to export foods in the cold-stored or frozen condition. This opened new avenues for the export of farm products from Australia. Meat was one such commodity. The number of cattle increased markedly, especially in Queensland, where some localities were not satisfactory for sheep. The possibility of exporting mutton and lamb also led some sheep farmers to change their breeding policy, while others decided to transfer to meat breeds. These various changes produced one result of significance to the flockmasters in the sub-arid zone, in that they afforded them an increased opportunity to sell their surplus ewes to farmers in better rainfall country who would use them as mothers for fat lambs.

Refrigeration also gave the dairy industry a chance to develop on an export basis; although its expansion mainly took place in wetter districts, its early successes led Land Departments in some States to settle some sub-arid regions for dairying. This regrettable policy was adopted as a result of political pressures stimulated by popular clamour for more farms. At that stage in the development of the industry the average dairy farm required less land and less capital than other forms of land settlement, and so some areas which would have been more effective for fattening cattle were subdivided into dairy farms.

This period of the 1890's also saw the start of many primitive attempts at irrigation. The fallacy that water alone will transform a dry-land pasture into an efficient one for irrigation was widespread. In all these early attempts, even where lucerne was introduced, the basic failure was the inability to understand that most of the soils were poor and lacked the amount of nutrients essential for luxuriant growth of high quality plants.

These four ways were the beginning of the diversification and intensification of land use which characterized the next half-century. Thanks to these changes the economic balance of Australian rural production was improved. Further, in the course of those changes experience was gained which, with adaptation, has been applicable to parts of the arid zone.

## PROGRESS OF INTENSIFICATION (1900-1958)[1]

### IN THE MORE ARID AREAS (DESERT AND 'ARID')

As already noted, the sheep industry in these regions reached a peak in the 1890s and has never re-attained the flock population reached in 1891. The present distribution of sheep (Fig. 4) shows that in the zone of Desert Formations the total number carried is only about 7.5 million, which is 5 per cent of Australia's total, and of these nearly half are in Queensland. The map also shows that south of the Tropic the sheep concentration generally increases markedly as one moves across the arid zone towards the semi-arid, and is highest in the subhumid areas where the rainfall permits active plant growth for nine or more months in the year—although the coastal zones of high rainfall carry few sheep owing to worms and foot-rot, and also because this land, where cleared, has been mainly settled with dairy farms. In the hotter areas of the north the average temperatures are higher and sheep do not breed effectively.

Cattle are more mobile than sheep, and it is possible to move them about from one district to another in accordance with the feed position. The cattle areas suffered less in the drought of the nineties, and moreover cattlemen were then extremely hopeful

1. For details see [38].

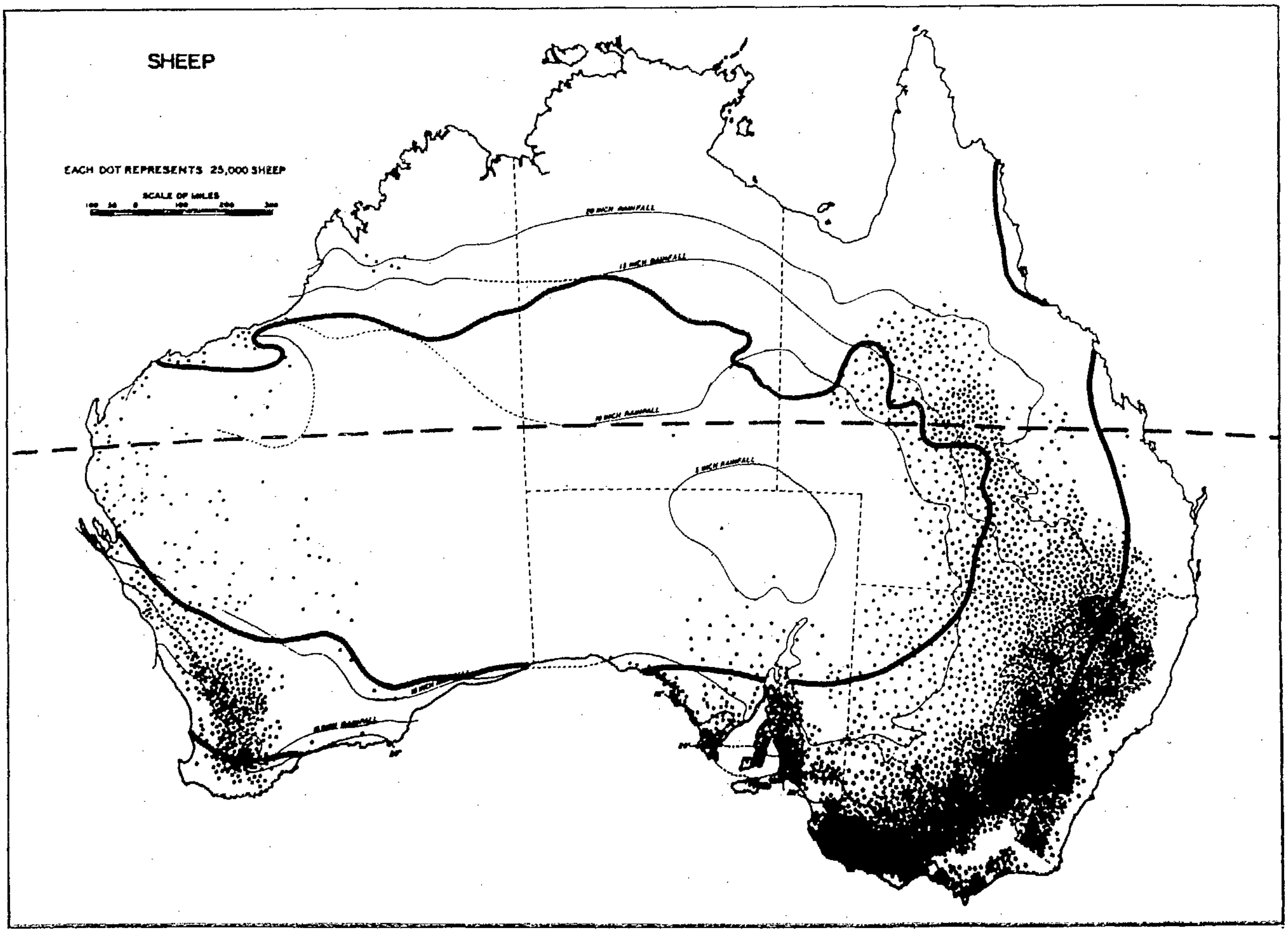



FIG. 4. Present distribution of sheep in Australia.

of their ability to export, thanks to refrigeration. The drought of 1901-1905 was more serious, but in these districts optimism was a marked feature at the end of World War I. Disillusionment soon came when the far greater capacity of the Argentine to produce beef cattle of 'chiller quality' was recognized. The industry has, however, made progress in many ways.

In the desert areas the vegetation varies widely according to the soil type. The rainfall is too low and too uncertain in its incidence for cropping to be a reasonable risk. The transition from desert to arid areas is gradual; the shrubs and trees become more frequent, but soil type is important. Over all this country any heavy rainstorm brings up a great wealth of short-lived, annual plants which are known to the grazier as 'herbage'. They belong to many species, and provide the livestock with abundant food while they last. The duration of these surges of growth varies. One inch of rain during the cooler season of the year will produce more growth than two inches in the hotter months. The animals live on the herbage whilst it is green, and also when it has dried off. Even if the storm is insufficient to let it grow to maturity, the dried up leaves are usually high in nutritive quality.

The mainstay of the grazing industries is, however, the perennial plants of which there are various types. Among the grasses in some districts spinifex and tussocks are dominant. These are harsh spiky plants when mature, but they produce green leaves after rain. Some of the species afford better grazing than others, and attempts are being made to select these. In many districts it is customary to burn the old tussocks. The Mitchell grasses (*Ashebla* spp) are characteristic of heavier soils. They also have a tussock-like way of growth, and generally are not eaten by stock until all the herbage has gone. At this stage they represent a reserve of material on which animals will continue to graze through a dry season although they are low in nutritive value. Flinders (*Iseilema memboanacea*) and many other grasses occur in appropriate habitats, but none of them has high enough protein content in the mature dry state to maintain animals in better than 'store' condition.

The shrubs are varied in character. The saltbushes occur chiefly in low-lying spots on soils which may have a considerable saline content. They have the special metabolism of succulents which enables them to endure long periods without rain. They store water in their leaves, and are in this way a partial reserve against drought, but if grazed down and denuded of their leaves they can be killed, or so reduced as to require a long time to recover. More important are the woody shrubs of which mulga (*Acacia aneura*) is the most important in most districts. These can grow to small trees; the stock graze the lower branches but the upper remain as a reserve. In good seasons the grazier does not touch them because the ground vegetation provides enough for his animals, but when this is reduced to small proportions the shrubs are either lopped or bulldozed and the leaves form food of fairly high quality for the animals. The maintenance and replenishment of this reserve of grazing material is important; when rabbits are abundant they eat the seedlings and prevent new shrubs from developing. The new plants are not safe from their depredations until they have been established for several years.

Apart from the attacks of the rabbit the chances of re-establishment of any shrub are poor unless it happens to start growth near the beginning of a run of favourable seasons, which may occur only once in a decade, or even less frequently. The same is true of the trees which are customarily found along the banks of the dry creeks, many of which only carry water at long intervals. In recent decades the regeneration of vegetation in these semi-desert zones has been studied in some detail [26, 27].

In many of these regions the rainfall is very seasonal in character and remarkably uncertain in regard to the month in which it starts. In the northern part the rains may start in September, but in other years they may begin as late as December or January, or they may fail altogether. This uncertainty as regards amount and time makes any attempt at cropping a risky procedure, especially as sowing on dry ground is usually hazardous, and on the other hand the rains are often so heavy that ordinary implements cannot be used for some weeks. This means that grain crops can seldom be grown, but forage crops are occasionally possible. These can be used as a bulk reserve for livestock against drought, but graziers find it more economic to move their livestock away from a drought-stricken district. The difficulty occurs when the whole country is in drought. At such times livestock losses are high. The need to keep this risk within reasonable limits necessitates very light stocking rates per hectare.

In these districts the nutritional life of the animal consists of a sequence of cycles. When the pasturage is good after the rains have come, the young animals grow rapidly and all types put on condition; they may become really fat in a good year. As the herbage dries up and its nutritive value diminishes they stop growing, lose condition and end up as 'stores'. If the dry season is unduly long they may even become emaciated, and deaths occur from various disorders associated with a falling nutritional plane and unduly fibrous fodder. When the season next 'breaks' deaths are frequent for a week or two until the animals adjust themselves to the improved condition, and then the cycle is repeated. In the areas more distant from the coast the chances of getting the stock away fat are poor. The function of these districts is to provide stores for areas where the pastures are of higher quality and have a longer season.

Unfortunately the areas of good fattening country near the coast are limited, and so far it has proved impossible to eradicate the cattle tick from them. One special fattening area is the 'channel country' of south-west Queensland. Here, in some seasons, the Cooper, Diamantina and Georgina rivers have heavy rains on the northern parts of their watersheds and come down in floods which spread over vast areas of the country surrounding their lower courses. A week or so later an enormous growth of nutritious herbage is available for grazing, and can fatten large herds of cattle. These floods occur about two years in every five, in the other three there may be a partial flood or none at all. Cattle are brought down from the drier areas of the north as soon as the rainfall on the watersheds is sufficient to make a flood likely.

This nomadic method of developing a grazing system has been widely adopted by a few graziers who have had control of a sufficiently wide range of properties, but it cannot be successful as a general system. Socially it is disastrous, and as a rule it can only be run by buying up cheaply the improvements in buildings, fences, etc. which are the ruins of the investment made by others who were less fortunate.

Although the cattle and sheep industries have not made much progress in these desert and semi-desert areas (Figs. 4 and 5), the improvement in social developments has been most marked. The possibility of conversing with specific centres within range of the pedal-wireless transmitters, the much publicised flying doctor service and its hospital centres, the broadcasting service with its news and 'classroom of the air' session for the children have done much to mitigate the problems of isolation. The kerosene-powered refrigerator, and the small-scale lighting and power generators have made modern household facilities possible. Some of the roads are

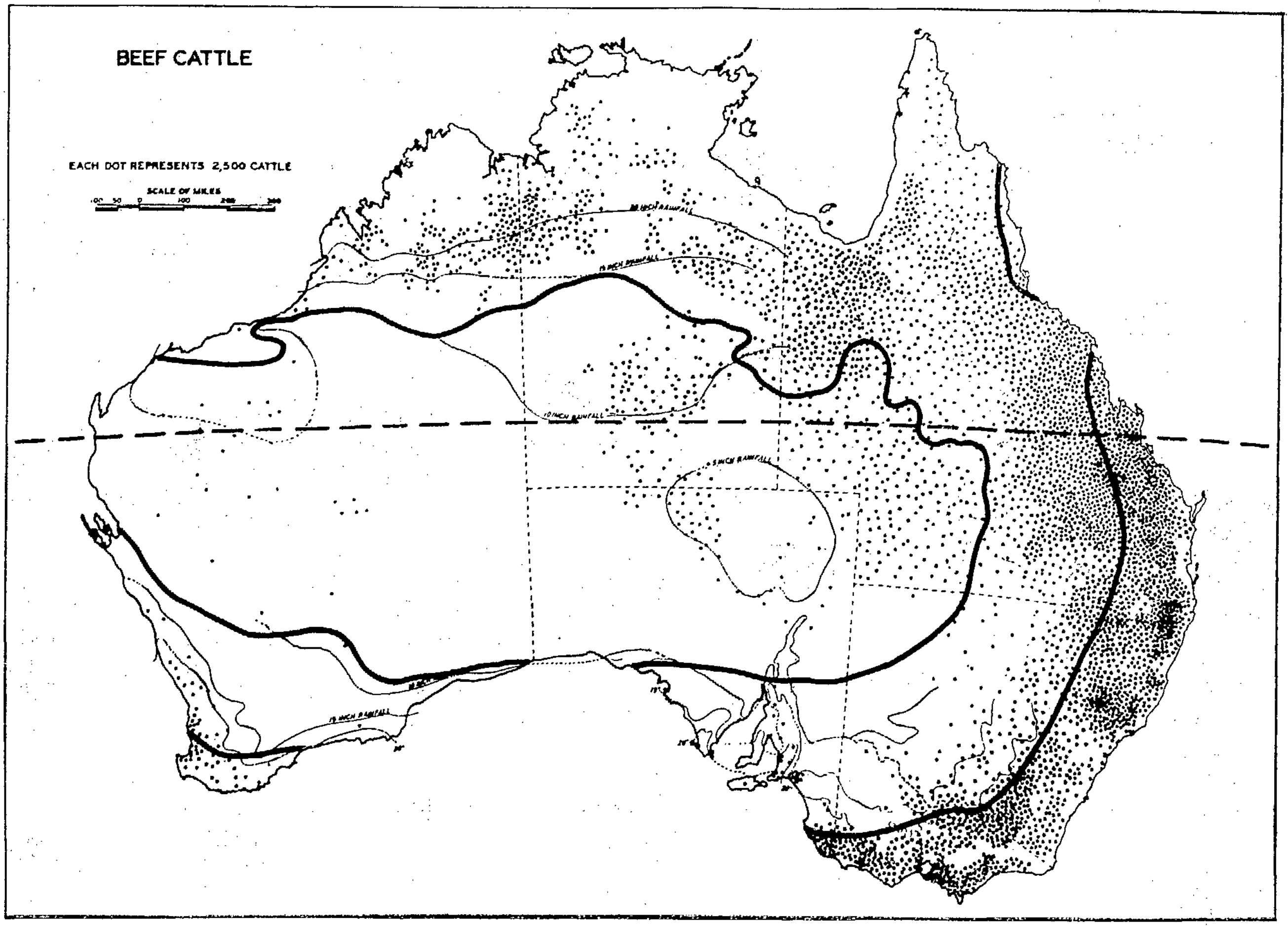



Fig. 5. Present distribution of beef cattle in Australia.

now passable throughout the year except after unusually heavy rains.

Many owners took advantage of their increased returns shortly after World War II to improve and re-equip the houses and also the living quarters for their workers. On such stations it is now reasonable for some or all of the married operatives to live and raise families. These developments are significant, but they represent a large capital investment. They are more easily paid for and maintained by large properties, because their cost can be spread over larger turn-off of stock. On the other hand, some owners, whether individuals or companies, are more concerned with profits than development, and are not prepared to spend much on amenities for the stations. In the past the Queensland Government has endeavoured to subdivide large properties whenever their leases expire. Some of the holdings still are very large and somewhat difficult to manage but, clearly, size should not be the sole reason for subdivision; under these arid conditions stock cannot be effectively run in small units even if they employ a group of workers on each. Each case deserves individual consideration—a principle that is not easily applied by a public department of the State under a democratic system which leaves it open to criticism that is not always well informed as to the real nature of the problem.

## IN THE SUB-ARID AREAS

### *Cropping and the evolution of mixed farming*

As already mentioned, men were ready to take up land in the south with the intention of developing wheat farms as soon as cheap transport to the seaboard was available. Their problems were both varied and numerous. Trees and stumps or dense scrub cluttered the land; yields were seldom high, and methods had to be devised to enable each man to deal with a large area if he was to earn a reasonable living.

The land problem was fairly simple because, although some early blocks were only 160 acres (64 hectares) in extent, the authorities soon increased the allotment to 320 (129 hectares) and then 640 acres (259 hectares) and to larger tracts in the drier areas. Mechanically-minded farmers were continually devising new machines all through the nineteenth century. Tree pullers, stump pump attachments for machinery, rollers with side draught to beat down the scrub, heavy timber 'smoogers' to grade the uneven land, the stripper in the 1840s and the harvester in the 1890s to deal with harvesting large areas. All gradually made the grain farmer's task the more manageable. In the meantime the horse teams increased in size until ten working abreast was a common feature.

However, the yields per acre were depressingly small in many seasons. The Australian average yield exceeded 10 bushels per acre only once in the period 1890 to 1905. This was commented on by Crookes [8]: 'Australasia, as a potential contributor to the world's supply of wheat, affords another fertile field for speculation. . . . Queensland has never had more than 150,000 acres under cultivation. For the second season in succession the wheat crop last year was destroyed over large areas in Victoria; and in South Australia the harvest averaged no more than about $3\frac{3}{4}$ bushels per acre.'

Improvement came through the efforts of Farrer and other plant breeders, who produced varieties with a growing period which corresponded to the distribution of the normal rainfall of the wheat-growing districts of that time—8 months (April to December). They bred wheats which could be stripped readily by the new machinery. More important still to these southern wheat-growers was the increased use of superphosphate, which began in South Australia in the 1890s. In northern New South Wales and Queensland speed of work is essential, and this extension of the wheat belt had to wait for the tractor before it could be really effective. The combined seed and fertilizer drill, which 'placed' the chemical in the soil where the first developing roots would grow, was useful in that it economized in fertilizer costs.

By World War I the industry was progressing fast. The high prices for wheat in the war years put many men on their feet financially; they also encouraged governments of every mainland State to organize more settlements for wheat growing by opening new areas. The new settlers were financed by government loans, much of the money being raised in London on the traditional plan under which Britain expanded farm production in her colonies and other countries and which, incidentally, provided large supplies of basic commodities for world markets. In the southern States most of these new settlements were inside the arid zone, or on land which in the average year only had 5 or 6 months with enough rain to meet the requirements of mesophytic annual plants such as wheat. This extension of settlement was, therefore, bound to be speculative, especially when the variability of the rainfall is 25 per cent [38].

Some of these new farms got their water from subartesian bores, but many were supplied through channelled or piped supplies. The Wimmera-Mallee Stock and Domestic Supply Scheme in Victoria has 8,000 miles (12,870 km.) of open earth channels but is lavish in its use of water; many of the other schemes are piped, and more economical.

Few of the new farmers had any sheep at the start. Most of them cropped their land annually while it was being cleared, and many continued to do so. The system of fallowing was introduced and was common by 1920. Some of the new districts had dry seasons in the later 1920s. Meantime, two bumper harvests in North America produced a world surplus of exportable grain, which depressed prices to levels ruinous to many growers. The low price did not stimulate world demand markedly, and the surplus remained till removed by a drought in North America in 1934 and 1935. But even this was only temporary relief, and a surplus was again dominating prices in 1938.

This depression brought social disaster to farming and especially to the newer settlements in the country with a 5-6-month growing-period. Some areas were evacuated or redesigned into large grazing farms. A Royal Commission was set up by the Australian Commonwealth Government [31]. It recommended the establishment of a subsidy financed from an excise on flour used in Australia for human consumption. This was on a sliding scale, and the money was paid to all wheat growers as a bounty. The Commission suggested that some wheat farms should cease production, that debt adjustment was necessary on many others, and that mixed farming with sheep should be encouraged.

The war years are unimportant in the present context. The postwar world wheat surplus has been further aggravated by a desire for self-sufficiency in foodstuffs in many European countries which, in some cases, has turned importers into exporters. Meanwhile, the modification of farming in the Australian wheat belt continues (Fig. 6). The first change is the increase in the number of sheep on wheat farms; they now constitute about a third of the total Australian sheep population.

In some wheat districts it became apparent that continued cropping, even on a crop-fallow basis, led to changes in the physical condition of the soils, which became tougher and less tractable, so that they could only be cultivated successfully over a narrow range of moisture content. Cropping them became difficult, especially as rain periods are few in many years. Experiments by Departments of

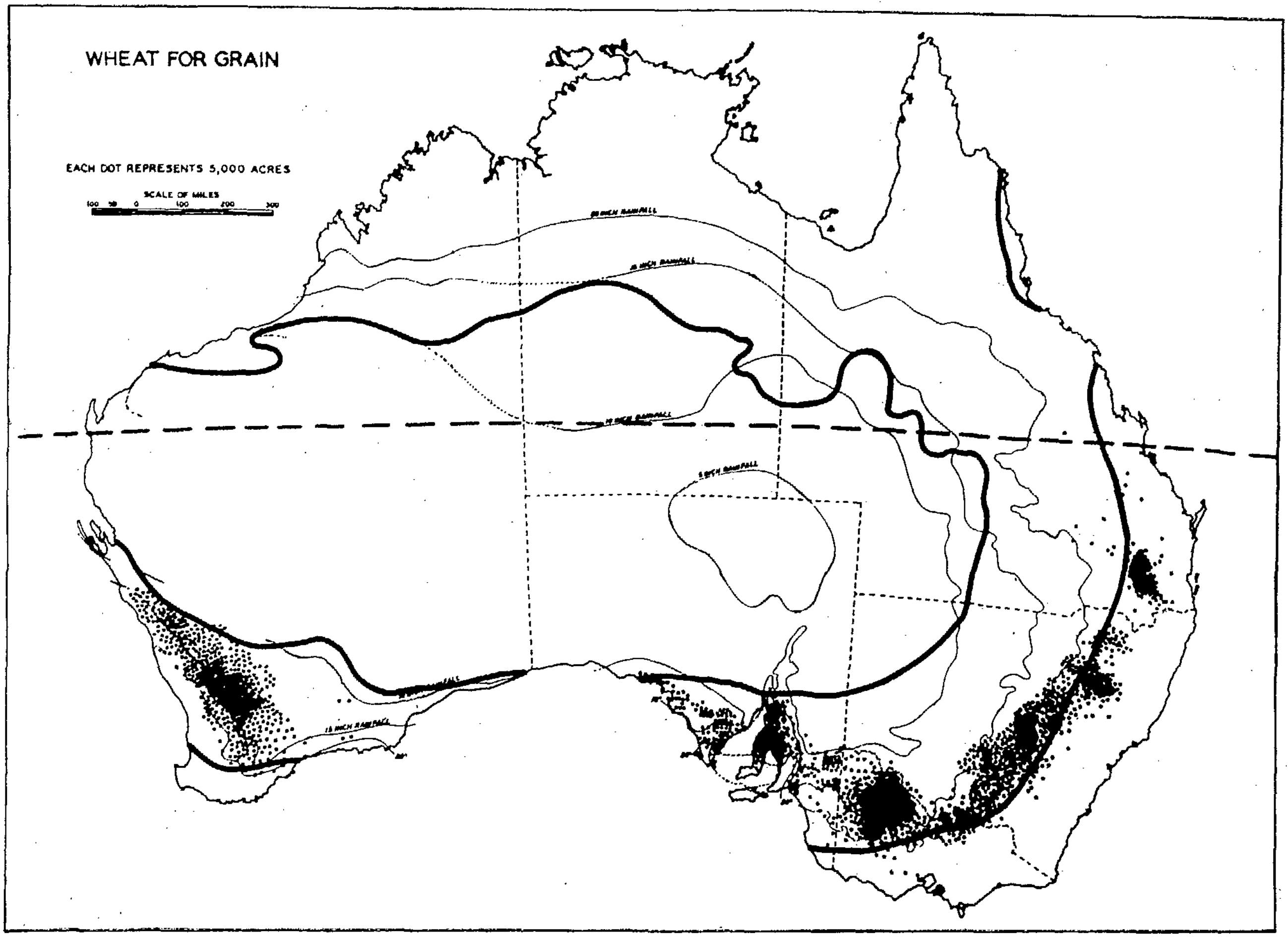



FIG. 6. Distribution of wheat acreage in Australia.

Agriculture, and the experience of farmers in many districts, showed that this deterioration could be reversed if the land were treated with superphosphate and used for growing an annual pasturage of clovers and improved grasses for a period of years. Virtually, they had rediscovered the process of ley farming under very special conditions. This practice is spreading steadily, but it requires the use of leguminous species with shorter and shorter life cycles for its successful adoption in the districts with shorter periods suitable for plant growth. By 1958 the 6-month growing-period line is about as far as the practice could go with a margin of safety. The additional number of sheep which can be carried on farms where the rotation of 4 years' ley to 3 years' cropping is adopted is considerable.

Tractors were essential for success in the wheat districts of northern New South Wales and Queensland where the wheat soils are deep and fertile, and the grain is grown as a winter crop mostly on the rain of the preceding summer. The tractor's special merit lies in the speed with which it can suppress weed growth during the wet period, and the faster rate at which it can enable the header to harvest the crop when compared with a horse team however expertly handled. Unless the weeds are controlled they will use up the soil moisture and decrease the available nutrients in the soil. Unless the harvest is taken off quickly the 'break' of the season in the early summer may prevent it from being garnered in good condition, or even at all.

Probably the general adoption of tractors on all Australian wheat farms has increased the average yield by 10-15 per cent; the ley-farming system will have effected an even greater increase when it is generally adopted. These improvements will be necessary to enable farmers to meet their rising costs. The whole situation of crop farming in the arid zone is fairly static as long as the present ratio of the farmer's returns to the cost of his supplies remains constant.

Conditions of life on the wheat farms have greatly improved since 1948 when social conditions on them was reviewed in detail by Holt [15], and most districts have regained some of the financial resiliency they had before the depression. If the world needed more cereals and were prepared to pay a rather higher price for its supplies, then wheat areas could be expanded by taking more risks in the 5-month rainfall belt. Alternatively, some areas in the moister regions could be brought into production.

Erosion takes a double form in the wheat zone. On sandy soils in the drier country a considerable amount of damage has been done. Remedial measures such as the planting of rye, less stirring of the fallows, and strip cropping have generally been successful, but the menace still exists, and careless farmers can soon initiate another erosion cycle, especially in rainless years. On the heavier soils on the sloping land which is common in some parts of the New South Wales wheat zone, gullying and sheet erosion have assumed alarming proportions, and many new precautions have had to be taken. In Queensland, where summer rain is the rule, some of the deep black soils have suffered severely. Less fertile types are not usually cropped.

*Pasture improvement and soil fertilization*

Modern pasture techniques in temperate humid districts made their first advance during the 1920s in New Zealand and Britain, owing to the stimulating research of the Aberystwyth School. The emphasis it laid on four concise points clarified thought. First, the need to find the species suited to the environment. Secondly, to pick out within the species those strains which would give the best results. Thirdly, to ensure that the soils were maintained at an adequate level of fertility in all respects. Finally, to work out a system of management which would stabilize the pasture complex at a high level of productivity for the required number of seasons.

Previously attempts at increasing pasture productivity were entirely haphazard, and even today it would be bold to claim that reform is complete. The early method consisted of introducing from other countries plants which rather casual inspection suggested might be suitable for some Australian districts. Occasionally success was achieved. Various pasture species from Britain suited southern Victoria and Tasmania. *Paspalum dilatatum* was very successful on the river alluvia of New South Wales. Kikuyu (*Pennisetum cladestinum*) and Rhodesgrass (*Chloris gayana*) suited some Queensland areas. Sometimes well-intentioned introductions were disastrous, e.g., the prickly pear *Opuntia inermis*, which overran many millions of acres and became a pest. Its ultimate control required extensive investigations which showed that the insect *Cactoblastis cactorum* would reduce it to manageable proportions. The introduction of *Argostemma calendulaceum* by Baron von Muller because it looked like a fast-growing bulky grazing plant did little credit to the Baron's capacity to think in terms of tons per acre. Many other introductions were the source of some of the bad weed problems of today. As a result rigorous quarantine measures have been adopted; these are a Commonwealth matter but authority is frequently delegated to State officials.

Among the introductions made by southern pastoralists was *Trifolium subterraneum* from the Mediterranean region, where the climate limits mesophytic growth to an annual period of 7-9 months. In a few places now recognized as spots with a highly fertile soil, this species established itself effectively. When, during the 1920s, the practice of top-dressing with superphosphate was widely tried, this species spread rapidly in areas with 8-9 months of effective rainfall. Numerous varieties were recognized; some of these had longer and some shorter growing periods. The latter were valuable down to the 7-month growing-period zone. In districts of higher aridity other species of legume have to be found, and the annual species of *Medicago* are more successful. The zone of *M. tribuloides* can be extended to the 6-month line effectively.

This evolution of 'sub' or subterranean clover as the key plant in a revolution of grazing practice is due to its capacity to raise the nitrogen content of soils by the aid of the *rhizobia* on its roots. This done, the soil can begin to support other grazing plants of high capacity. The Australian economy is normally unable to consider buying nitrogenous fertilizers for pasture or cereal crops, and it is fortunate that the bacteria replace them so well under these conditions in the southern States.

On the grass side, the discovery of Wimmera Rye Grass—a chance hybrid—was of great value; while some of the local semi-aestivating strains of *Lolium perenne* are helpful; but no non-aestivating perennial or broadleaved grass can withstand the effects of three months of high temperature drought. The aestivating *Phalaris tuberosa* is spreading steadily.

No pasture plant can produce an abundance of high quality fodder unless the soil contains the appropriate nutrients. Perhaps South Australia was fortunate in that the most frequent deficiency was phosphorus, and that superphosphate was readily available. This one fertilizer, which contains calcium and sulphur as well as phosphorus, was able to remedy deficiencies in soils in which any (or all) of these elements were lacking. Its 'shotgun' nature improved its value as a primary fertilizer.

*Trace element discoveries*

In some areas with rainfall suitable for the development of the process described above, the excepted results were not achieved and it became clear that the soils were deficient in other elements. Some New Zealand work suggested a lack of cobalt, and both in Western Australia and South Australia research revealed that small quantities of copper, zinc and molybdenum were necessary additions to the superphosphate if the clover were to be established luxuriantly, whilst extra cobalt was sometimes necessary if stock were to be healthy. As a result of much experience and experimentation wide areas in which these deficiencies occur have been delineated, mainly in poor soils on the foothills of the ranges or on sandy soils especially near the coasts. Consequently, considerable areas of land previously regarded as unhealthy or valueless have been brought into practical use. The cost of removing the original vegetation, ameliorating the soil and developing the farms is high, and so far, the annual cost of maintaining the fertility is somewhat uncertain, but when the developmental cost can be used as a deduction from gross income for taxation purposes the enterprise is attractive, and may be a sound long-term investment. It is not so advantageous as a means of enabling men without capital to become independent farmers, because so much of the developmental work requires big machinery and the expenditure of large sums on fertilizers and materials, consequently it cannot easily be replaced by long years of toil and frugal living. The latter was the basis on which earlier generations cleared forested areas on good soils which required less chemical treatment.

Although most of the districts in which these developments are taking place are in regions where the climate is usually arid for only three months or less, similar responses may be expected on poor soils in some of the drier regions. The widespread interest in the matter ensures that further investigations will be made, although, as the average rainfall diminishes its variability always increases and is automatically coupled with an increased economic risk. Such areas are consequently less attractive as an investment. In all these matters the ultimate factor is the extent to which the world needs the products which can be produced from these lands, and the price it is prepared to pay for them.

### *Pasture improvement in areas with spring-summer rainfall*

The progressive development which has been described in the southern areas where the rainfall has an autumn-winter-spring incidence has been impressive, and has resulted in the trebling of the stock-carrying capacity on many farms. In the northern areas with higher summer rainfall—the limits of which may roughly be set as 33° S. latitude in the eastern half and 25° S. in the western—progress has been less spectacular. The starting point was farther back, because the modern ideas of productive pasture and its correct management have not yet been applied with complete success in any tropical or subtropical area, and so there was no long-term experience overseas on which Australia could draw. In particular, no wholly satisfactory legume has been found to take the place which subterranean clover occupies in the southern scheme.

The relations between the plant's water loss, its root development and the fertility and structure of the soil require analysis if the plant's capacity to maintain itself under dry conditions is to be understood [3]. The study of pasture problems in these regions is now being pushed ahead vigorously. It is already clear that in some districts a wide range of soil deficiencies exists. The fact that in the past the only areas used for cropping in these rainfall regions have been those with exceptionally fertile soils is not helpful, because as these usually failed to respond to fertilizers (sugar lands excepted) many farmers and others assumed that the pasture problem would be as simple over the wider range of grazing land. It is practicable on certain deep soils to grow wheat as a winter crop, mainly on the water conserved in the soils from the preceding summer, provided weeds are controlled and the surface soil stirred to avoid deep cracks. But on other soils where the root range is shallower the result would be quite different.

Of the summer crops in this northern sub-arid region maize is usually disappointing because its broad leaf surfaces are unable to withstand the desiccating power of the fierce winds that at times sweep across from the interior. Sorghums can be grown more easily, and their production would expand rapidly if a satisfactory export market were available. As animal foodstuffs they have not yet been widely adopted, because the export market for pig-meats has diminished. Skerman [34] has analysed the potent climatic factors and their influence on crops for various stations in Queensland. His analysis reveals that the south-eastern part of that State is relatively superior in this respect to other sub-arid and arid parts.

### *Irrigation*

The attempts to use water to increase productivity in dry times began with small private schemes. Some of these were so successful that Victorian farmers in areas near the Murray were attracted by the idea of collective action, hoping to avoid in this way the effects of the droughts which periodically upset their production. District schemes were started in the 1880s in several districts but they soon ran into difficulties. First, because those who planned the schemes did not understand that the native pasture plants are attuned to dry summers and when irrigated do not give enough extra growth to pay for the cost, nor did they appreciate that irrigation is often a difficult art and nearly always requires land drainage. Secondly, the farmers did not understand that plants cannot produce larger amounts of nutritious material without corresponding increases in the amount of plant nutrients available to their roots, and that only the richest soils contain these materials in abundance. Thirdly, some summers had good rainfall and the landowners were not prepared to pay their water rates when they did not use irrigation water.

The schemes failed and the Victorian Government took them over. In its Water Acts of 1902-1905 it resumed the ownership not only of the water, but of the beds and banks of all streams in the State. In this it removed at one stroke any question of riparian disputes, and deprived the legal fraternity of a large potential source of income.

The States went steadily ahead with their irrigation schemes, Victoria in the lead because the Goulburn River is one of the most reliable in the continent. After Federation in 1901, the Commonwealth and the three interested States set up a joint commission for the control of the waters of the Murray. This body has erected weirs, locks and barrages down the length of the river, starting from the Hume Weir which impounds 1.25 million acre-feet (15.5 million hectare-centimetre) near Albury, and finishing with the locks on the river mouth at Goolwa.

The present position is that completed storages in all States have a capacity of 7.2 million acre-feet, but some of these are more concerned with stock and domestic supplies in rural areas than with irrigation, although all are for the sub-arid and arid zones. The figure will be increased considerably when certain works under construction are completed, notably the Snowy Mountains Hydroelectric Scheme. When assessing these figures it is necessary to remember that some of the storages are not filled every year, so the out-turn may not equal the total capacity. The actual areas irrigated at present are of the order of 1.75 million acres (700,000 hectares) of which two-thirds is pastureland, some used for dairy farms, other for stock fattening. Large areas are under orchards or vineyards, and market gardening is locally important. The dried and canned fruit industries, both of which are on an export basis, are very largely based on irrigated culture.

Some of the water is used extravagantly, and in time the salinity of the drainage water will fall low enough to use some of it again, but even when these savings have been made the volume available will be small when compared with the enormous volumes conserved in India and other countries. Already in Western Australia all streams of any size south of the Tropic have been impounded. South Australia may be able to irrigate acreages by pumping water from near the mouth of the Murray when the salinity has fallen further. Victoria has used all its rivers except those with a short flow to the sea. In New South Wales the westward-flowing streams have rather small catchments, and flows which vary greatly from year to year. Those with eastward courses run through steep country until they reach the narrow coastal strip. In Queensland the schemes so far developed have been small and local, but a big project on the Burdekin is under discussion. At this stage in the world's economic history it is not quite clear which crops are worthy of expansion. One forecast seems safe, namely, that as time goes on more and more of the Australian acreage of special crops such as tobacco, linseed, etc., will be irrigated, because the costs of irrigation are less than the losses caused through partial droughts. In the meantime, more irrigated pastures will reduce the stock losses which afflicted the meat and wool industries in the past.

The total volume of irrigation water which can be consumed is so small compared with the needs imposed by the climate, that the question of where the water should be used is significant. The most economical method is to store the water in the deep valleys of the ranges, whenever such are available, and use it in the sub-arid areas. Under existing conditions there can be no serious proposal to convey it as far inland as the desert (see Fig. 1) because the losses due to evaporation would be high and, also, abundant land is available in the sub-arid regions.

During the last quarter-century many investigations have been carried out on irrigation problems at various research centres. Most of the losses due to faulty irrigation in past decades can now be retrieved—at a cost. In future, it should be practicable to avoid mistakes if engineers and other planners take the trouble to realize the importance of soil structure and the factors which control it. This does not mean that every type of soil can be irrigated easily, or even successfully, and political issues have sometimes forced unnecessary risks. The general position in Australia of irrigation and its potential in 1946 was discussed in a Report of the Rural Reconstruction Commission [2].

## POSSIBLE FUTURE DEVELOPMENTS

### GENERAL

Before the second world war the arid zones of the continent and the sub-arid zones of the north were remote and difficult from every point of view. Economically the land industries of these parts were a somewhat doubtful asset. Much capital had been spent on them and a great deal of it lost. The life these areas offered to the pastoralists was hard, and the chances weighted against the man with limited resources.

During the war many Australian Servicemen lived for months in these regions. A few roads were built, other tracks improved, many aerodromes were constructed and flying became an everyday means of communication. There was much talk about the food supplies of the world and the permanent shortages which some people expected. After the war the British Government sent a committee to discuss the whole question of meat production in Australia. It also came to an agreement with the Queensland Government to try a scheme for producing sorghum and pigs in the ranges behind Rockhampton.

These varied forces influenced Australian opinion to take more interest in these somewhat difficult regions, and as the findings of the previous twenty years of scientific research were beginning to produce very practical results in the less arid parts of the southern half of the continent, numerous investigations of varied types were started in the north as soon as the necessary research stations and equipment could be obtained and, more difficult, the appropriate personnel recruited. Agricultural Departments in the States have combined with the CSIRO (Commonwealth Scientific and Industrial Research Organization) to further these researches, and at times universities have played a part in the programme. Many of the first results of these efforts are now appearing, and the series of short papers presented by Australian workers to the Canberra Symposium on Climatology and Microclimatology is indicative both of the lines of approach to the problems and of some of the results so far gleaned [4, 5, 6, 9, 14]. To those who have long been interested in the problems of land use, the focus of attention on the day-to-day and hour-to-hour relationships of the plants and animals to their environment is extremely refreshing.

Annual and monthly averages of daily climatic factors are valuable in the general way, but it is the period of a few hours of excessive temperature combined with low humidity which kills the seedling or spoils the pollen or stigma at the flowering stage. Furthermore, a difference of a few feet in altitude may, through its influence on frost liability, entirely ruin the chance of ripening grain over considerable areas of certain soil types, or, in irrigation areas, the development of flowering shoots in vines or leaves in citrus trees. These slight variations from the means or the expected range of climatic constants have in the past been the causes of the failure of many enterprises. The estimation of their frequencies and their probable effects should be an essential precursor to any fresh attempt at intensifying land use. In arid regions the odds are generally against the farmer. The courage of new investment of money and sweat in an enterprise which has the microclimatic odds against it may be magnificent, like the Charge of the Light Brigade at Balaclava, but it does little in forwarding man's progress in the war against the desert.

## PLANT PROBLEMS AND INVESTIGATIONS

The broad climatic features of the continent and their effect on vegetational groupings have been appreciated for many years. Griffith Taylor [36] noted the inverted similarity to North Africa which Emberger [11] has extended. Prescott in 1931 produced vegetational and soil maps of the continent [24]. In 1934 the Council for Scientific and Industrial Research (CSIR)[1] published a pasture map [20], and numerous other workers (e.g. Moule [22]) have provided local information. But the first systematic attempt to investigate soils and plants on the grand scale in northern Australia began with the establishment of the Land Research Section of CSIRO in 1946. Christian [4] has briefly reviewed the type of work done in its regional surveys, and the relationships of ecoclimatic factors to the welfare of plants at specific stages of development. This approach has been applied to a consideration of certain communities under grazing conditions by Christian and Slatyer [6] where the microclimatic effects of overgrazing a vegetation unit of *Acacia aneura*, which is common in many areas, are analysed. In that paper the comparison is made between a crop and the native vegetation in the following sentences: 'It will be observed that the rate of evapotranspiration and hence of soil moisture depletion was much greater in the case of annual crop species. It should be noted, however, that even in its restricted growing period the crop species produced ten times the total dry matter of the native perennial pasture.'

The problem of the grazier in arid areas in the past was to decide how intensively he should stock each paddock in order to avoid degradation of the pasturage. Today, the further problem is how far he can increase the out-turn of his property by getting an increase similar to that referred to in the quotation, in such a way that reserves of fodder can be stored against the annual dry season and the periodical drought.

Thoughtful graziers who have studied the growth of their sheep or cattle admit that the animal's growth is a series of jerky progressions. During and shortly after each rainy season the weight of the individual animal increases, but some of that gain is lost in the following 'dry', and especially towards the end of it, because the material remaining on the pastures is so low in protein. When the rains fail in any year, the grazier usually gets rid of the less important of his animals, either by selling them or buying agistment elsewhere; if these methods are insufficient, the females are not mated and the males take their chance on the less valuable pasturage. Sometimes fodder is bought in for stud sheep, but for the more distant stations this is expensive. The economics of this purchase are well understood, except that no one knows how long the drought will last. It is scarcely surprising that stock numbers fluctuate widely over the years, especially on the more distant stations. Many men have been broken financially through trying to hold

1. This body was subsequently reorganized as the Commonwealth Scientific and Industrial Research Organization (CSIRO).

on too long; a smaller number have made fortunes by buying in at the subsequent low prices and then being favoured by some chance of the weather. The problem is a dual one—first of raising the nutritional value of the dried-up fodder, and secondly, of providing reserves.

The former might be assisted if some leguminous plant could be found which would grow in the climate, and which might be harvested before ripening and then its stubbles grazed. An alternative method which has had success under similar conditions in South Africa is to spray the dried material on the paddocks with a mixture of urea (or other fertilizer with an ammoniacal base) and molasses, and then let the cattle graze the area. Under this method the bacteria in the animal's rumen will build up simple proteins, which will subsequently be absorbable. This is probably the most promising method for combating the annual dry season; it may also help with the drought problem if roughage can be conserved. But it has not yet passed beyond the experimental stage—in any case the value of the method depends on the prices of urea and molasses on the one hand, and on the final value of the beast on the other.

The question of conservation is a vexed one. The surface of the ground is usually too uneven for the direct use of close-cutting machinery such as that used in humid temperate regions. The natural vegetation does not make a close sward but consists of spaced tussocks. These factors do not facilitate haymaking; nevertheless, hay crops of Mitchell grass are sometimes taken. The material so conserved is low in protein and not always readily eaten by stock. The alternative is to grow a crop, e.g. sorghum, and harvest it. Skerman [34] has pointed out that the effects of heat waves are acute during the seedling stage and at flowering, and that such waves occur with increasing frequency towards the western and northern parts of Queensland. He further points out that the time of planting is dependent on the very uncertain date of the first significant rains (3 cm.). He has further ascertained from records of rainfall the chances of being able to sow before each week, and then the chances of damage to the crop from heat waves. He concludes that as far as sorghum is concerned, grain production is uncertain, and forage should be the objective. If the molasses-urea treatment proves generally applicable this seems a practicable solution, but its economics have yet to be demonstrated; clearly, they are related to the market price of beef.

Some new variety or species may be found which is more suitable than the sorghums at present in use, but unless this can be done the problems of successful intensification of dry-land crop production in the arid and semi-arid areas—the eastern side of northern Australia—are likely to continue to be difficult, and this would be true irrespective of the size of the farms or the skill of the cultivators. On the western side of the continent data are lacking, and it may be that the chances of avoiding the devastating desiccation of the heat waves may be better. In that case the potential for crop husbandry will be greater in those regions where the terrain is sufficiently even—a proviso which must be added in view of the ruggedness of much of the Kimberley country.

### THE ANIMAL INDUSTRIES

Research on animals carried out in Australia has increased markedly in recent years, and the proportion of it specially directed towards life in the arid zones has also improved. The success achieved in the control of many of the more important diseases and of worm parasites, and the evolution of the Mules operation for reducing blowfly attack on the crutch of the sheep have been heartening. The discovery and use of modern insecticides has assisted in the control of buffalo fly on cattle and of blowfly body strike in sheep. There are hopes that greater progress will be made in future with the elimination of cattle tick.

Recent promising lines of inquiry are those being made into the heat tolerance of various breeds of animals—their resistance to the effects of heat [19, 37]. It seems clear that within a breed individuals show marked differences in this regard. The analysis of various anatomical and physiological characteristics, which are important in determining heat tolerance, may be significant in providing a basis for breeding new races of domestic animals with a greater capacity for acclimatization in arid zones. The success of the Santa Gertrudis breed recently introduced from the United States, together with the obvious capacity of hybrids descended from earlier importations of Zebu cattle to survive in bad times, suggests there is good reason for confidence in the ultimate outcome of the present investigations.

Research has been extended into all phases of the wool industry in recent years. The large new laboratories at Prospect, near Sydney, are equipped with all stages of air-conditioning, so that physiological and other determinations can be carried out under a range of artificially controlled environments [19]. This work will investigate further the conclusions of previous research and observations which necessarily were carried out in the field. Moule [22] has reviewed the problems of the sheep industry in Queensland, and Fyfe [30] reported on its position in Western Australia at the end of the drought of 1935-1937.

Research can assist the livestock industries, but their basic problems are generally economic in character. In the arid zone many of the pastoral stations are still ill-equipped in a variety of ways, but improvement depends on capital expenditure, and unless the prices of the commodities produced are sufficiently profitable to encourage further investment, the likelihood of improvement is small. Before 1939 the improvements on many of these properties had become dilapidated. The wool boom of 1951 encouraged many owners to remedy these defects and install much new equipment on sheep stations. Similarly on the cattle side the higher price of beef animals has had the same effect, and here the British-Australian Fifteen-Year Meat Agreement of 1952 has also promised an improved stability of the market.

In the southern sub-arid zone the problems, though less acute, are still of the same type. Pasture improvement is possible in most of the zone with from 6 to 9 months of effective autumn-winter-spring rainfall. This is frequent in some districts, but by no means universal in these regions. To change from native pastures to those of improved type and to increase with safety the stock carried, costs from £15 to £20 per acre, and such expenditure cannot be undertaken lightly on farms whose land is usually only of moderate quality, and which could have been bought with their improvements for between £5 and £12 per acre before the war. Critical observers sometimes suggest that the farms are too large but, although there are exceptions, in most cases size is an advantage because it lowers overhead costs per unit of production. The owners of the smaller farms are those who are most frequently in financial difficulty, especially when the prices of products fall. The economic position of the sheep industries was reviewed by the Commonwealth Bureau of Agricultural Economics in 1954 [2], at a time when the industry was flourishing and its expenditures high. These surveys showed no great margin of profit above that necessary to cover the cost of interest at 5 per cent on invested capital. These costs would have had to be pruned considerably if owners were to have any margin of profit in 1958, as wool prices have fallen by 50 per cent since 1954.

### IRRIGATION—LARGE-SCALE AND LOCAL

In various parts of the sub-arid regions irrigation is a potential source of intensification of land use. In the Kimberleys the Ord River presents great possibilities, as the local Carr Boyd Ranges offer several dam sites where large quantities of water could be stored in the rainy season. These could be passed down the river to be held up by weirs and pumped on to parts of the surrounding country. A research station has been investigating the crops which could then be grown. The great need of the area however is the provision of high-class pasturage on which animals from the cattle stations farther back from the coast could be topped off and sent to the meat factory at Wyndham.

Irrigation for rice growing has been started at Humpty Doo near Darwin, but so far many of the difficulties have not been surmounted and its establishment has proved more laborious than its optimistic proponents expected. It is also practicable on limited areas near the Katherine and other rivers. Here and there small schemes could be constructed on individual properties in the arid and sub-arid areas where water holes exist on the otherwise waterless river beds in the dry season. But in general, the sources of suitable water are limited, and only occur in a few places in these regions. Towards the south-east there will be a large expansion of district schemes on the Murrumbidgee, and on the Murray when the Snowy Mountains Scheme has been completed. On private properties in rolling country it will probably be practicable to put in small storages using some of the hilly paddocks as catchments, and subsequently spray-irrigating small areas of improved pastures from the conserved water. When well planned and effectively managed, small private irrigation schemes have much to commend them in preference to the large State-operated irrigation districts. The areas to be irrigated can be chosen carefully so that the soils are suitable. The water can be used at exactly the time when it is wanted and not according to a roster. But these small schemes are expensive, and the evaporation loss from the rather shallow reservoirs tends to be high.

### FUNDAMENTAL RESEARCH

Fundamental research aimed at helping the dry areas is also directed to a study of clouds and rain formation. It is confidently claimed that rainfalls have been enhanced on some occasions. It is difficult to be certain of the reliability of these results and the small amounts involved have caused comment, but the actual amount of rain necessary to give a cereal crop a start is not large, and a good establishment a fortnight earlier than would have occurred naturally is important because it lengthens the period of growth before the winter cold sets in [1].

The possibility of reducing the evaporation loss from water surfaces by the use of cetylalcohol has been demonstrated, and a reduction of 50 per cent is claimed for appropriately-sized reservoirs [21].

In certain areas the development of metalliferous mining on a large scale may result in such an improvement of rail services to the coast that adjacent farming industries may benefit from improved transport of their livestock and other products, in the same way that railways to Ballarat and Bendigo opened up new districts for farming in Victoria in the 1870s.

These developments and researches and many others may give the farmers in the districts concerned a better control over some of the problems which have beset them in the past. This control should reduce the losses of stock and money which have hitherto retarded the Australian countryside. To the extent that they reduce the net cost of production they will add to the stability of farming. But the chances of making the really arid zones blossom like the rose, except for a week or two after the very occasional rains, are not yet in sight. This does not mean they are beyond the bounds of possibility in a world on the threshold of atomic power which, if only sufficiently cheap, might be used to remove salinity from sea water [16]. At the present time commercial machines capable of dealing with several thousand gallons a day, and suitable for the provision of drinking water for humans or livestock, are on the market. But such equipment can only work at a cost greatly in excess of the most expensive irrigation water. The possibility of cheap power for this purpose is not confined to atomic sources. The north-west coast of Australia has very high tides, and schemes have been mooted for obtaining power from this source, while the effective harnessing of solar energy is always a possibility [12].

In the event of atomic or solar energy being available cheaply all the deserts in the world might become cultivable areas, though Central Australia would scarcely be the first on the list for development. In all these cases, although water is the basic need, the development of farms from virgin soils requires large expenditure of capital for soil amelioration and for general equipment especially in a treeless terrain far removed from cheap supplies of timber.

## CONCLUSION

In many ways Australia has been fortunate in the history of her arid and semi-arid zones. The nomadic habits of the aborigines and their failure to develop the arts of cultivation prevented any degradation of the soils.

The inhospitable character of the land along most of the shores of the continent deterred people from attempting to occupy it until a fairly late stage in the development of political thought.

When settlement began it was from organized centres, not a matter of individuals or groups landing at various spots and being brought under central control at a later period.

The great capacity of the country to support wool-growing sheep ensured that development was on a commercialized basis after 1830. Commerce requires law and order, which can only be maintained over a long period by a centralized authority.

Although the governments of the Colonies were for a time flouted by the squatters, yet they never abandoned the basic principle of their control of land and its ownership, and in process of time that control was strengthened.

The ownership of the land by individuals, or their occupation of it on long leases with prospect of renewal, has generally resulted in practices which have maintained the condition of the soils. Erosion has occurred in places, but it is only serious in a few localities.

The relative poverty of most of the soils and the harshness of the climate have militated against small-scale farming in the arid and semi-arid zones except where irrigation lifts the land out of that climatic category—and irrigation in these areas usually requires large scale community effort and large capital expenditure.

As a result of this developmental sequence Australia has avoided most of the problems of the arid areas of the Old World so cogently summarized by Jacoby [17]: 'Communities, still ruled by time-honoured customs, struggle, without any economic backing, against the obstacles of climate and lack of water and the risks of farming and grazing.'

Generally the development and the use of the more arid regions in Australia have been logical in character, and wholly governed by the economic possibilities. At times, over-optimistic attempts have been made to extend the boundaries imposed by droughts and unfavourable circumstances. Now and again inter-State jealousies have hindered wise development, e.g., in railway construction or unification. At certain periods labour disturbances in the transport and processing industries have added to the costs. In general, however, development has been in accordance with the capacity of the country and its farmers to meet the needs of the world's markets. In earlier years this world demand was relatively unfettered by the action of overseas governments, but more recent developments have been less reassuring.

The need for expansion in the world's supply of farm products from exporting countries has seldom been as uncertain as at the present time. Populations increase, and in most countries it may be assumed that gradually the need will develop for more food and clothing, and for a greater variety of these. As this happens changes will occur in the relative demand for various commodities. Higher meat consumption may reduce the demand for bread, cereals and rice, and increase that for coarser grains. The availability of vegetable and whale oils at prices far lower than butter fat, and the lack of any decided preference for butter are steadily undermining the dairying industries in exporting countries, just as better ideas about the importance of milk in the nutrition of children have improved the economic basis of the same industry in industrialized nations.

The noncellulosic fibres are the most serious competitors wool has ever had to meet, and it is well within the capacity of governments to turn the balance of consumption by their nationals in the direction of these fibres to the detriment of wool.

To urge that the Asiatic populations need more attention from food-exporting countries is an over-simplification of the position, for in many cases these countries are not accustomed to the products of which Australia has a surplus: vegetable oils are preferred to butter, and meats are not acceptable to peoples of many creeds. Further, the reorganized agriculture of many Asiatic countries is steadily diminishing the need for food imports. For the time being therefore, wholesale agricultural and pastoral expansion are scarcely justified, although in the long run, as world populations expand beyond the capacity of improved technology to supply raw materials from the land of importers, the situation will probably change.

Some commentators will doubtless contend that Australia's rural development would have been even more rapid if governments had accepted settlement on small-scale farms as a policy. The evidence is all in the opposite direction; numerous attempts to set up such settlements have been made; almost all have failed. Those settlers who succeeded usually acquired the land of their neighbours until they had a large enough unit to make a living on a semi-commercial basis. Only on the rare patches of rich soil in the non-arid regions have such settlements been able to survive for any length of time.

Other observers remark on the infrequency of cropping in the arid, and more especially in the sub-arid zones of Australia. Actually the zone of cultivation in the southern sub-arid zone, extending as it does to the region of five months of effective rainfall in the cold season, has probably been extended as far into the arid zone as the cropped land in any country in the world. The special problems in the summer rainfall zone have been analysed by Skerman [34]. The climatic risks of cropping and the somewhat low level of fertility in most of the soils have resulted in the general dominance of the pastoral industries, for which large areas are required per head of livestock because of these same climatic and edaphic disabilities.

The present situation generally is admirably summed up by White [38, p. 162] : 'Under a modern system of land use based on conservation of natural resources and their improvement, costs are necessarily higher than under a exploitative system. The cheap food era, which was possible only with uncontrolled exploitation of the natural resources of the producing countries, is being replaced by a period in which there is increasing realization of this fact, and of the urgent necessity to restore the damage which has been done. The next stage will have to be the building up of the productive capacity of the land to meet the needs of a growing human and livestock population.'

The relatively high prices for farm products in the last ten years has provided a great stimulus to that 'building-up' process in most Australian districts where new knowledge has made it reasonable.

# BIBLIOGRAPHY


1. Bowen, E. G. The artificial stimulation of rainfall and its application to the arid regions. *Climatology and microclimatology. Proceedings of the Canberra Symposuim.* Paris, Unesco, 1958. p. 269-271. (*Arid zone research* XI.)
2. Bureau of Agricultural Economics. *The Australian sheep industry survey, 1954.* Canberra, Bureau of Agricultural Economics, 1957.
3. Burgos, J. J.; Tschapek, M. Water storage in arid soils. *Climatology and microclimatology. Proceedings of the Canberra Symposium.* Paris, Unesco, 1958. p. 72-91. (*Arid zone research* XI.)
4. Christian, C. S. The nature of climatological problems encountered by the Land Research Section, CSIRO. *Climatology and microclimatology. Proceedings of the Canberra Symposium.* Paris, Unesco, 1958. p. 148-151. (*Arid zone research* XI.)
5. ——; Jennings, J. N.; Twidale, C. R. Geomorphology. *Guide book to research data for arid zone development.* Paris, Unesco, 1957. p. 51-65. (*Arid zone research* IX.)
6. ——; Slatyer, R. O. Some observations on vegetation changes and water relationships in arid areas. *Climatology and microclimatology. Proceedings of the Canberra Symposium.* Paris, Unesco, 1958. p. 156-158. (*Arid zone research* XI.)
7. Crawford, R. M. *Australia.* London, Hutchinson, 1952.
8. Crookes, Sir W. *The wheat problem.* (3rd ed.) London, Longmans, 1917.
9. Davidson, J. Climate in relation to insect ecology in Australia. 3. Bioclimatic zones in Australia. *Trans. Proc. Roy. Soc. S. Aust.*, vol. 60, 1936. p. 88-92.
10. Davies, J. Griffiths. Australia. *Plant ecology. Reviews of research.* Paris, Unesco, 1955. p. 114-131. (*Arid zone research* VI.)
11. Emberger, L. Afrique du Nord et Australie méditerranéenne. *Climatology and microclimatology. Proceedings of the Canberra Symposium.* Paris, Unesco, 1958. p. 141-146. (*Arid zone research* XI.)
12. Golding, E. W. Sources of energy. *Guide book to research data for arid zone development.* Paris, Unesco, 1957. p. 176-187. (*Arid zone research* IX.)
13. Hills, E. Sherbon. The hydrology of arid and semi-arid Australia, with special reference to underground water. *Arid zone hydrology. Reviews of research.* Paris, Unesco, 1953. p. 179-202. (*Arid zone research* I.)

14. Hills, E. Sherbon. Geology and geophysics. *Guide book to research data for arid zone development.* Paris, Unesco, 1957. p. 44-50. (*Arid zone research* IX.)
15. Holt, A. J. *Wheat farms of Victoria—a sociological survey.* Melbourne, Melbourne University Press, 1946.
16. Howe, E. D. Utilization of sea water. *Utilization of saline water. Reviews of research.* Paris, Unesco, 1954. p. 78-91. (*Arid zone research* IV.)
17. Jacoby, E. H. Land tenure. *Guide book to research data for arid zone development.* Paris, Unesco, 1957. p. 152-155. (*Arid zone research* IX.)
18. Leeper, G. W. Reliability of rain in Australia as compared with the rest of the world. *J. Aust. Inst. agric. Sci.*, vol. 11, 1945. p. 188-189.
19. Macdonald, I. W. Facilities for studies in climate of physiology of sheep and cattle at the Sheep Biology Laboratory, Prospect, NSW. *Climatology and microclimatology. Proceedings of the Canberra Symposium.* Paris, Unesco, 1958. p. 247-250. (*Arid zone research* XI.)
20. McTaggart, A. *A survey of pastures in Australia.* Melbourne, Government Printer, 1936. (*CSIR bulletin* no. 99.)
21. Mansfield, W. W. Reduction of evaporation of stored water. *Climatology and microclimatology. Proceedings of the Canberra Symposium.* Paris, Unesco, 1958. p. 61-64. (*Arid zone research* XI.)
22. Moule, G. R. The performance of sheep in semi-arid Queensland. *Climatology and microclimatology. Proceedings of the Canberra Symposium.* Paris, Unesco, 1958. p. 235-241. (*Arid zone research* XI.)
23. Onslow, S. MacArthur. *Early records of the MacArthurs of Camden.* Sydney, Angus & Robertson, 1914.
24. Prescott, J. A. *The soils of Australia in relation to vegetation and climate.* Melbourne, Government Printer, 1931. (*CSIR bulletin* no. 52.)
25. ——. Climatic indices in relation to the water balance. *Climatology and microclimatology. Proceedings of the Canberra Symposium.* Paris, Unesco, 1958. p. 48-51. (*Arid zone research* XI.)
26. Ratcliffe, F. N. *Soil drift in the arid pastoral areas of South Australia.* Melbourne, 1936. (*CSIR pamphlet* no. 64.)
27. ——. *Further observations on soil erosion and sand drift with special reference to South Western Queensland.* Melbourne, 1937. (*CSIR pamphlet* no. 70.)
28. Roberts, S. H. *The squatting age in Australia.* Melbourne, Melbourne University Press, 1935.
29. ——. *History of Australian land settlement 1788-1900.* Melbourne, MacMillan & Co., 1924.
30. *Royal Commission appointed to enquire into and report upon the financial and economic position of the pastoral industry in the leasehold areas in Western Australia.* Perth, Government Printer, 1940.
31. *Royal Commission (Australian) appointed to report on the wheat, flour and bread industries* (Reports nos. 1, 2 and 5). Canberra, Commonwealth Government Printer, 1934-35.
32. Rural Reconstruction Commission (Australia). *Eighth report, irrigation, water conservation and land drainage.* Canberra, Government Printer, 1945.
33. Shann, E. O. G. *Cattle chosen.* Oxford, Oxford University Press, 1926.
34. Skerman, P. J. Heat waves and their significance in Queensland's primary industries. *Climatology and microclimatology. Proceedings of the Canberra Symposium.* Paris, Unesco, 1958. p. 195-200. (*Arid zone research* XI.)
35. Taylor, Griffith. *The Australian environment.* Melbourne, Commonwealth Government Printer, 1918.
36. ——. *Australia.* (6th ed.) London, Methuen, 1951.
37. Turner, H. G. Factors affecting heat tolerance of cattle. *Climatology and microclimatology. Proceedings of the Canberra Symposium.* Paris, Unesco, 1958. p. 243-245. (*Arid zone research* XI.)
38. Wadham, Sir Samuel; Wilson, R. K.; Wood, J. *Land utilization in Australia.* (3rd ed.) Melbourne, Melbourne University Press, 1957.
39. Whyte, R. O. Animal husbandry. *Guide book to research data for arid zone development.* Paris, Unesco, 1957. p. 156-167 and especially p. 160-163. (*Arid zone research* IX.)

# PUBLIC HEALTH FACTORS
# Part I: MALARIA AND BILHARZIASIS

*by*

PAUL F. RUSSELL

*The Rockefeller Foundation (retired); Medical Consultant, World Health Organization; Malaria Consultant, International Cooperation Administration*

## INTRODUCTION

Public health factors in the history of land use in arid regions have been many and varied, ranging through a number of diseases primarily due to heat or dust, others due to parasites given free rein by the lack of sanitation that has characterized many arid lands, and still others due to certain aspects of the use of water to irrigate arid soil.

The records give little or no information about specific effects of heat or dust or of parasitic diseases in general in the development of arid land use. But they make it clear that two major diseases —malaria and bilharziasis (schistosomiasis) have been intimately related to water supplies and to irrigation practice in the past as in the present. Therefore, this chapter will be devoted chiefly to those two diseases.

Such miscellaneous conditions as heat pyrexia, heat cramps, heat exhaustion, desert sore or Oriental Sore (cutaneous leishmaniasis) and certain other skin lesions, some eye afflictions, vesical and renal calculi, mucous membrane irritations due to sand and fine dust, certain bacterial and parasitic infections, and some anaemias and avitaminoses are today encountered in arid lands and no doubt have long been nuisances associated with hot and dusty environments. But they do not have a serious impact today and probably never did greatly influence the course of events in any region in the past.

However, malaria and bilharziasis are major public health factors in arid lands today and undoubtedly they have been the principal public health factors throughout the history of land use in arid regions. Indeed, the causal relationship between the watering of arid lands and the prevalence of malaria and bilharziasis has been troublesome ever since man first attempted irrigation farming. Irrigation schemes in recent as in ancient times have brought one or both of these diseases, and sometimes death, to millions of farmers. Some schemes have had to be abandoned because health factors were ignored in plans and operations so that malaria or bilharziasis or both became rampant. The reasons for this will become clearer in the following paragraphs.

## MALARIA [3, 4, 12, 13][1]

Malaria is a disease characterized by periodic chills and fever, by enlargement of the spleen, and by anaemia. It is caused by an infection with microscopic protozoan parasites of the genus *Plasmodium*, transmitted from man to man by *Anopheles* mosquitoes. When these insects take malarious blood into their stomachs, certain male and female parasites, called gametocytes, are not digested, as they would be in other than anopheline stomachs; instead they mate and produce cysts which develop on the stomach wall of the insect. When the cysts are ripe they burst open and their 'seeds', called sporozoites, move into the insect's salivary glands and ducts. This development period, from gametocyte to sporozoite lasts from 7 to 25 days or more, being slower at lower temperatures. Until sporozoites are in the salivary glands the insect is harmless. After the parasites are in the glands the insect, whenever it feeds, injects not only saliva but also sporozoites into its victim's blood, thus starting another case of malaria. The insect may continue to spread malaria throughout its life of a month or more. Only female mosquitoes transmit the disease. Males have no stylets capable of penetrating skin; they live on plant juices and are harmless.

In man the injected sporozoites leave the blood stream in the liver where they enter certain cells, grow in size, and divide into broods of young parasites. These escape from the liver cells into the blood

1. The figures in brackets refer to the bibliography at the end of the chapter.

stream and penetrate red blood cells, generally one parasite to a cell. In the red cells the parasites grow and then most of them split into segments called merozoites. The parasitized cells disintegrate, liberating the merozoites which enter other red cells. The cycle continues with more and more red cells parasitized, until checked by the patient's defences of immunity, by treatment, or by the patient's death. Fatalities may result from severe anaemia, excessive fever, or from the choking of the capillaries of the brain or other vital organ by masses of parasitized cells and free parasites.

Some of the parasites formed within the red cells do not split into segments but develop into the male and female parasites, i.e., gametocytes, that develop into sporozoites when taken into a mosquito, as explained above. If not taken by a mosquito they are destroyed in the human blood stream.

In typical cases, liberation into the blood stream of merozoites plus metabolic products of the parasites such as pigment, plus red cell debris, periodically upsets the body's heat-regulating mechanism so that there is severe shivering, then intense feverishness, followed by copious sweating. These characteristic bouts of chills and fever are timed by the length of the development period of the infecting parasites. Four species may infect man : *Plasmodium vivax*, called the tertian parasite, with a cycle of about 48 hours, chills and fever coming typically every other day; *P. ovale*, another but much less common tertian parasite; *P. malariae*, the quartan parasite with a 72-hour cycle; and *P. falciparum*, which has sometimes a daily and sometimes a tertian periodicity, being often quite irregular. The incubation period from the time a mosquito infects a man until he has his first noticeable fever averages 12 days in falciparum malaria, 14 days in vivax and ovale, and 20 days or more in malariae. Because the symptoms and course of malaria are often not typical, positive diagnosis of malaria depends upon observing the parasites in blood smears examined microscopically.

Man has little natural immunity to malaria and there are no protective serums or vaccines. But once the body is invaded, strong defences are developed so that the chances of escaping death are excellent. Certain white blood cells, called phagocytes, destroy many parasites, and the spleen filters out parasites, parasitized cells, and cell debris from the blood. These activities, assisted by suitable therapy, usually end acute attacks promptly. But there may remain some parasites hidden away in the liver cells and these parasites may be responsible for subsequent attacks, called relapses. Often not much immunity persists even after several attacks. Strong tolerance occurs only in those who from birth are exposed to repeated infections or who have some racial immunity as, for example, certain peoples of tropical West Africa.

Ancient authors ascribed the intermittent fevers to the anger of gods, invasion by demons, black magic, evil eye, marsh water, and swamp vapours. In mediaeval Italy, people blamed bad air—'mala' 'aria', 'mal'aria', later 'malaria', a term that at first referred to the cause of the fever and then by the end of the nineteenth century to the disease itself. As the germ theory of disease gradually gained acceptance, scientists searched for malaria germs and finally in 1880 Laveran found the malaria parasite in the blood of a patient in Algeria. He did not know how the parasites got into a man's blood although he hinted that perhaps an insect like the mosquito spread them about. It was Manson, in England in 1895, who first published a well-reasoned hypothesis that mosquitoes transmitted malaria after the parasite had undergone development in the insect's body. But Manson did not know how the mosquito became infected. The first experimental proof came in 1897-1898 when Ross in India found malaria parasites of man growing as cysts on the stomach wall of *Anopheles* mosquitoes. Experimenting with bird malaria, he next found that a *Culex* mosquito could take the parasites from one bird, develop them and then inject them with saliva into another bird, thus infecting it. These two discoveries, in man and bird, explained malaria transmission. In November 1898, Italian scientists Bastianelli, Bignami, and Grassi, demonstrated sporozoites of human malaria in the salivary glands of *Anopheles* mosquitoes. Then Manson, in a very convincing experiment, had living infected *Anopheles* mosquitoes sent from Rome to London where he fed them on a volunteer (his son) who developed typical malaria and was cured with quinine. It was soon clear that only *Anopheles* transmit human malaria and that malaria is not transmitted naturally except by these mosquitoes. At first, all *Anopheles* mosquitœs were suspect. But it became apparent that the females of many species of that genus seldom take human blood, preferring that of animals. In fact, only about 60 of the more than 200 *Anopheles* species are considered to be significant transmitters of human malaria. Another early misconception was that malaria-carrying species bred principally in marshes and stagnant water. Some, such as *A. labranchiae* in Italy, are indeed marsh-breeders, but throughout the world there is wide variation in types of breeding places of malaria vector mosquitoes.

In the first place, it is now clear that all *Anopheles* mosquitoes lay their eggs on water and that all develop through aquatic, air-breathing larval and pupal stages. The winged adults emerge 7 days or more after the eggs are laid, usually not sooner than 10 days and sometimes not for 2 weeks or more, depending on the temperature of the water of the breeding place. Most species of *Anopheles* are known to have preferential larva habitats where their aquatic forms are most likely to be found. As examples, *A. sundaicus* larvae in Indonesia are usually found in coastal lagoons, *A. stephensi* in Bombay in wells, *A. sinensis* in South China in rice fields, *A. minimus flavirostris* in the Philippines in running water of foothill streams, *A. maculatus* in Malaya in springs and seepages, *A. gambiae* in West Africa in rain puddles, and *A. bellator* in Trinidad in the axils of certain tree-growing bromeliads, high above the ground. In arid regions, it often happens that there are species of *Anopheles* that transmit human malaria and that live in standing or running irrigation water as, for example, *A. culicifacies* in the valley of the Indus.

Malaria has a *reproduction rate* that varies from place to place and time to time. This rate equals the number of secondary infections originating from a single primary case. It depends on such factors as the density, man-biting habits, and longevity of the local malaria-carrying *Anopheles*, the length of the developmental period of the parasite in the insect, and the length of the period of infectivity in non-immune humans. If this basic reproduction rate falls below 1, successive generations of malaria cases will be smaller and smaller and malaria will gradually disappear. On the contrary, if the reproduction rate exceeds 1, the incidence of malaria will rise.

However susceptible to malaria a local species of malaria-carrying mosquito may be, the insects cannot maintain malaria transmission in a given area unless the species is numerous enough to support a malaria reproduction rate of 1 or more. Naturally, the more avidly the anophelines take human blood and the longer the span of life during which they feed, the smaller will be the number of them required to maintain malaria transmission. So for any combination of man-biting habits and longevity, there is a *critical density* of a malaria-carrying species of mosquito, i.e., a certain number below which malaria transmission cannot be maintained. A malaria mosquito such as the Madras *A. culicifacies*, which has a relatively short life and which has a 90 per cent preference for cattle blood, must be present in great numbers to maintain malaria transmission. By contrast, African *A. gambiae* in many areas has a relatively long life and often a 90 per cent preference for human blood. Therefore, smaller numbers can maintain transmission of malaria. In fact, a critical density of 0.01 for *A. gambiae* in West Africa maintains intense malaria which a critical density of 30.0 for *A. culicifacies* in Madras cannot equal.

Thus it is apparent that if the watering of arid lands results in the increased density of a malaria-carrying anopheline it may bring increased malaria to the area. Of course, in the absence of the parasite there can be no transmission of malaria. The greater the parasite index the less the increase in the density of the anopheline need be to initiate or to augment the endemicity of malaria. In most irrigation projects in the tropics and subtropics the parasite is not only present in the local population of the oases or fringe communities but it is also brought in by the construction labourers and by the farmers who come to use the water. With both increased vector mosquito density and increased parasite density, it may take only a short period after the opening of an irrigation system to establish heightened malaria endemicity, frequently with an initial epidemic.

### REGIONAL CONDITIONS [3, 14]

*Arabian Desert region.* Malaria today is highly endemic in Saudi Arabia wherever there is water to support *Anopheles* breeding. Such vectors as *A. gambiae* in the west and *A. culicifacies* and *A. stephensi* in the east do very well in irrigation water. *A. stephensi* is the most important malaria vector along the entire coast of the Persian Gulf, being especially prevalent in irrigated date-palm groves. It breeds in wells, ditches, seepage waters, swamps, and borrow pits. Historical records are meagre but there is reason to believe that malaria has been prevalent in the area for centuries wherever there have been oases, pools or irrigation ditches.

Israel, Jordan, and Syria have also been highly malarious but today each has a malaria eradication programme. Israel is nearly malaria free today (as is also Lebanon). *A. sergenti*, the most troublesome vector, is known to be associated with irrigation water and fish ponds and has no doubt been responsible for malaria in the region for centuries. It is specially troublesome in that it feeds both indoors and outdoors and that it often rests outdoors in the day-time. Most malaria vectors feed indoors and also rest indoors and are thus more susceptible to attack by spraying of residual insecticides on the inside walls of habitations.

Malaria has been prevalent in the Tigris-Euphrates basin for thousands of years and allusions to intermittent fevers are fairly common in Babylonian-Assyrian medical history. Today, Iraq has a malaria eradication campaign that has already reduced considerably the prevalence of malaria in several areas. But the disease has been a great problem, especially in irrigated areas. Among several malaria-carrying *Anopheles*, *A. sacharovi* and *A. stephensi* have often been associated with the irrigation of arid land.

*Iranian Plateaux area.* Iran has also been highly malarious over the centuries but now has a malaria eradication programme that is progressing towards success. Among the five, or perhaps more, malaria vectors, *A. culicifacies*, *A. sacharovi*, and *A. stephensi* have been especially associated with irrigation waters. For instance, *A. stephensi*, breeding in the irrigation ditches of date-palm groves in the Basrah area, has been an important source of much malaria.

In Afghanistan, malaria has been one of the principal diseases and *A. culicifacies*, breeding in irrigation water, has been a major carrier.

Turkey has suffered severely from malaria in the past but has now greatly reduced the endemicity of the disease and is proceeding to eradicate it. One of the chief vectors, *A. sacharovi*, readily associates itself with irrigation waters.

*Nile Valley.* Historical records seem to indicate that malaria was not common in the Nile Delta in ancient times but it may have been more common in the Upper Valley. Enlargement of the spleen and fever attacks with chills are mentioned in the Papyrus Ebers [5]. Some say that the inscription 'A A T', found on the temple at Denderah, refers to malaria. The principal malaria vectors in the Egyptian oases and the ones chiefly associated with irrigation water are *A. sergenti* and *A. pharoensis*. Today Egypt has a malaria eradication programme.

In the Sudan, malaria is still a serious problem. All four of the suspected malaria vectors, *A. funestus*, *A. gambiae*, *A. nili*, and *A. rufipes*, may be found in irrigation waters.

*South Asia.* The malaria problem in India has been a colossal one in the past but today there is in operation a nation-wide malaria eradication programme. Malaria incidence has already been greatly reduced. There are many references to this disease in the ancient medical writings of India, leaving no doubt that it was highly prevalent in past centuries. Of the many malaria vectors, *A. culicifacies* has been the one of chief importance in irrigation waters. Many malaria epidemics due to this mosquito have followed the opening of new irrigation systems and undoubtedly irrigation waters have been responsible for a great deal of endemic and epidemic malaria in India.

In West Pakistan, especially in the valley of the Indus, *A. culicifacies*, assisted by *A. stephensi*, has brought much malaria to communities adjacent to irrigation waters. The benefits of irrigation have been greatly curtailed by concomitant malaria.

*Central Asia.* Malaria does not appear to be endemic in the Mongolian People's Republic or in any part of the Gobi Desert or westwards into the Taklamakan Desert of Sinkiang, or in the arid lands of Asian USSR north of Azerbaidzhan. The last named has been moderately malarious and two of its malaria vectors, *A. maculipennis* and *A. claviger*, are sometimes associated with irrigation waters. Still farther west in the Ukraine the chief vector is *A. messeae* which may also be found in irrigation waters.

*North Africa and the Sahara.* In Morocco, Algeria, Tunisia, and Libya there has been and is endemic malaria transmitted chiefly by *A. labranchiae* in coastal areas and by *A. sergenti* and *A. multicolor* in the oases, most of which have been highly malarious. Wherever in the Sahara area water is available for irrigation it is also used by either *A. sergenti* or *A. multicolor*, or both, and the result is endemic malaria.

*North America.* Today malaria has been eradicated from the continent north of the USA-Mexican border. Except in the central valleys of southern California and along the Mexican borders of New Mexico and Texas, the irrigated arid lands of the USA have never been malarious. In California, *A. freeborni*, breeding in irrigation waters, has in the past been a source of considerable malaria.

*Latin America.* Except for non-malarious Uruguay, all continental Latin American countries today have malaria eradication programmes and several have reduced the disease to a low level, to the point of eradication in Chile. In many, malaria has constituted the principal public health problem. In western South America, the irrigation of arid lands in Colombia, Ecuador, Peru, and Bolivia has often been accompanied by malaria, transmitted by one or more of the species *A. darlingi*, *A. pseudopunctipennis*, and *A. punctimacula*. In Mexico, *A. aztecus* and *A. pseudopunctipennis* may be associated with malaria and irrigation water on arid lands. In Yucatan *A. darlingi* is also suspected.

No records suggest that the irrigation projects of the pre-Colombian civilizations of Central and South America were complicated by malaria. In fact, whether or not malaria existed in the Americas prior to the time of Columbus is debatable. The historian Gualberto Arcos [2] of Ecuador believes that malaria was rampant in the armies of the ninth Inca king, Pachacutec, before the landings of Colombus in the Americas. He suggests that the plasmodia came to the Americas from Asia, brought by the original migrants to the New World in very early times. Others, like Boyd [3], believe that malaria came with the European *conquistadores* and colonists and with African slaves. The question must still be considered as unanswered.

*Australia.* Malaria is only mildly if at all endemic in Australia today, although in the past the disease occurred in Western Australia as far south as 18° S., in the Northern Territory as far as Wave Hill at about 17° 30′ S., and in Queensland as far as 19° S. along the coast. It seems doubtful that, with reasonable precautions, malaria would complicate the use of arid lands in Australia in the future if in fact it ever has in the past.

IRRIGATION AND MALARIA [11, 12]

Many illustrations exist in recent history of how the irrigation of arid lands is a source of malaria : two of which the author has had personal knowledge and experience were respectively in the Sind and in Madras.

For centuries people of the Sind have excavated canals from the Indus to convey water to their lands when the river level was high. If the water in the canals was too low to flow over the land, the farmer erected Persian water-wheels to lift the water into smaller channels which distributed it to his crops. The fields watered by gravity direct from the canals were said to have 'flow irrigation', while those supplied by wheels had 'lift irrigation'. Only with moderately high river levels was there flow irrigation. The canals taking this water were called 'inundation canals' and they generally held water only from about the first of June to the end of September. For the remainder of the year they were dry except that while drying they formed a series of pools in which the malaria-carrying *A. culicifacies* bred abundantly.

A good deal of fluctuation was usual in the river level and landowners had the habit of taking all the water they could draw while it was available, allowing the surplus to flood low places. These low areas were also flooded when high river levels sent excessive amounts of water into the canals. As a result, low places frequently contained surface water and were a source of *A. culicifacies* breeding.

One form of cultivation was called *bosi*. For this the land was flooded to a depth of about a foot near the end of the inundation season and this water was retained on the land by small bunds. The water soaked into the ground and as soon as possible the area was planted to wheat which grew during the cold season without further watering. The flooded fields were another source of *A. culicifacies* breeding.

Still another type of irrigation was the 'Pancho system' which was designed to get rid of the excess of salts with which the soil was impregnated. These salts of calcium, magnesium, potassium, and sodium were collectively called *kallar*. When the water on a *kallar* field of young rice stood for a few days it took up so much salt that it had to be run-off and fresh water run-on. This process was repeated many times during a crop season. The run-off water was allowed to flow where it would, into low-lying areas, into village washing places, called *dhands*, and into swamps. This water formed many breeding places for *A. culicifacies*.

About 1850, there began a systematic effort by the government to control the forces of nature in order that floods might be prevented and a more regular supply of irrigation water provided. The early efforts were confined to establishing regulators on the old canals, deepening and straightening them, and supervising operations. Then, in 1923, work was begun on the Lloyd or Sukkur Barrage Scheme designed to supply water for the cultivation of some 6 million acres of crops. The system included a 'barrage' type of dam, a system of perennial canals and a central 'rice canal' which flowed from May to September.

When the author visited this area in 1934 the barrage scheme had raised subsoil water levels and increased the amount of standing water in five ways : (a) by bringing water on to the land without providing drainage channels; (b) by the percolation of water from new canals through certain sandy sections of their banks; (c) by percolation of water into the soil of areas above the barrage, from the newly created lake; (d) by the abandonment and blocking of certain old irrigation canals, thus trapping the water; (e) by providing an increased amount of water for the 'Pancho system'. Not only had the breeding of *A. culicifacies* been enormously multiplied, with consequent increase of malaria incidence, but some 7,000 acres of farm land and 31 villages had become waterlogged. Malaria spleen indexes were as high as 90 per cent in some of the villages.

In 1933-1934, a new irrigation scheme was constructed in Pattukkottai *taluk* of Tanjore district in Madras and irrigation malaria promptly appeared. The author had charge of a field station set up in 1936 to study the epidemiology and control of malaria in the area. With the help of an agricultural engineer, a medical entomologist, an agronomist, and a physician, the subject of irrigation malaria was carefully investigated. The general conclusion reached was : 'A great deal of stress must be laid on the fact that, for the most part, it is not irrigation *per se* which gives rise to malaria but it is *defective and untidy irrigation* which, by *misplacing water*, allies itself with malaria-carrying anophelines, multiplying their breeding places.'

Specific ways in which irrigation produces malaria were listed as follows [11] :

1. Defective sluice gates which permit water to flow when and where not required, forming pools and unwanted channels in which malaria vectors breed.
2. Seeping canal banks through which canal water escapes to form mosquito-breeding pools.
3. Borrow-pits dug to make canal embankments and repairs : these quickly fill by seepage, by water leaking from sluice gates, by flow from minor channels, and sometimes by rains, and they make excellent mosquito nurseries.
4. Defective distributing chambers which send water in directions not indicated by requirements so that mosquito-breeding pools are formed : such chambers may actually block the flow and cause ponding.
5. Excessive supply of water frequently seen in

the canals, above the amount they were designed to carry and considerably more than is required by the farmers : this causes a great deal of mosquito breeding directly, along canal banks, and indirectly, by pools and irregular channels.

6. Improper delivery of water, for example, into a roadway or roadside ditch, or into an open uncultivated field, or a village square, to form mosquito-breeding places.
7. Improperly maintained canal banks which through scouring or vegetation provide shelter for anopheline larvae.
8. Improperly maintained canal beds so that the current is too sluggish and permits more breeding or so that many mosquito-breeding pools appear at the end of the irrigation season.
9. Absence of any planned or controlled system of field channels : when water leaves the distribution channels it passes beyond any jurisdiction of government; the farmers send it where and when they please and it finds its own way into any convenient low-lying places; this is a prolific source of mosquito breeding.
10. Insufficient number of bridges across canals, so that villages are isolated from main roads : of course, canals must be crossed and this causes serious breeching of canal banks with nearby ponding of water, thus causing mosquito breeding.
11. Absence of drainage canals : this is invariably a menace not only to the health of the community but to the land itself; water-logging due to lack of drainage is a source of many evils.
12. Cutting off and leaving sections of old canals which happen to be in the way of new ones; these sections become elongated ponds, often breeding malaria-carrying mosquitoes.
13. General untidiness : here a pipe is missing, there a bridge was forgotten; here is a leaky gate, there a defective distributing chamber; here a small section of canal was never dug, there two channels do the work of one; here a bathing *ghat* should have been built, there cattle protection is required.

Waste irrigation water is an agreeable sight to entomologists collecting mosquitoes and, as noted below, to malacologists collecting snails. But to the irrigation engineer it represents failures in water distribution, with wastage of an expensive commodity; to the agronomist it suggests higher water-rates and more waterlogged land; to the health officer it means more malaria and, as explained in the next section, often more schistosomiasis. The history of land use in arid regions holds many instances of public health tragedies due to defective and untidy irrigation practices.

That irrigation is a source of malaria has been clearly observed for many years. Recent examples have occurred in India, Mesopotamia, Egypt, and elsewhere. Sometimes malaria has been simply a nagging nuisance, reducing the expected dividends in human welfare, but at other times irrigation malaria has done severe damage to a community. The extent to which malaria contributed to the failure of irrigation systems in ancient times can only be conjectured since specific historical records on this point do not exist.

For instance, what part did malaria take in the decline of prosperity and the eventual failure of irrigation agriculture in the once great Fertile Crescent? No doubt remains that in ancient Mesopotamia there were vast irrigation projects supporting thriving communities for centuries. But for some reason these irrigation systems decayed and the civilization dependent upon them disappeared.

Competent observers, such as Jacobsen and Adams [6], have made it clear that progressive changes in soil salinity and sedimentation associated with the irrigation systems probably were prime factors in the break-up of these Mesopotamian civilizations. These fatal changes came about through over-irrigation and failure to provide proper drainage and sufficient maintenance. As Jacobsen and Adams point out, 'with conditions of social unrest and a preoccupation on the part of the political authorities with military adventures and intrigues, the maintenance of the system could only fall back on local communities ill-equipped to handle it'.

Is it not likely that malaria, too, was an important factor in the failure of ancient Mesopotamian irrigation schemes that were so successful at first and such utter failures in the end? Historical records make it certain that the disease was endemic in the area in ancient times and there is no reason to believe that the epidemiology of malaria then differed essentially from that seen today. One can logically assume that the same *Anopheles* malaria vectors were present and that they found irrigation water as agreeable for their breeding places as they do today. The progressive changes named above probably increased the vector mosquito incidence. Demonstrations in the area in modern times make it clear that the poorer the drainage, the more the over-irrigation, and the less the maintenance, the larger the output of malarial mosquitoes and the higher the incidence of malaria, with its well known anaemia-producing and debilitating effects. Incantations and sacerdotal hygiene could not have been very effective measures of malaria control.

A point to be emphasized is that, as a rule, the more intensive the cultivation of land and the more careful the use of irrigation water the lower will be the incidence of malaria. Malaria-carrying mosquitoes thrive in water collections created by *untidy* irrigation practices. Very likely, when the civilizations of the Euphrates and Tigris, as well as those of the Indus and Nile basins, were flourishing the irrigation systems were well maintained, with careful attention to the canals and to the conservation of water. But when the irrigation systems began to be neglected, no doubt malaria began to increase. This sort of phenomenon in modern times sets off a 'chain-reaction': the more neglect→the more malaria→ the more neglect.

Community progress is possible in the presence of endemic malaria, as witness the history of the Upper Mississippi Valley in the eighteenth and nineteenth centuries [1]. At that time and place other factors had sufficient power to drive the people ahead to more and more intensive development of agriculture and industry in spite of their 'chills and fever'. This led to a decline in malaria incidence. Communities served by an irrigation system may be plagued by malaria and yet the system may for a time bring net gains to the people if sufficient diligence and supervision is somehow maintained. This was probably the situation in the first centuries of the great irrigation civilizations of Mesopotamia. But there is a nice balance to consider. The chain reaction is always a potential threat if the scales become weighted, for example, by social unrest or wars.

One would not maintain that malaria has ever been the sole or even the major cause of the decline of a civilization, although such a claim has been made as regards Greek, Roman, Singhalese, and certain other civilizations. But that malaria at times has been an important factor in the complicated equation of civilization decay cannot be doubted. Very likely this was true in ancient Mesopotamia and one has the uncomfortable feeling that in this respect history could some day repeat itself, unless the current malaria eradication programmes can be put through to a successful conclusion.

## BILHARZIASIS (SCHISTOSOMIASIS) [4]

Certain schistosomes or blood flukes cause a widespread disease known as bilharziasis or schistosomiasis,[1] which is frequently associated with the irrigation of arid lands. The parasitic schistosome worms require fresh-water snails for one stage of their development. Only certain species of snails are suitable. If such snails are found along the banks of streams or ponds or irrigation channels in countries where sanitation is poor, schistosomiasis is likely to be endemic. The incidence of the disease is increasing and is estimated to exceed 150 million cases throughout the world, thus constituting a major public problem [19]. While human schistosomiasis is of primary concern, snail-borne fascioliasis and amphistome infections in cattle is of increasing importance in some areas, such as in India and Southern Rhodesia.

Three species of schistosomes are important parasites of man. Two cause intestinal and hepatic disease: *Schistosoma japonicum* in Japan, China, Formosa, the Philippines, and in the Celebes of Indonesia; and *S. mansoni*, in Arabia, the Nile Delta, Sudan, East, West and Central Africa, Mozambique, Madagascar, north-eastern Brazil, British and French Guiana, Surinam, Venezuela, and the West Indies. The third schistosome causes vesical or bladder disease: *S. haematobium*, found in most of Africa including the entire Nile Valley and Madagascar, Arabia, Iraq, and the Middle East, with small foci in Portugal, Cyprus, and Bombay State of India. Several other species of schistosomes have minor importance, e.g. *S. intercalatum*, found sporadically in the ex-Belgian Congo.

The sexually mature schistosomes, which vary in length from about 7 to 26 mm. and in width from about 0.3 to 1 mm. and have the appearance of elongated threads, live in the mesenteric and portal veins and, in the case of *S. haematobium*, in the pelvic veins of the human host. Here are deposited their eggs, characteristic for each species, measuring from 70 to 170 microns in length and from 40 to 70 microns in width. They are excreted by the host in the urine *(S. haematobium)* or faeces *(S. japonicum* and *S. mansoni)*. The eggs hatch in fresh water, each liberating a minute larva called a 'miracidium'. The miracidia swim about for some 16 to 24 hours and then die unless they come into contact with an appropriate snail. If so, they infect the snail and undergo an essential developmental stage in the mollusc, lasting some 4 to 8 weeks. In the snail the miracidia develop into sporocysts within which thousands of larvae called 'cercarias' develop. The latter are fork-tailed larvae and are discharged into the water by the snail in daily broods. The cercarias swim about vigorously, tail first, for 24 to 72 hours without feeding and they die if they fail to contact their definitive host which as a rule must be man in *S. mansoni* and *S. haematobium*, and is often man in *S. japonicum* but may also be dogs, cats, rats, mice, cattle, water buffaloes, pigs, deer, or horses.

When the cercaria contacts the skin it is able to cling to it and fairly quickly to penetrate through into subcutaneous tissue. Entering the venous circulation, cercarias are carried through the right chambers of the heart to the lungs; thence, after squeezing through the pulmonary capillaries, they are carried through the left chambers of the heart into the systemic circulation, many being destroyed on the way. The worms that reach the intrahepatic portal circulation via the mesenteric artery and

1. The International Commission on Zoological Nomenclature ruled in 1954 that the generic name of human blood flukes is *Schistosoma* Weinland, 1858. Hence many authorities prefer to use schistosomiasis for the disease. But the Commission recommended the use of the older name, bilharziasis.

capillaries, proceed to feed and grow and, in about 2 weeks, to migrate into the mesenteric venules. There the worms mature and mate and the females begin to lay eggs. The biologic incubation period for *S. japonicum* is 4-5 weeks; for *S. mansoni*, 6-7 weeks; and for *S. haematobium*, 10-12 weeks. The diagnosis of schistosomiasis depends on finding the characteristic egg in the faeces or urine.

The symptoms and signs of schistosomiasis caused by *S. japonicum* and *S. mansoni* are much alike. During the incubation period there is often a skin rash and characteristic diarrhoea with liver enlargement and tenderness, variable fever, and sometimes lung disturbances. During the period of egg laying and extrusion there is typical dysentery with frequent bloody stools, liver and spleen enlargement and tenderness, often rectal lesions and other even more serious complications. In the final period of tissue reaction and repair, various lesions such as intestinal papillomata, ulceration and fistulas may develop. The spleen and the liver are often greatly enlarged, there is usually serious diarrhoea, and there may be ascites and other major disturbances.

In *S. haematobium* infections the urinary system is involved and there are often serious lesions of the bladder, ureters, and other organs, with fever and general distress. Bloody urine is a usual sign. In uncomplicated cases there is usually no diarrhoea or dysentery in *S. haematobium* infections.

During the incubation period the symptoms and signs of bilharziasis are due chiefly to toxic products of the worms and to allergic reactions. In the egg-laying period the extrusion of the eggs causes various tissue damage with consequent bleeding and distress. Gradually, cellular reactions tend to block the eggs and to cause fibrosis of the affected organs. This impairs functional activity of the liver and intestines or of the urinary system. Bacterial infections of damaged tissues may cause abscesses and fistulas. With modern treatment in uncomplicated cases the chances of avoiding death are quite good and in early cases full recovery may be expected. But as the disease becomes chronic, vital tissues are destroyed and in advanced cases the prognosis is hopeless.

Modern treatment of early cases of schistosomiasis is quite effective and may result in some 80 per cent cures. But the treatment of chronic cases is less satisfactory.

Human infection with *S. mansoni* and *S. haematobium* is derived from water pollution from human sources. But *S. japonicum* infections may be derived from water pollution not only by humans but also by various mammals subject to the infection, as noted above. In some countries, human faeces and urine commonly pollute water in which appropriate snails live. Extensive use of raw human excreta for fertilizing garden and field crops greatly increases the chances that snails will be infected. Untreated sewage from houses in endemic areas emptying into streams may add to the danger.

The molluscan hosts in some cases can survive several months without being in water, meanwhile conserving the infective schistosome larvae. Eggs of *S. japonicum* have been found to remain viable for almost three months under winter conditions in China.

In Egypt and the Middle East, Puerto Rico, Brazil, and elsewhere, irrigation ditches have been an important source of infection in farmers who wade in the channels in the course of their work. Bathing and washing clothes are other ways of becoming infected. In some areas schistosomiasis is spreading, as appropriate snails are carried from infected foci into new irrigation projects. If a single snail is introduced into a favourable habitat it is possible, owing to exceptional reproductive capacity, to have a flourishing snail colony in about 40 days and transmission of bilharziasis in about 60 days. Snails may be carried by canal flow, on plants, by birds, or in other ways. Perennial irrigation from high level canals seems more likely to extend the range of schistosomiasis than does alternate flooding and drying. Children playing in cercaria-infected water are common victims. Neither sand filtration nor aluminium sulphate clarification will rid an infected water supply of cercarias. But chloramine, sodium hypochlorite, and gaseous chlorine will kill cercarias.

Schistosomiasis cannot become endemic in an area unless the appropriate molluscan intermediate host is present. In the case of *S. japonicum*, snails of the genus *Oncomelania* seem to be required, e.g. *O. nosophora* in Japan. *S. mansoni* uses the genus *Biomphalaria*, e.g. *B. boissyi* in Egypt; also the genus *Australorbis* e.g. *A. glabratus* in the West Indies; and also perhaps some other genera. *S. haematobium* prefers the genus *Bulinus*, e.g. *B. truncatus* in Egypt; also the genus *Physopsis*, e.g. *P. africana* in West Africa, and perhaps others. All of these schistosome-carrying snails are small in size, averaging 1.0 to 1.5 cm. in length and 0.4 to 1.2 cm. in width. Their life span may be as long as 4-5 years. Malacologists stress the need for clarification of snail taxonomy and for much more information about snail bionomics.

Schistosomiasis haematobia has probably been common in Egypt for several thousand years. Bloody urine was mentioned at least fifty times in Egyptian medical papyri and no doubt was often the result of schistosomiasis. There is no doubt at all about the characteristic, although calcified, eggs of *S. haematobium* found in the kidneys of two mummies of the Twentieth Dynasty (1250-1000 B.C.) by Ruffer [10]. During Napoleon's campaigns in Egypt, 1799-1801, many of his soldiers suffered from this form of schistosomiasis.

Assyro-Babylonian medical literature mentions a disease attributed to a worm and accompanied by bleeding from the urethra. This was probably a *S. haematobium* infection [5]. No clear proof is available of the existence of schistosomiasis in ancient times elsewhere in Africa or in the Middle or Far East, or in the Americas. The disease was first recognized in modern times by Fujii in Japan in 1847 and schistosome eggs were first found in excreta by Kasai in 1903. Adult worms of *S. japonicum* were first found by Fujinami early in 1904 and later in the year by Katsurada who named them. The life cycle of *S. japonicum* was worked out by several Japanese scientists between 1909 and 1914.

*S. haematobium* worms were first recovered by Theodor M. Bilharz, professor of zoology in Cairo, in 1851 and named by him in 1852. The eggs were first identified by Harley in Natal in 1864. Leiper in 1915 differentiated *S. haematobium* and *S. mansoni* infections in Egypt and showed that the worms and eggs for each species were characteristic. He also proved that each had its preferred genus of snail host. *S. mansoni* was named by Sambon in 1907.

## IRRIGATION AND SCHISTOSOMIASIS

That there is a direct relation between irrigation and schistosomiasis [9] has been known for some time. The Joint OIHP/WHO Study-Group on Bilharziasis in Africa [7] in its first report stated that: 'The introduction or development of irrigation schemes, as well as the change from basin to perennial irrigation, has always resulted in a considerable increase in the incidence and intensity of bilharziasis wherever that infection existed or was introduced by outside labourers. The severity of the infection may be such as to cause the abandonment of an irrigation system created at considerable expense.'

The Executive Board of the World Health Organization (WHO) at its fifth session (January 1950) adopted the following resolution :

Considering the danger to health entailed by the establishment of irrigation schemes in areas where bilharziasis is present, if the necessary sanitary precautions are not taken at all stages of the development of the schemes,

*Requests* the Director-General

(a) to call the attention of governments and of the appropriate bodies and specialized agencies of the United Nations interested in irrigation to such danger and to the safeguards recommended by the Joint OIHP/WHO Study-Group on African Schistosomiasis; and

(b) to make appropriate arrangements to provide the said governments and organizations with the technical advice which they may require.

Lanoix [9] points out that:

In spite of the importance of the relationship between irrigation engineering and agricultural practices and the spread of bilharziasis, very little effective action has been taken in the past by either public health or public works authorities in most countries affected. In fact, very little is known today of several aspects of snail ecology and of the effects of irrigation factors on the growth, survival and multiplication of disease-carrying snails. On the other hand, irrigation engineers are generally not trained to understand and take into consideration the health aspects of irrigation schemes, in spite of the fact that they aim at increasing the welfare and economic level of the whole population.

Lanoix quotes from the 1953 annual report of the Department of Health of Southern Rhodesia as follows :

Despite continual advice given by the Health Department, irrigation schemes are planned and developed without due consideration of the health aspects. There is absolutely no doubt that every irrigation area in the Colony will become infested with vector snails which will eventually become infected with bilharziasis unless the danger is realized at the outset, and plans for prevention made. The statement has been made before, and must be made again, that large scale irrigation schemes may well wreck the health of the country and bring the most grandiose schemes to a pitiful end. So many people see only the economic advantages of irrigation, and refuse to recognize the great disadvantages inherent in such schemes if adequate precautions are not taken *from the outset.*

Lanoix quotes the director of health as stating that one of the first irrigation schemes established in Southern Rhodesia after World War II has been a complete failure and is now largely abandoned because malaria and bilharziasis were left out of the preparatory calculations.

Khalil [8] gives an example in Egypt in connexion with the scheme for the perennial irrigation of four areas in the Quena and Aswan provinces of Egypt. Quoting from Lanoix :

Irrigation engineers disputed this relationship for some time, until conclusive evidence developed when these areas were carefully surveyed, three years after the introduction of irrigation. The following increase in bilharziasis prevalence was noted :

| | Percentage of population infected | |
|---|---|---|
| | 1934 | 1937 |
| Sibaia | 10 | 44 |
| Kilh | 7 | 50 |
| Mansouria | 11 | 64 |
| Binban | 2 | 75 |

Since the erection of the Aswan Dam and the introduction of perennial irrigation into most of the provinces of Egypt, bilharziasis has spread out and the health and mentality of the individuals has deteriorated.

Watson [18], referring to Iraq, wrote :

The vast new irrigation schemes that have been planned and are in some cases already under construction (November 1950) will, however, inevitably add to the extent and gravity of the problems of bilharziasis in Iraq. The enormous areas of barren but potentially fertile land which will thus be brought under cultivation in the central and southern provinces will certainly become bilharzial endemic areas unless adequate steps are taken to prevent the spread of snails into the new irrigation systems and to stamp them out rapidly whenever they appear.

An estimated 20 per cent of the population of Iraq is now infected with bilharziasis.

Van der Schalie [17] also emphasized the fact that schistosomiasis in some areas is spreading rapidly. He commented that:

It is important to note that in Egypt more than half the population, or an estimated 15 million people, have intestinal or vesicular schistosomiasis or both. Under present conditions of sanitation, education and medical treatment, the only hope of alleviating this serious situation lies in the control of the vector snails.... Wherever the system of drainage has been changed from basin to perennial irrigation, the human incidence of schistosomiasis has increased from about 6 to 60 per cent or more. At present there are various schemes in Egypt for converting large areas to perennial production. The spread of schistosomiasis in these regions may well cancel many of the benefits envisioned by those who ignore the threatened increase of this debilitating disease.

Van der Schalie also refers to a similar spread of schistosomiasis in the Sudan and Iraq and to the imminent danger of damage to the health of the inhabitants of areas it is now planned to irrigate.

Stagnant and slow-moving water, with associated water plants and muds rich in decaying matter, is often found to be the habitat of schistosome-carrying snails. For this reason improperly maintained banks of reservoirs, channels with water flowing at too slow a velocity and with poorly maintained banks and bottoms, and misplaced irrigation water lying stagnant in low-lying places often provide dangerous snails with the environment they prefer. Large canals with briskly moving water are not so often suitable for snail breeding but the unlined smaller channels are often infested with snails. Frequently, the snails are most common in that part of an irrigation system nearest a community and thus most often polluted by human excreta as well as most often the source of infections. Weed growth in irrigation channels is especially apt to provide snail-breeding places.

Methods of snail prevention and control include: removing vegetation from banks and shallow margins of reservoirs and channels; varying the water levels; cleaning, regrading, and straightening channels; flushing, draining, and the lining of channels with hard-surface materials that do not require a covering of earth. In some areas, concrete pipes instead of open channels have been found feasible not only to control snail breeding but to provide certain practical advantages as regards the use and conservation of water.

Snail destruction is still not a very rewarding approach to the problem. Such measures as netting out the snails and putting into the water certain predators and snail-killing bacteria have been tried with varying degrees of success; also using such chemicals as recently slaked lime, copper sulphate, sodium pentachlorophenate (Santobrite) and dinitro-*o*-cyclohexylphenol have all been tried, occasionally with considerable success. But much more study is required for the development of snail control measures.

Most important is the fact that the snails in question are harmless to man in the absence of schistosomes. If the eggs are kept out of the water the snails cannot become infected and obviously cannot transmit the disease. Hence the prevention of water pollution is of very great importance. Longer ripening of nightsoil, adding such fertilizers as ammonium nitrate to the nightsoil to kill the schistosome eggs, providing sanitary conveniences such as latrines, public baths, and laundry tanks, more effective public health education, must all be considered.

*Other health hazards.* Other health hazards may arise from irrigation besides the major ones of malaria and bilharziasis described above. For example, irrigation waters have been shown on occasion to spread the pathogens of various bacterial infections, diarrhoeas, cercarial dermatitis, guinea worm, poliomyelitis, and possibly histoplasmosis. Anthrax organisms are also spread in this way [16].

Finally, it requires emphasis that bilharziasis, like malaria, is a debilitating disease and debility is not conducive to good farming. The practice of irrigation agriculture in particular requires industrious and healthy farmers. Thus, throughout history malaria and bilharziasis have interfered with the use of arid lands. Today these two diseases harass irrigation farming in many areas. Moreover, as suggested above, there is a crucial chain reaction that in some instances has contributed to the virtual abandonment of an irrigation system: the more debility, the less canal maintenance, therefore the more *Anopheles* mosquitoes and the more snails transmitting more malaria and more bilharziasis, thus leading to more debility, and so on. This is the most important health factor in the history of land use in arid regions.

## CONCLUSION

Obviously, much more co-operation is needed between irrigation and public works engineers and public health officers. The governor or cabinet minister who has the final responsibility of authorizing an irrigation system in his country will be well advised to exert his full authority in this vital matter and to insist that such co-operation be early, active and continuous. Only then will effective consideration be given to ways and means of preventing and controlling snail and mosquito breeding and of establishing concomitant sanitary water supply, waste disposal, bathing, and laundering facilities for the communities involved in a proposed irrigation system. The ancient history of land use in arid regions suggests and recent history has demonstrated the great importance of the direct relationship between irrigation waters and public health.

# Part II: OTHER PUBLIC HEALTH PROBLEMS

*by*

JACQUES M. MAY

*American Geographical Society, New York*

Disease is a maladjustment between a living thing and the milieu in which it lives. Thus to produce this maladjustment two orders of factors will be at work : those arising from the environment which are physical and biologic in nature, and those arising from the host which are genetic in nature. In this general framework, medical problems that history has shown to be connected with human settlements in arid zones arise from three sources : the challenges of climate on man's physiology, e.g., heat stroke; the challenges of other living things sharing the same ecological niche on man, e.g., trachoma; the challenges on man that result from his efforts, successful or inadequate, toward controlling the environment in which he finds himself, e.g., malaria and schistosomiasis (discussed in Part I of this chapter), and dracontiasis and nutritional disorders, mentioned here.

The study of the past has little more to offer to the student of public health problems in arid zones than broad indications. The effects of climate have for long been confused with the action of the living things that grew under its influence. Coincidences have been mistaken for correlations, diseases mistaken for one another, recording of medical events has usually proved to be fractional and sketchy. Few if any of the diseases found in arid zones cannot be found in other areas.

While the study of the past is somewhat disappointing, it leaves, however, no doubt that the exploration of the arid zone frontiers will confront man with new challenges to which his organism will or will not adjust. This risk is the price to be paid for the creation of new settlements and new resources.

## THE CHALLENGES OF CLIMATE ON MAN'S PHYSIOLOGY

Lee [34] has pointed out the many difficulties that arise when an investigator looks for 'correlations between easily recognizable disturbances and easily recorded climatic events'. He remarks that such correlations cannot prove anything on the direct action of climate on man, only coexistence. However, the so-called statistically collected climatic events represent most certainly only a small part of the climatic disturbances that really take place. It can be easily predicted that unknown forces such as cosmic rays, radiations, radioactivities and others will be found to be present in arid zones, as elsewhere, in significant quantities, each geographical area having its own particular endowment of such forces.

In 1950 the present author endeavoured to list the various physical factors that might play a part in the occurrence of disease, and tried to correlate the knowledge available at the time with a selected list of pathological complexes. Needless to say that the correlation resulted in an impressive number of question marks.

These factors included luminosity, nebulosity, barometric pressure, temperature, winds, radiation, rainfall, humidity, dryness, terrestrial magnetism, static electricity, ionization of the atmosphere, soil conditions. This long list did not certainly begin to cover the multiplicity of unknown factors that are bound to influence man's settlement in arid zones.

Taking some of these factors analytically, either singly or in combination, a very small body of knowledge has been gathered. While most human beings feel comfortable between dry-bulb temperatures of 24° C. and 30° C. the reasons for the discomfort that is experienced below or beyond these limits by the majority of human beings are not known. To be sure, the extreme effects of this thermal strain have been observed, but the bio-physiological explanation is only partially understood.

Man like other homeostatic animals adjusts to heat mainly through radiation, convection and evaporation. In these mechanisms, sodium chloride and urea play an important role as do other electrolytes, and genetically conditioned physiological, individual characteristics. Malfunction of one or all of these systems may lead to one or several of the following clinical conditions.

Heat is one of the climatic factors causing some well known clinical conditions especially encountered in the past in the dry tropics.

### HEAT STROKE OR HEAT FEVER

This condition can manifest itself by subacute or acute symptoms. In the *subacute form*, the onset is insidious and there is an almost apyrexial period of increasing derangement of the body chemistry with a final phase of high fever. The patient complains of fatigue, headache, nausea, even vomiting, giddiness and insomnia. There is frequency of micturition and the patient becomes irritable. Signs of dehydration appear, the chloride in the urine drops to below normal. This may last a week or a little longer, according to the treatment instituted.

In *acute heat stroke* the breakdown of the defence mechanism against heat is quite sudden. An apparently healthy man is affected and very soon after the onset of excitation and delirium, he falls unconscious and sinks into a coma. In certain cases, convulsions have been reported; the skin becomes absolutely dry, the face congested, and the muscles rigid. The heart beats quickly and the blood pressure is low; the rectal temperature rises to 41° C. or 42° C. Even 46° C. has been reported at the time of death.

### HEAT EXHAUSTION

The onset is marked by giddiness and general fatigue, the pulse is rapid and weak, the temperature rises to 38° C. then to 40° C., usually the condition, if treated at this stage, does not become worse and health may be restored. Less often, the patient sinks into drowsiness, the heart quickens and the blood pressure drops. This heat exhaustion seems to be the result of a circulatory deficiency and is caused by the transfer to the surface of too great a volume of blood. If the condition is recognized, it is beneficial to increase the circulation of oxygen by inhalation and to reduce the superficial vasodilatation by cold aspersion or cold baths.

### HEAT CRAMPS

The condition is characterized by spasmodic contractures of certain muscular groups especially the flexodigitorum. Sometimes, too, the muscles of the abdomen become rigid, simulating an acute abdominal condition. Usually these contractures are spasmodic, lasting two or three minutes, only to relax and start again a few minutes later. These cramps are sometimes extremely painful, and under their influence the pupil of the eye dilates and the heart beats more quickly. Such patients should be taken care of at once. The pathogenesis of the condition seems to be dehydration with the lowering of chloride ions and sodium ions in the plasma, an absence of chloride in the urine, and a concentration of proteins in the serum.

The hot winds (sirocco) that blow over dry areas are said by the folklore to cause discomfort in predisposed people—no adequate study exists of this phenomenon—but winds have an important mechanical action especially in arid areas where the soil is broken into sand. Considerable amount of dust is moved about which is inhaled, eventually reaching the blood stream. The effects of these aerosols while as yet not accurately measured, can be neither minimized nor ignored. Again they will vary with a large number of other factors such as the chemical nature of the dust and the genetic constitution of the host, but it is safe to assume that certain particles of sand will create microscopic lesions in the mucosa of the respiratory system through which the intrusion of inanimate or animate things in the internal environment will be facilitated.

Entering now the world of speculations, we may remember that there is evidence that cosmic rays do interfere with human-built electronic apparatus as has been observed on several occasions. It would be unreasonable to assume that the electronic exchanges that occur in the economy are not influenced by such little-measured elements as cosmic rays and other radiations. A special study of their variations in arid zones in the context of the physical environment of these areas has yet to be made.

In addition to the physiological effects of the arid climate, the importance of its psychological effects cannot be minimized. Under natural conditions a complete change in outlook on life in unacclimatized people occurs. It has often resulted in a greater desire to separate oneself from reality than when man is left in the environment to which he is accustomed. This may result in drug addiction, and especially alcoholism. There is loss of mental initiative, a blurring of the sense of accuracy in reporting, and a need for greater concentration than that required to produce an identical performance in a less demanding climate.

## THE CHALLENGES OF OTHER LIVING TINHGS ON MAN

The arid environment may determine the occurrence of disease because it supplies an ecology that is adequate for the breeding of certain agents, vectors, or intermediate hosts. From the long list of such maladjustments trachoma and the cutaneous form of leishmaniasis have been selected as being the most significant.

### TRACHOMA

Trachoma, also called granular conjunctivitis, is a chronic disease of the conjunctiva and cornea; it is the result of an infection of the submucosal tissues by a virus whose presence together with other infective agents results in scars involving considerable damage to the vision apparatus. It is an important cause of blindness and is a major public health problem in vast areas, predominantly in the arid and semi-arid zones. The number of people suffering from trachoma is estimated at 300 million, while approximately 6 million children, women and men are blind as a result [3]. While the direct influence of the climate on the distribution or severity of trachoma is not well known, there seems to be no doubt that the combined effects of 'low humidity, wind and dust, could cause intense hyperaemia of the conjunctiva and play an important role in converting the comparatively benign, uncomplicated trachoma into the terrifying disease it can be' [2]. The disease is known to be particularly severe in North Africa, India, some parts of China and Australia where dust and sand storms are frequent. Freyche says that it is, however, not certain that all kinds of dust have the same effect. Workers in the phosphate mines of Morocco where the dust is intense seem almost free of the disease.

In Tunisia, from 40 to 50 per cent of the population is said to be infected, and in Algeria almost 1 million people are trachomatous. The prevalence in all African countries increases from north to south. It is widespread in the Union of South Africa among the Bantus, in the Transvaal along the Limpopo River and in various areas of the French Community Republics of West Africa.

In Asia, China is one of the most ancient and most heavily infected foci in the world. In India, the most infected States are Rhajastan, East Punjab, some areas of Uttar Pradesh and Madhya Pradesh.

In Australia, the disease is common in the Western and Northern Territories around Darwin and Alice Springs. It was at one time common in the United States in the so-called 'trachoma belt' which included most of the Western States in the Dust Bowl area. In recent years the disease seems to be controlled even among the Indian population. In Mexico, trachoma is found in the State of Sonora. It is reported in Chili and in certain territories of Brazil. While mostly prevalent in the dry areas of the tropics it is also found in the humid tropics.

Not only climatic factors but also biological and organic factors are of importance. The viral agents, *Chalamydozoa trachomatis* and *C. oculogenitale*, are usually associated with other micro-organisms that play an important role in the severity of the disease. It is even believed that if it could remain free from secondary infections, trachoma would be a mild infection. Most common among the agents combining their action to that of the trachoma virus are *Moraxella lacunata*, the Koch-Weeks bacillus and *Haemophilus influenzae*. Pneumococcus and gonococcus bacteria may in certain cases also add their action to that of the trachoma virus. The role of flies in its transmission may not be insignificant, though it seems likely that their role is purely mechanical. The fly may increase the seriousness of the infection because it carries agents of bacterial conjunctivitis. A number of cultural factors, such as ritual ablutions, increase the spread of the disease, especially where water is scarce and when many people use the same ponds for this religious practice. The crowding that occurs in the oases and villages of the arid zones is also an important cultural factor in enhancing the spread of the disease.

### CUTANEOUS LEISHMANIASIS

Cutaneous leishmaniasis is a very ancient disease. It seems to have been recorded as far back as biblical times. It is characterized at the beginning by an itchy, subcutaneous papule which soon ulcerates and is covered by a scab. When this is detached, a shallow ulcer is revealed that very soon becomes secondarily infected. The agent, *Leishmania tropica*, can be transmitted by direct contact or by a sandfly of the genus *Phlebotomus*. The Phlebotomi are very sensitive to the effects of the climate and need a constant temperature of around 26.5° C. to survive. New cases of Oriental Sore crop up at the end of the summer. It has been noted that the species of Phlebotomi that are vectors of *Leishmania tropica* can withstand dryer climates than the species carrying *L. donovani*, agent of visceral leishmaniasis (kala-azar). Two forms of Oriental Sore are known : a dry type essentially urban, and a moist type essentially rural. Wild rodents such as gerbils are known to play a role in the transmission of the latter in Asia.

The disease is not confined to arid zones but it is more prevalent there. It occurs in Iraq, the Near East, especially in Lebanon, Jordan, Israel and Syria where it has been given the name of Aleppo Boil. It is also found in the dry zones of Saudi Arabia. It is absent from the major part of the Indian peninsula except in the north where it is common and known under the name of Delhi Boil in the Punjab and Uttar Pradesh. It is found in the dry areas of Ceylon. It is common in Egypt. It is widespread in Tunisia where two main foci of endemicity exist in Gabes and Gafsa where it is known as "Bouton de Gafsa". It is common in the southern territories of Algeria down to the northern margins of the Sahara Desert. It is prevalent in a large part of Morocco from the southern oases to Fez. It has been found recently described in the areas south of the Sahara Desert especially in the northern parts of Nigeria and in the French Republics of Central Africa, especially in the zones bordering the desert. It is also found in certain regions of South and Central America such as in Mexico where it coexists with the mucocutaneous form of leishmaniasis.

## THE CHALLENGES THAT RESULT FROM MAN'S EFFORTS TO CONTROL THE ENVIRONMENT

Most important in terms of number of humans afflicted are the great scourges malaria and schistosomiasis, which were discussed earlier, but other threats to man's survival occur as a result of his quest for water in arid and semi-arid zones.

### DRACONTIASIS

Dracontiasis is a chronic infection of the cutaneous tissues caused by a nematode, *Draconculus medinensis*. It is also known as dracunculiasis, 'guinea worm', 'medina serpent', 'dragon of Medina', etc.

Dracontiasis is one of the oldest diseases known to man. It may have been first described in an Egyptian papyrus together with the story of the solar god. Moses is said to have alluded to it in the Pentateuch, when he spoke of 'fiery serpents' which attacked the Jews on the shores of the Red Sea, he also described the proper technique for its removal, a technique that has changed but little, if at all, today.

The distribution of the nematode is erratic, zones of heavy infestation being close to areas where it is unknown. It is not so common in Medina as might be expected, but it is very prevalent along the coast of the Hedjaz and Yemen. In India, it occurs frequently in the Southern provinces. It is known in Russian Turkestan and in Korea. It has been reported from Equatorial Africa, Sudan, Abyssinia, the Nile Valley, Iraq, East Africa, Nigeria, the Cameroons, Togo, Dahomey, Ivory Coast, Gold Coast, Senegal, Mauritania, Upper Volta, Tanganyika and Uganda. It has been observed in the Fiji Islands. The adult female worm has an average length of 60 cm. reaching in some cases 120 cm. The male worm is little known and seems to disintegrate as soon as he has impregnated the female.

The uterus is in the head of the female just behind the mouth and shoots the living embryos forward at the time of parturition. Young adults live in the connective tissues and also in the mesenterium where, according to certain authors, copulation takes place; then the male disappears and the female works her way, through the connective tissues, to the skin in order to give birth.

She seems to be guided by tropism for water, thus explaining why in countries where populations wade barelegged into step wells, as in India, the adult worm is found mostly in the leg, while where water buckets are carried on the back by water-carriers, there is a higher prevalence of localization of the adult worm in this part of the body. When the embryos are mature, the skin blisters and breaks up and the larvae are expelled outside where they have to fall into water to pursue their evolution. This usually takes place when the patient crosses a stream or walks into a step well. In water, the larvae may survive a few days until they are absorbed by a small copepod *(Cyclops)*. These are then swallowed by persons who drink the contaminated water. In the stomach, gastric juices dissolve the copepod thus liberating the larva; the trail through tissues then begins until the impregnated female reaches her subcutaneous habitat.

The initial local signs consist of a tender zone in the midst of which a small blister appears and the patient complains of itching. The blister bursts, usually after 24 hours, leaving a small ulcer (5-10 mm.). There is exudation of a cloudy sebaceous and sterile fluid. In the deepest part of the ulcer a small white head is visible which is the protruding uterus of the female. In certain cases, the worm can be felt as a hard twisting cordon in the skin. The expulsion of live embryos lasts 8-10 days, then the head of the worm appears in the middle of the ulcer, after which the process of healing is under way. In some cases, the worm is not eliminated and may be calcified in the tissue, where it can stay as long as 20 years without giving rise to any accident.

According to Stoll [4], writing in 1947, the disease affected 48 million people between Africa and Asia, the present figure may be nearer 60 million. Control of the disease involves far-reaching changes of living and cultural standards, such as the suppression of step wells, and the construction of safe drinking water systems.

NUTRITIONAL DISORDERS

Unless transformed by powerful industrial methods none of the arid zones provide adequate diets for their inhabitants. People living in oases and on the fringe of these zones suffer from various types and degrees of malnutrition. Vitamin deficiencies abound, especially among children; a study of these disorders and their correlation with agricultural practices would trespass the limit of this study.

Animal protein deficiencies are essentially represented by the syndrome known as kwashiorkor. This occurs essentially in young children who have been weaned from their mothers' milk and put suddenly on a starchy diet. While it is a cultural disease it must be thought about in areas where lack of moisture and lack of pasture will render the development of animal husbandry more difficult. The same can be said of urinary calculi found in the bladder of infants, a disorder which may also be correlated with animal protein deficiencies.

UNKNOWN DISEASES

An important aspect of the question of public health in arid zones are the new, as yet unknown diseases or maladjustments that the settlement of people in a new area entails.

Though it is not possible to forecast what these will be, they will arise from the new ecological niches that the control of the new environment will create and also possibly from the new responses offered by the hosts under the genetic changes that the new environment may foster. Man-made malaria is as well known as man-made schistosomiasis, but there are other transmissible diseases that can be arthropod-borne and that may occur in the future as a result of the particular ecological situation that will be created in bringing arid zones under irrigation. The new pattern of maladjustments or disease will then depend upon the nature of the soil that must be fertilized. The presence or absence of certain trace elements may make themselves felt in the diets of the settlers.

The genotype of the crops that will grow on these lands will also be important in terms of disease patterns, not only because they will or will not be able to synthesize the nutrients needed for man from the soil on which they will grow, but also because they will be able to absorb or to reject the newly discovered radioactive materials that might occur as a result of atomic explosions. The uneven distribution of Strontium-90 has already been noticed by scientists. The future of nutritional disease patterns in arid zones may very well depend in part upon the exposure of the land to these radioactive fall-outs, as well as it will depend upon the genetic capabilities of the plants that will grow, of the animals that will graze on that cover, and of the people that will feed both on the animals and plants. Further, and not to be forgotten, will be the changes brought about in the living things that will grow on these arid zones, by the mutations which environmental factors will determine both in plant, animal and human life.

Here we are delving into the unknown, but, as a result of recent acquisitions in knowledge in various fields, it is possible to recognize dimly the pattern along which these new maladjustments may develop as they have always in the past when the physical environment has been changed.

The public health problems that will arise in connexion with the future development of arid zones will be as numerous as they have been in the past but they will not be the same problems. The transmissible diseases mentioned above are unlikely to cause great concern. Once the sands of the deserts will have revealed to what degree they are capable of supporting animal and human life, it is likely that slow-acting nutritional disorders will emerge as the most important problems.

# BIBLIOGRAPHY

*Part I*

1. Ackerknecht, E. H. *Malaria in the Upper Mississippi Valley 1760-1900.* Baltimore, Johns Hopkins Press, 1945.
2. Alves, W. Bilharziasis in Africa. A review. *Central African J. Med.*, vol. 3, 1957. p. 123-127.
3. Arcos, G. Evolución de la medicina en el Ecuador. *An. Univ. Ecuador*, 1938. p. 1024.
4. Boyd, M. F. *Malariology.* Philadelphia, Saunders, 1949. 2 vols.
5. El-Nagar, H. Control of schistosomiasis in the Gezira. *Sudan. J. trop. Med. Hyg.*, vol. 61, 1958. p. 231-235.
6. Faust, E. C.; Russell, P. F. *Clinical parasitology.* Philadelphia, Lea & Febiger, 1957.
7. Gelfand, M. *Schistosomiasis in South Central Africa.* Capetown, Juta & Co., 1950.
8. Hoeppli, R. The knowledge of parasites and parasitic infections from ancient times to the seventeenth century. *Exper. Parasit.*, vol. 5, 1956. p. 398-419.

9. JACKSON, J. H. Bilharzia. A background to its endemicity and control in Africa with particular reference to irrigation schemes. *South African J. Lab. and Clin. Med.*, vol. 4, 1958. p. 1-54.
10. JACOBSEN, T; ADAMS, R. M. Salt and silt in ancient Mesopotamian agriculture. *Science*, vol. 128, 1958. p. 1251-1258.
11. JOINT OIHP/WHO STUDY GROUP ON BILHARZIASIS IN AFRICA. *World Health Organization technical reports series*, vol. 17, 1950. p. 14.
12. KHALIL, M. J. *J. Egypt. med. Ass.*, vol. 32, 1949. p. 820.
13. LANOIX, J. N. Relation between irrigation engineering and bilharziasis. *Bull. World Health Organization*, vol. 18, 1958. p. 1011-1035.
14. MAEGRAITH, B. Schistosomiasis in China. *Lancet*, 1958. p. 208-214.
15. MANDAHL-BARTH, G. *Intermediate hosts of schistosoma : African Biomphalaria and Bulinus.* Geneva, 1958. (*WHO monograph series*, no. 37.)
16. McMULLEN, D. B.; HARRY, H. W. Observations sur l'épidemiologie de la bilharziose et sur la lutte contre cette maladie. *Bull. Soc. Path. exot.*, vol. 50, 1957. p. 901-916.
17. ——; ——. Comments on the epidemiology and control of bilharziasis. *Bull. World Health Organization*, vol. 18, 1958. p. 1037-1047.
18. OLIVER-GONZALEZ, J.; FERGUSON, F. F. Probable biological control of *Schistosomiasis mansoni* in Puerto Rican watershed. *Amer. J. trop. Med.*, vol. 8, 1959. p. 56-59.
19. PAULINI, E. Bilharziasis control by application of molluscicides. A review of its present status. *Bull. World Health Organization*, vol. 18, 1958. p. 954-988.
20. RUFFER. In: R. L. Moodie. *The antiquity of disease.* Chicago, University Press, 1923.
21. RUSSELL, P. F. Malaria due to defective and untidy irrigation. A preliminary discussion. *J. Malar. Inst. India*, vol. 1, 1938. p. 339-349.
22. ——. *Malaria, basic principles briefly told.* Oxford, Blackwell Scientific Publications, 1952.
23. ——. *Man's mastery of malaria.* London, Oxford University Press, 1955.
24. ——. World-wide malaria distribution, prevalence, and control. *Amer. J. trop. Med.*, vol. 5, 1956. p. 937-965.
25. ——. KNIPE, F. W.; RAO, H. R. On agricultural malaria and its control with special reference to South India. *Indian med. Gaz.*, vol. 77, 1942, p. 744-754.
26. SMITHCORS, J. F. *Evolution of the veterinary art.* Kansas City, Veterinary Medicine Publishing Co., 1957.
27. VAN DER SCHALIE, H. In a schistosomiasis symposium. *Amer. J. trop. Med.*, vol. 4, 1955. p. 424-425.
28. WATSON, J. M. *J. Fac. Med. Iraq*, vol. 14, 1950. p. 148.
29. WORLD HEALTH ORGANIZATION. *Expert Committee on Bilharziasis.* Geneva, 1953. (*Technical reports series* no. 65.)
30. ——. *African conference on bilharziasis. Brazzaville, French Equatorial Africa, 26 Nov.-8 Dec. 1956.* Geneva, 1957. (*Technical reports series* no. 139.)
31. ——. The problem of bilharziasis. *WHO Chronicle*, vol. 13, 1959. p. 2-56.

*Part II*

32. FLYNN, F. Trachoma among the natives of the Northern Territory of Australia. *Aust. med. J.*, vol. 14, no. 2, 1957. p. 269-277.
33. FREYCHE, M. J. The ecology of trachoma. In: *The ecology of human disease.* New York, M.D. Publications, 1959.
34. LEE, D. H. K. *Climate and economic development in the tropics.* New York, Harper & Bros., 1957.
35. STOLL, N. R. This wormy world. *J. Parasit.*, vol. 33, no. 1, Feb. 1947. p. 1-8.

# SOME CONCLUSIONS

*by*

L. Dudley Stamp

The first objective of this book, a history of land use in arid lands, was and remains an attempt to ascertain what lessons could be learnt from the past which might help in understanding the problems of the present and in preparing plans for the future. The areas considered have been vast and varied, the problems as difficult as they are diverse. Each chapter is itself a summary of a wide range of varied knowledge and it seems to me that little would be gained by attempting further to condense what is already a highly concentrated mass of factual information.

It has accordingly seemed to me as editor that a more useful task I might at least attempt is to separate and elaborate some of the lessons which appear to me to arise from a study of the separate contributions and what immediate action is needed. Admittedly, this is a highly subjective approach, the selection of topics and the assessment of their importance must rest on my own personal judgement. Whilst indicated by the separate contributions, the problems for further study are often suggested as much by what the contributors do not say, since information is lacking, as by what they do say.

In the first place there can be no doubt concerning the startling and fundamental character of recent advances in the techniques of investigation and in the complete re-orientation of interpretations which have resulted. Broadly this is true in all fields of knowledge. It follows that conclusions drawn only a few years ago may now be far from valid : the facts need to be looked at again. Provided the observations made in the past are sufficiently precise and accurate they will still provide the basic factual information : it is the interpretation which will be different. Nor is the position at present static : on the contrary in some studies it changes with kaleidoscopic rapidity as new knowledge is acquired. This is true for example of the fundamental causes of aridity itself. As further observations, especially of the upper atmosphere and remote regions such as Antarctica are made, the character and behaviour of air-masses become clearer though as yet far from fully understood.

It is within the memory of most of us when aridity was equated simply with mean annual precipitation. It is still roughly true that the great deserts do coincide with areas of deficient total rainfall, but the more exact correlation is with precipitation efficiency, which brings evaporation into the picture. But it is potential evaporation rather than actual evaporation. or better, loss of moisture either directly or through plants which introduces the complex problems of evapotranspiration. It is no longer permissible to think in terms of a mean annual precipitation—itself highly irregular from year to year—when in fact the life cycles of plants are related to seasons. Aridity during a normal period of vegetative growth may be disastrous, whereas aridity during a normal resting period—for example of grass—may be almost immaterial. Much new thinking is thus still needed regarding both the meaning of aridity and its influence on plant life.

The rapid development of ecological studies has thrown doubt on the primeval character of much tropical vegetation. Whether any of the savannas or tropical grasslands with scattered trees can still be regarded as climatic climax vegetation, uninfluenced by man, becomes increasingly doubtful and the same is true of the 'natural' vegetation of semi-arid and arid lands. If deserts are spreading it remains uncertain how far the spread reflects climatic change and how far the conscious or unconscious work of man.

The mention of climatic change should serve to call attention to a very great recent advance in the techniques of investigation. By means of carbon-14 tests it is now possible to date, with a precision previously undreamt of, a wide range of archaeological material and so to construct a time-scale against which climatic fluctuations can be plotted. In due course, when records and finds have been fully re-examined, it will be possible to establish a complete chronology and to know precisely the relationship between the northern glacial periods and the pluvial periods of lower latitudes. When this has been done, we shall know whether or not the climatic fluctuations to be observed in different continents were synchronous or complementary in time. Light will undoubtedly be thrown on the reasons for migrations of peoples and their cultural centres and on the reasons for the selection or abandonment of settlement areas at least in a general way, but it seems more likely that an intensive study of recent times—the last few centuries, perhaps the last few decades—will be of the greatest direct value in the immediate task of planning a better use of arid lands. For the present is but a stage in evolution from the past into the future: what we need to know are present trends, to be established by comparing the present with the immediate past.

If there is one lesson which seems to stand out above all others in this review, it is the almost complete lack, in many areas, of precise knowledge of the present position. Land use is a matter of area and location and can never be expressed adequately by statistics, only by maps. It would seem obvious that the sequence of changing land use or, equally important, lack of use can only be traced properly by a series of maps. It is only when the changes can be definitely located in space that one can look for the factors which, in any given case, are responsible. It is true that some extraneous factor—i.e. extraneous as far as the land itself is concerned—such as a fall in commodity prices or the loss of a market may swing a whole region from one type of land use to another. But when it comes to assessing the influence of increasing salinification of the soil, or the incidence of local erosion, or the deterioration of grazing, such can only be fully shown when expressed cartographically.

Fortunately the last few decades have seen the emergence and perfecting of a new technique of study—through air photographs. It was clear from such early days of aerial photography as the nineteen-twenties that land could be photographed from the air which was difficult of access on foot or otherwise by surface transport. It was clear, too, that differences showed up from the air which were not apparent, or not readily apparent, on the ground. The surface of the earth has often been compared to a palimpsest—an old parchment used over and over again in which traces of older writing show through the efforts to clean them off, and to re-use the parchment. Through the pattern of present-day land use as shown on a vertical air photograph, there can often be traced some vestiges of former land use, of long-forgotten settlements, of abandoned roads and canals. In recent years there have been great advances not only in the actual quality and clarity of photographs, but also in their interpretation and use. Essentially the photographs are taken with a 40 per cent overlap and are examined in stereoscopic pairs. A range of elaborate machines by different makers from different countries is now available for the construction of maps from the photographs, but the emphasis has been on the production of ordinary topographical sheets. This is certainly a first necessity: vast areas of the earth's surface still remain unmapped in detail; only highly generalized and often very inaccurate maps exist for example of large areas of Africa. Most governments have active plans to remedy this position: in the case of British territories for instance the Directorate of Overseas Surveys is engaged in producing outline maps usually on the scale of 1:50,000 drawn from aerial photographs of many overseas territories, especially in Africa. These 'preliminary plots' as they are called are simple uncoloured maps showing diagrammatically the main physical features (but no contours), a rough indication of dominant vegetation such as forest, and a delineation of human settlements and lines of communication.

The really important point is that an infinitely greater amount of information is available from the air photographs. They should be freely available to researchers; they should be worked over with the help of experts in different fields.

In the first place the air photographs provide a complete picture of the surface cover. Although the expression commonly used is 'land use', non-use of land is equally important and, away from areas of cultivation, this becomes a survey of existing natural and semi-natural vegetation. It cannot be too strongly emphasized that air photographs show differences in the intensity of vegetation far more clearly than they can be detected from the ground. It is possible, therefore, to construct complete and detailed land use maps which are further discussed later.

Especially in arid lands where the surface vegetation is sparse, air photos reveal many details of the ground itself. The drawing of outline or preliminary geological maps from air photos is now almost an essential prelude to geological survey on the ground. Although it has been claimed that soil maps can be constructed from air photographs, this claim needs careful examination. In so far as soils are identified and classified by their profile, which lies below the surface and cannot possibly be seen in air photographs, the construction of a soil map is impossible. But certain soil features, especially in arid lands, do show up very clearly in air photographs. Rocky outcrops, screes, fans and floodplains are obvious surface features with closely related soil characters which can readily be mapped. But air photographs show areas of salinification and waterlogging with remarkable faithfulness, indeed far more accurately than can be easily seen on the ground. In cultivated areas depth or quality of soil is often reflected in the pattern of crop intensity. Thus it is possible to construct what may be called reconnaissance soil maps. Side by side such soil maps and land use maps frequently show the influence of increasing salinification in leading towards abandonment of land : on the other hand they may indicate areas where favourable physical and soil conditions suggest the need for further investigation and possibilities of settlement. This approach, by a parallel land use and soil survey from the air in an arid region, was first undertaken on a large scale when the Government of West Pakistan commissioned an aerial survey of the Indus Valley in 1954 from which generalized maps on the scale of 1:250,000 were prepared.

That air photographs reveal traces of former land use, almost unsuspected on the ground, was appreciated when photographs of southern Britain showed clearly the pattern of small square fields from Celtic times on what are now the open grasslands of the Downs. Since then archaeology from the air has become a highly skilled branch of study, and over large areas of arid lands it has become possible to construct maps of past land use complete with such features as settlements, roads and irrigation canals. The material exists, especially now many of the features revealed can be accurately dated, for the construction of such land use maps of past periods over many areas. By comparison with the land use maps of the present day the areas of maximum or minimum change become apparent and causes can be investigated. In the few areas where such detailed comparative studies between past and present have been made it would seem that, as would be expected, the poorest lands have defied the efforts of man at utilization through the ages. But there has also been remarkable stability of land use wherever physical conditions are fully favourable to human settlement. The virtues of Nile alluvium, with water available, have been appreciated for many millennia and intensive cultivation has been the rule throughout the centuries. If mankind is to survive, the evidence points to the long-term need to conserve the world's best soils for food production. Everywhere it seems to be established that the maximum of change has been on land of intermediate qualities. Land which, in times of high prices or strategic necessity, it pays to cultivate will be abandoned in the face of competition from more favoured regions when prices are lower. This accounts for the very wide fluctuations of settlement and use on many arid margins.

To my mind the historical review in the preceding pages reveals the tragic lack of exact information regarding the past, and highlights the necessity for creating an historical document relating to the present as a basis for future work. A broad general picture, highly generalized, can be included on maps on the scale of 1:1,000,000 or smaller but, gigantic as the task may be, what is needed is a full record on maps of a large scale—something at least of the order of 1:100,000 or 1:50,000.

There is no doubt that land use in arid lands in the past has been dictated in large measure by the detailed relief of the ground. On the same geological formation may be found elevated plateaux incapable of being supplied with irrigation water, eroded badlands where the terrain precludes development and level plains where change is possible. Clearly therefore the detailed maps should show micro-relief or geomorphological units. Obviously water is of such paramount importance that any indication of its existence in surface streams, intermittent or perennial, or in wells and springs should be recorded, together with those indications of soil and hydrological conditions such as salt crusts. The map, in short, embraces what can be shown, often very little, of hydrogeology and soils. But, in general, vegetation and land use (or non-use) become an index of the total influence of physical, historical and human factors. In his account of Egypt, Professor Hamdan has used the master key proposed by the Commission on a World Land Use Survey of the International Geographical Union—simple in outline and designed for the inclusion of whatever subdivisions may be locally necessary. It advocates nine main classes : 1—settlements and associated non-agricultural uses of land (red); 2—horticulture or intensive cultivation (purple); 3—perennial or tree crops (orchards, vineyards, palm groves, etc.) (light purple); 4—cropland, (a) continuous (b) land rotation, distinguishing irrigated and non-irrigated land (browns); 5—improved grassland or meadow (light green); 6—various types of unimproved grassland (yellow and orange) allowing for the differentiation of the many vegetation types; 7—forest and woodland (different greens), again allowing for botanical differentiation of many types; 8—marsh and swamp (blue); 9—unproductive (grey), allowing for the separation of the several types of desert and semi-desert.

Such maps are factual documents, the classification is essentially objective and avoids the danger inherent in 'land capability maps' and the subjective judgement as to potential land use.

When such a record for the present day is compared with whatever similar records may exist of the past it is often possible to detect trends in change —it may be evidence of desiccation and deterioration of vegetation or increasing salinity. Planning for the future becomes the encouragement of such trends as may be good—natural regeneration of vegetation for example, or the reversal of trends judged to be bad, such as salinification.

Any detailed survey of the present position, such as the accounts given above of South Africa and Australia, suggests the delicate balance between the environment, the natural vegetation, fauna, land use and development. Everywhere basic research in ecology cries out for attention: almost daily, new factors are being introduced. Especially significant is the present chemicalization of agriculture: so very, very little is known of the long-term effect of chemical manures, toxic sprays and dressings such as fungicides, insecticides and selective weed-killers.

Among the positive lessons to be learnt from this historical review that may serve to guide our present thinking and future actions, there is one which seems to me to be of outstanding and overriding importance.

It is the delicacy of balance between man and his activities on the one hand and the environment on the other, in all arid lands. So long as an equilibrium is maintained efforts to use the arid lands may well prove highly successful, but that equilibrium is very easily upset by any one of a large number of factors and success is at once turned to failure on a large scale. The prize is large but the dangers are great. This concept of a delicate balance can be illustrated in a number of ways. Where man by dry-farming methods relies on the natural rainfall or available water he will be successful in years which are average or better than average, and may be rewarded by crops which are excellent in quality and reasonable in quantity. He may survive a year of poor rainfall and partial crop failure but a second year of less than average rainfall or a single year of real drought will result in complete crop failure and starvation. Similarly with the pastoralist in the semi-arid grazing lands there is a delicate balance between the scanty herbage—often nutritious and itself very resistant to climatic vagaries—and the grazing animals. This balance can be permanently upset by overgrazing in a poor rainfall year when the animals fail to find enough fodder to survive, but in the attempt so destroy the vegetation as to prevent its recovery the following year. History abounds in examples of mass migrations of men and animals occasioned by famine resulting from one or more years of deficient rainfall. The carrying capacity of the land in men and animals is that of the poorest years, not that of the average years. By way of contrast in the better watered countries harvests may be scanty in one year by reason of deficient rainfall or in another by excessive rainfall causing floods, but there is always a greater latitude. Rarely is failure complete.

The introduction of irrigation water does not alter this concept of balance or equilibrium; it merely changes the emphasis. The more primitive forms of irrigation—by inundation canals, 'tanks' like those in India, and 'hafirs' for stock-watering in the Sudan—may themselves fail to carry water in poor rainfall years. Even when perennial irrigation from modern dams and wells is available the utmost care is needed in controlling the amount of water used. With only a little too much, waterlogging will soon appear if the drainage is not adequate; with slightly too little, evaporation will quickly result in salinification of the land by the salts always present in the water. The balance between water led on to the land and water drained off is still insufficiently studied and the position is complicated by the physical, chemical and biological character of the soil. There is certainly no doubt that many successfully irrigated areas have in due course been abandoned by increased waterlogging or salinification.

Man in the well watered lands, whether in the tropics or mid-latitudes, can live to a large extent if he so chooses in small units—even family groups. A peasant farmer can clear the land, till it, and live on the resulting subsistence crops. With a reliable source of water such as a spring or well he may at times do the same in arid lands, but it is more likely that his source of water is a precious resource for a large area: he must share his water. The age-old conflict between sedentary agriculturalist and semi-nomadic pastoralist persists to this day. The sharing of a water supply involves co-operation and the evolution of a social system of some sort. Any considerable work of irrigation, even if it be only a village tank, involves co-operative action. Those civilizations of the past which depended upon large-scale irrigation relied therefore not only on a high degree of technical skill but also the maintenance of law and order within a community. In such cases a new and delicate balance was set up, a balance easily destroyed by any upset of physical or social character. An exceptional flood would sweep away a barrage, and a river change its course; an invading army needed only to destroy an irrigation dam to render a whole region powerless. Today even a small well-placed bomb could destroy vast areas of irrigated land.

It is often difficult to ascertain, in reading the historical records, which of the many possible factors led in any given instance to the abandonment of the former centres of civilization; one suspects that warring armies and internecine strife have often been important. Professor Kovda, for example, has given specific cases along the Amu Darya. On the other hand there are numerous examples of wise conquerors providing just the discipline needed to maintain an irrigation civilization in good order—and to extend it.

Where a civilization depends upon one or a small number of major sources of water, it is peculiarly vulnerable to epidemic killing diseases. Before the causes were known vast areas may have been so devastated by malaria as to leave abandonment as the only solution. This would seem to have been the reason for the disappearance of the population from the tank-irrigated dry zone of Ceylon. Was it possibly the cause of the fall of the great Harappa civilization of the Indus basin?

It does not seem to be generally realized that the whole concept of irrigation in arid lands has been changed fundamentally in the course of time. This is splendidly brought out by Professor Hamdan in his account of the history of land use in Egypt. In early days, and indeed for many millennia, it was the purpose of irrigation in Egypt to allow the muddy waters of the Nile, bringing their load of material rich in both inorganic and organic plant food from the distant mountains of Ethiopia, to spread over the riverside lands during the high water season, there to deposit their invaluable load as a thin film carefully spread over the fields. The deposition was controlled by the division of the land into basins, the crops relied for nutriment on the fertile silt, holding moisture long enough for the plants to mature. Gradually the picture has changed, mainly in the last century. The basin-irrigation of Egypt had obvious disadvantages. It depended upon the height of the Nile in the high water season: in some seasons the river might not rise sufficiently to flood the basins, and the Nilometer, measure of the height of the river, became an index of the country's prosperity. In any case only the lower riverside lands could be flooded : land with good soil but a few feet higher could only be watered by the laborious *shadūf* or *saqia* or Archimedian screw. So gradually irrigation from the river water impounded by dams across the river has superseded the old system. But now, only clear water is led on to the fields; artificial fertilizers must take the place of the annual layer of silt. By maintaining a good current in the main river much of the silt will remain in suspension to be lost eventually in the Mediterranean Sea. Otherwise it will be deposited on the floors of the reservoirs there slowly to cause them to silt up.

In nearly all parts of the world irrigation is conforming to the standard pattern: the large masonry dam behind which water collects to form a permanent lake from which it is led off first in main canals and then through distributaries. The area 'commanded' is related to the height of the water, and so to the height of the dam.

Evidence is growing that such a system may be fundamentally wrong. North America already has examples of reservoirs which have silted up completely in a few years. Everywhere in sunny arid lands evaporation is very high and is of course directly proportional to the surface area of water—it is greatest in shallow desert basins. Evaporation continues from the main and distributary canals, indeed right until the water which has percolated into the soil is taken up by plant roots. Evaporation from a free surface of water may be as much as 50 inches of water a year, and the total may amount to a high proportion of water available. Dissolved salts do not evaporate : they are left behind and an increasing salinity is the result.

A review of the history of irrigation suggests a number of changes needed in present practice. All over the world underground storage has played a large part in the past : where a natural reservoir or acquifer existed within reach of plant roots from the surface it has been used direct as in many oases. Dr. Armillas records those cases where superficial layers of soil or sand have been skimmed off. In many parts of the world the alluvial cones or fans at the base of mountain ranges form natural underground storage and water has been reached by those tunnels known variously from Mauritania to Sinkiang as *foggara*, *quanat* or *karez*. The modern equivalent would be to tap the water by pipes, from which the flow is readily controlled. A modification of this is seen in the recent developments in Israel where water is being piped from the streams of the rainy north right to the dry southern Negev, there only to be used when vitally necessary. Loss by evaporation is virtually eliminated; the precious water is only turned on when actually needed. Further, it can be led into light movable pipes for the production of 'artificial rain', rapidly proving itself the most natural form of irrigation—in addition to being economical and effective.

In northern India and Pakistan where the streams often come down in disastrous floods from the hills, a technique in some respects resembling the ancient basin irrigation of Egypt has been developed. The silt-laden waters are allowed to spread widely over a valley floor behind a low earthen dam : the silt is dropped and clear water is collected centrally and allowed to escape through a masonry or concrete channel near the centre of the dam. Crops can then be sown in the moist mud, the waters permitted to escape can be used to irrigate other land below the dam.

This successful recent development in arid West Pakistan is indeed getting back to a settlement pattern typical of many arid lands in the past. The floodplains of the rivers with their fertile moist alluvial soils provided the food crops, grown as and when water supply and climate permitted; the villages were sited on the valley margins safe from flooding and rough unenclosed grazing was provided by the range lands beyond. The villages of necessity were sited near a spring or permanent tributary water course. Cultivation and water control were co-operative efforts; hence a village and not scattered farmsteads. Two lessons from this successful model from the past tend to be forgotten. First, the fertile cultivable lands were built up naturally by river-borne mud or silt. What is needed with many projects today are effective means of trapping and distributing this river mud, so often encouraged by 'river training' works to run to waste. The second lesson lies in the siting of the nucleated settlement. Too often in modern reclamation works the people have been expected to dwell in isolated farmsteads, which they may refuse to do.

The emphasis placed here on the need to collect and distribute where required to build up new cultivable lands the silt and mud load of rivers should lead us to some reassessment of the erosion problem. Geologists have always recognized erosion as one of the unceasing inexorable processes of Nature. Towards the end of last century W. M. Davis made familiar the concept of the geographical cycle or cycle of erosion—land raised above sea level at once subjected to forces destined to wear it down almost to a plain—in other words a peneplain. Such a cycle was only interrupted by a renewed uplift of the land which accelerated erosion and initiated a new cycle. In the youthful or early stages of a Davisian cycle the attack of the elements on uplifted areas was fierce, from the highly accidented relief of the uplifted mountains vast quantities of material were washed down to lower levels. In the later stages of the cycle not only was erosive action on gentler slopes itself more gentle, but a mantle of soil and protective vegetation slowed the process still more. Rain and wind were prevented, by this protective covering, from reaching the underlying rocks, and erosion was narrowly limited to stream courses. It was American experience in particular which drew world-wide attention to the problem of soil erosion. There, the great grass-covered plains of the prairies grazed, but not overgrazed, by herbivorous wild animals such as the buffalo, had become stabilized, and erosion was negligible except along the actual stream courses. But the coming of the agriculturalist with his plough exposed the soil to the destructive action of rain and, in dry seasons, to the force of the wind. Soil was quickly removed by rain along plough furrows, which became gullies, by wind over hugh stretches which became dust bowls. The phenomena, previously known to be serious in other lands, were found to be enormously widespread. They were recognized in the bare hillsides of China, the southward spread of the Sahara in West Africa and in the *dongas* of the South African veld. In the world as a whole it seemed that soil was being lost faster than new lands were being reclaimed. Phrases like the 'greatest scourge the world has ever known', the 'rape of the earth', 'our plundered planet' set off a world-wide fight against soil erosion. In this review of the history of land use in arid lands, it is difficult to say in how many cases abandonment of settlements has been due to soil erosion and the consequent spread of 'man-made deserts', but it would certainly seem to be the prime cause in some. In the subsequent efforts to prevent soil erosion, however, the pendulum may have swung too far. Erosion, cutting first through the soil and then into the rocks below, is a world-wide geological phenomenon. In many upland areas it cannot be prevented and viewed on a long-term basis the great fertile alluvial plains of the world are the result of erosion in the mountains. There would be no fertile Nile Valley in Egypt were there not erosion in the mountains of Ethiopia. Whilst erosion must be controlled, it would seem that much more thought should be given to the control of the eroded material. Too little attention seems to have been paid to the results achieved by P. A. Yeomans in the arid margins of Australia. It is often claimed that a few inches of soil are the result of hundreds or thousands of years of soil formation, and may be lost in a few days of severe erosion. Yeomans has shown that, in suitable cases, by leading water round the contours of a hillside and allowing it to seep gently down that hillside he can create conditions suitable for a micro-fauna and micro-flora to live and multiply and to convert the mineral subsoil into a good deep workable soil in a couple of seasons. This is essentially enlisting the forces of Nature in the work of reclamation. The description by Professor Kovda of the 'liman' cultivation in the USSR, where moisture and soil are arrested on valley side terraces, is closely comparable.

This leads naturally to a consideration of the great dilemma of the present day which affects practically all forms of land reclamation and improvement. A good 'natural' soil has a base of mixed mineral particles and a considerable proportion of organic matter : it has a texture and structure of its own, a soil hydrology and a soil climate which promote the life and well-being of countless millions of soil organisms, mostly minute, but including creatures as large as earthworms several feet long, which convert decaying matter into valuable plant food. Such a natural soil provides a firm footing as well as the required nutrients for the crops of man : its quality is maintained by careful cultivation and the addition of organic manures; this is the method of working with Nature and of enlisting the services of Nature for the benefit of mankind.

But economic plants can be and are being effectively grown simply by giving them a mixture of inert mineral particles to provide their roots with a hold and then feeding them with water containing essential nutrient salts in solution. In its extreme form this is hydroponics, but to a large extent it eliminates soil, has no need of soil organisms (except in special cases such as for soya beans), but very heavy application of chemical fertilizers or 'artificials'. It would seem probable in many cases that the application of the chemical fertilizers may actually destroy both soil structure and soil organisms. The history of land use in arid lands suggests that, provided toxic salts are absent, a suitable mixture of mineral particles to hold roots, fed by water with requisite fertilizers, can produce outstanding crops. 'Soil' as understood in mid-latitudes can be eliminated. This opens up vast possibilities of mixing sand, silt and clay in right proportions by modern earth-moving machinery and so making 'soil' as a permanent asset. Vital trace elements can be added—Australian experience is fundamental in this regard—or noxious ones counteracted.

Reading carefully the history of land use in arid lands it is clear that small details of micro-relief have often been of the utmost importance. This is well illustrated by Professor Kovda's account of the *padiny* of the Russian steppes—shallow depressions in the rolling or otherwise featureless plains but sufficient for more moisture, especially from melting snow, to collect and to encourage a development of soil with above average organic content and so to lead to 'depression farming'. In the arid savanna lands of the west central Sudan the shallow *hafirs* occupy similar depressions : they collect water and serve stock from a considerable radius. There it has been found possible to use modern machinery to dig out similar shallow depressions—in other words to create artificial *hafirs*. Micro-relief of the land is usually closely associated with the water table. Professor Kovda has described the *kair* farming along the Amu Darya and Sir Darya where fresh groundwater from the rivers percolates laterally into the alluvia of the flood terrace sufficiently near the surface to be reached by plant roots. In some of the sandy lands of dry regions in Spain and Portugal magnificent and valuable market-garden land has been created on the same principle. It is important to note that in other lands such potentially valuable areas could only be detected by *detailed* topographical, geological and hydrological surveys.

To my mind this historical review does little towards solving the vexed question of the relationship between vegetation cover, especially forest, and climate. The influence of a close cover of grass or trees in preventing soil erosion is clear enough, the value of trees as windbreaks is similarly obvious. Undoubtedly deforestation is a potent cause of the spread of man-made deserts and so is overgrazing of grasslands and scrublands. The evils of erosion can be prevented or minimized by afforestation and the maintenance of a grass cover. Plant life is helped by improved water circulation and creation of microclimates, but whether the climate is changed to any appreciable extent is another matter.

What this historical review does seem to do is to call into question the whole concept of a climatic climax vegetation, at least insofar as the arid lands are concerned. From the dawn of geological time when life appeared on the surface of the earth animals and plants have lived together, the animals deriving their sustenance ultimately from the consumption of plants which alone can manufacture organic food. What vegetation may exist is therefore not only the result of the physical factors which make up climate but also of the nature of the soil and of the symbiotic relationship with animals.

In arid and semi-arid lands the vegetation must obviously be far from a climatic climax one. The pressure of wild animal life on vegetation is usually severe, even without man's domestic animals. It has also been argued by many ecologists in recent years that the plants in a natural habitat are not those best suited to the climatic conditions but those best able to survive in the struggle for existence by their ability to adapt themselves to adverse circumstances.

Two theories of the domestication of animals advanced in the preceding pages are of interest in this connexion. One is that man, relying on the chase, often went hungry and so seized upon the idea of retaining his prey alive until required—whence followed the whole technique of pastoral farming. The other is that in time of drought, animals and man lost their mutual enmity at the common waterhole, engendering a mutual co-operation leading to domestication. In either case there was a pressure, either temporary or becoming chronic in areas of progressive post-glacial desiccation, of animals on vegetation. A climatic climax vegetation could not have existed, but what did exist was a symbiotic balance between plant and animal life.

With the concept of such a balance as the usual rule in arid lands, it becomes easy to understand the frequently disastrous results of exotic introductions, whether of plants or of animals into an alien environment. The classic example is of course Australia, briefly related by Sir Samuel Wadham, and the introduction of the prickly pear, *Opuntia.* A succulent plant which might, as desired, have formed a useful addition to the arid grazing land found an absence of competition which enabled it to invade successfully 2,000,000 acres of farmland. A similar example is afforded by the jointed cactus, introduced from South America into South Africa as an ornamental plant—to become officially the most noxious weed in the sub-continent. In the reverse direction Australian eucalypts have, with the help of man, invaded the arid lands of a large part of the earth, but in this case with beneficial results.

The lesson again is one that stems from that permanent problem of arid lands : the ease with which the existing delicate balance can be upset.

The development of arid lands is at present being associated very closely, almost identified, with the bringing of water from surface or underground sources to make possible the growth of crops or of fodder for domestic animals. It is being identified, in other words, with the development of farming and animal husbandry. Yet this concept of arid land development ignores one of the clearest lessons to be drawn from the history of land use. With the exception of Australia the great developments in arid lands in the past have been associated not only frequently but even usually with cities. Civilization in the deserts has often been essentially an urban civilization. This is true not only of Nineveh and Babylon and of the Indus plain; it is true of the Roman *limes* in North Africa, to a larger extent of the Mandingo and other empires which flourished on the southern margin of the Sahara; it applies also to pre-Columbian America. The example of Damascus, a beautiful city surrounded by intensively cultivated gardens watered by the Barana, is indeed typical: farming, or more correctly horticulture, was subsidiary to the needs of a thriving urban centre. Although Whyte states categorically that 'Ur, like other Sumerian cities, started as the administrative centre of an irrigated district' it would seem equally possible that it might have originated as a 'city state' and that the irrigation of surrounding lands was of necessity developed to supply food. The fact that Ur was abandoned when the Euphrates changed its course might result in either case. It is interesting to note that Harappa has revealed its secrets of a high-living urban civilization: it is only presumed that there were irrigated lands to provide the city folk with their food.

The modern urbanization of arid lands is associated in part it is true with the exploitation of minerals, especially oil, but the trend in the arid parts of the United States is of particular note. From 1950 to 1960 the population of the United States as a whole increased by 18.6 per cent but the population of the arid state of Nevada by 76 per cent, of Arizona by 71 per cent and New Mexico by 38 per cent. But the increase in the arid states of North America does not reflect increased intensity of irrigation agriculture nearly so much as a purely urban growth. In the same 10 years non-agricultural employment increased in Arizona by 99 per cent—manufacturing by no less than 204.5 per cent. The factors which are favouring this industrial development in arid regions are the same as those which favour the development of other urban centres as resorts—Reno and Carson City in Nevada or San Jose in California. Abundant sunshine favours outdoor living, the modern air-conditioner has ensured homes and offices at an optimum for physical or mental work and cool nights for sleeping. It is cheaper to cool a building in a hot summer than heat a similar-sized one in a cold winter. American manufacturers are finding employees will accept lower wages in arid lands where they can live more cheaply as well as more happily. But water in arid lands is scarce and its most economical use is in an urban water supply. In the Tucson area of Arizona it has been estimated that water sufficient to irrigate 14,000 acres of land employing 1,500 people would support more than 200,000 urban dwellers and the waste domestic water could still be used for intensive horticulture, itself benefiting from nitrogenous urban waste.[1]

It may well be therefore that the best development of arid lands in the future may be of industrial centres surrounded by and stimulating intensive market gardening—far removed from the usual picture.

It is not easy to see what lessons can be drawn from present day Australia where half the population already live in the capital cities of the well-watered fringe, and the general tendency seems to be to withdraw from the arid and semi-arid lands, despite modern transport, radio communication, artesian water and possibilities of home air-conditioning, in favour of more intensive use of the better watered lands.

When emphasizing how many of the successive arid zone civilizations of the past have been associated with great cities set in the midst of irrigated lands, what was the social organization involved? It was frequently of a feudal character—well seen in the Rajputs of India described by Professor Bharadwaj. Sometimes it was the organized exploitation of the conquered by the conquerors, sometimes the use of slave labour. On a smaller scale the successful *huerta* or *vega* of Spain and North Africa noted by Professor Despois resulted from control by a wealthy nobleman; sometimes the whole focused round his elaborate pleasure gardens. However successful such social organizations may have been in the past they are out of harmony with democratic ideals of the present day. Some would urge that thinking must be entirely forward; the past must be ignored. But one vital lesson remains: the need for a strong, stable government and a truly united effort.

This raises the question whether enough attention is being paid to social studies.

Many present day attempts to utilize more fully the arid lands and to secure better conditions for their inhabitants would seem to be based, if history is read aright, on false assumptions and false standards of human values. The camel nomad of the Eurasian wastes, or the black-tented Bedouin would seem, by western standards, to lead a hard and precarious life with a food supply scanty, uncertain and dull. Bring water to the arid wastes and with irrigation there can be assurance of abundant food for both man and his animals—a general rise in the standard of living which must surely prove an irresistible magnet. But is the basic assumption here correct? Why should the nomad, free to wander at will, exchange his life for the day-in, day-out ceaseless grind of being tied to a single plot of land? As Professor Despois notes, there are examples in North Africa of the nomad, induced to adopt a sedentary life, reverting to his former nomadic ways. The highest form of human existence would indeed seem to be semi-nomadism. Two phenomena at the present

1. Data from A. W. Wilson, Urbanization of the Arid Lands. *The Professional Geographer*, 12, 1960, p. 4-8.

day are world-wide. The first is the growth of the million-city—i.e., the very large city, which would seem to suggest that the deliberate choice of the majority is a city life. The second is the inexhaustible attraction of what is now called tourism—i.e., longer holidays, longer journeys farther afield, often with a caravan or chalet in the wilds to recapture the free and open life. This is getting very close to semi-nomadism and a modern transhumance from winter quarters in the city to summer camp by sea, lake or mountains. Why, then, should the nomad of the arid lands be expected to enjoy becoming a sedentary peasant farmer, or worse still, a peasant farmer isolated in the midst of irrigated fields demanding constant attention?

There are other reasons why a modernized version of semi-nomadism may be the right answer for vast areas of the arid lands. The balance between grazing animals and available herbage is a particularly delicate one. Both undergrazing and overgrazing produce disastrous results. If land, whether range land or improved pasture, is undergrazed the animals select the palatable plants and leave the less palatable to thrive and become dominant. With overgrazing this does not happen, but the whole is so eaten over as to render recovery difficult, and often to induce soil erosion. Yet no type of grazing in arid or semi-arid lands with an inevitably varying annual rainfall has a *constant* carrying capacity for domestic animals. Adjustment can be perhaps by killing off animals in poor fodder years, but far more naturally by moving to more favoured areas—nomadism and transhumance. There are two ways in which modern developments could be used to evolve a new technique of semi-nomadism—one by using modern transport for either animals or fodder, the other by using irrigated fodder as required to supplement grazing.

It has often been pointed out how, in other spheres, Stone Age man is being translated direct into the 'jet age', or at least into the age dominated by the internal combustion engine. Is it reasonable, in another sphere, to expect satisfaction from a move from semi-nomadic pastoralism, an inherently free life, to the semi-slavery of peasant farming already outmoded elsewhere?

In the preceding pages are found many examples of the highly specialized economic incentives frequently found in the history of land use in arid lands. Professor Talbot in his account of South Africa points out how the Merino sheep made possible the pioneer colonization of the arid interior, as it did also in Australia. The introduction of the Angora goat into South Africa enabled still more arid lands to be utilized but only so long as a world demand existed for the product—mohair, now so largely supplanted. Then came the spectacular rise of ostrich farming which lasted just as long as the vagaries of women's fashions in the sophisticated western world provided a market for ostrich feathers. Although ostrich farming led incidentally to an extension of irrigation—thus illustrating the very important lesson that the unforeseen secondary developments are often the more significant—it only supported the use of certain arid lands for a brief generation. Today, over vast areas in arid South Africa and the adjoining parts of South West Africa economic motive is supplied solely by the demand for 'Persian lamb' or 'Karakul' at present in fashion for women's fur coats in western countries. The fur must be that of the new-born lamb: because the mother does not have to suckle her offspring she requires less food and is able to sustain life in a far more arid climate than if living normally. This again is an outstanding example of the 'delicacy of balance' which keeps in production large tracts of arid lands. Australia affords many examples of the common trend: a withdrawal from the marginal conditions of the arid lands in favour of a more intensive development of the better watered margins.

In the past enormous areas of arid land depended for their economic life on the camel, just as those same vast areas supported virtually only one domestic animal—the camel. Apart from a small international demand for camel-hair, the camel was important essentially as the beast of burden of the arid lands: the ship of the desert. Now the motor has supplanted the camel—almost entirely in Australia where camels were introduced but have become wild and practically valueless—to a large extent even in their native lands of Eurasia and in the Sahara. The economic motive has been removed for the use of huge areas of the arid lands.

This changing use of arid lands may have unexpected but far-reaching effects. Are lands which, in the past, provided sustenance for camels if no other animals doomed to be entirely deserted except for posts which serve the motor routes crossing them? Thus, on several counts, a decreased human use of some arid lands must be faced.

In conclusion it may be fairly stated that many great civilizations have flourished in the past in the arid lands or on their margins. Indeed it would seem that the arid lands, more than any other parts of the earth, have favoured the highest developments of mankind: great heights in technical achievement, in standards of living, in wealth, material and cultural, have been reached. Yet in so many cases destruction has been complete—far more than in mid-latitudes, where slower developments have led to more lasting results. The root cause is seen to be the delicacy of balance between man and his environment and how many factors there are to introduce a disastrous unbalance. Disastrous because there is much less latitude of action than under other conditions.

This delicacy of balance still exists and it points the need to the greatest care in the planning and execution of development projects. A great dam may be a complete success from the engineer's standpoint, a complete failure because the land it is designed to irrigate has soils incapable of successful irrigation. Or again, the dam may be successful, the irrigation successful, yet it fails to benefit the people either because the hydrologist and doctor have not worked together in control of disease, or, more likely, the sociologist's knowledge of the organization of the people has not been used or understood.

Every development project must be based on full detailed, co-operative and integrated surveys: every aspect of the problem must be studied. It is vital to make haste slowly if lasting benefits are to be achieved.