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APPLIED GEOMORPHOLOGY IN INTEGRATED SURVEYS

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AU LECTEUR

Monsieur,

« Scientia » *est, en* 1969, *dans sa 63ème année de vie, ayant repris pleinement sa fonction traditionnelle de synthèse scientifique vraiment internationale.*

Qu'il nous soit permis, à cette occasion, de rappeler les considérations que suggère l'histoire de soixante-trois ans de publication de la Revue.

Lorsqu'en 1907 *un groupe d'amis et de collègues fonda* « Scientia », *elle se présenta au public avec un programme dont les points principaux étaient les suivants:*

« *La production scientifique actuelle — énonçait le programme de* 1907 *— est aujourd'hui plus que jamais caractérisée par le fait qu'elle est circonscrite à des disciplines diverses, quant à leur objet et aux méthodes de recherches. C'est contre cette tendance à la spécialisation à outrance que* « Scientia » *veut justement réagir, cherchant à unir les efforts des savants, à élever la vision des buts scientifiques au dessus de toutes formes particulières de la recherche. C'est dans ce but que la Revue s'adresse à tous ceux qui excellent dans un domaine quelconque afin qu'ils concourent à cette oeuvre, laissant de côté, pour un moment, le langage technique usuel, pour agiter, de la façon la plus accessible, quelque problème général, que d'autres, avec autant de liberté et d'indépendance, éclairciront sous d'autres points de vue* ».

En un demi-siècle le monde de la pensée et de la science s'est transformé profondément en ce sens qu'il a réalisé un grand progrès vers l'unité. Les différences qualitatives de la matière ont disparu; il s'est opéré une vaste fusion des disciplines physico-chimiques et une révision des problèmes de l'astronomie et de la géographie physique; et c'est encore dans le sens de l'unité que procèdent les développements de la recherche biologique.

Mais devant cette tendance à la synthèse et à l'unification de la pensée scientifique, les exigences de l'investigation ont cependant développé à l'infini des méthodes et des langages techniques particuliers qui rendent peut-être encore plus difficile la compréhension réciproque des savants. D'où le fait que la nécessité d'un organe de synthèse scientifique comme « Scientia » *se fait sentir aujourd'hui, non moins qu'il y a de cela soixante-trois ans, et son programme et son action, s'ils ne préconisent plus, comme alors le progrès unitaire scientifique, mais le reflètent, ont toujours pour but de rendre réciproquement compréhensibles les conceptions et les principes généraux qui se basent sur des procédés techniques et se servent de langages techniques non moins éloignés les uns des autres qu'ils ne l'étaient jadis.*

C'est dans sa compréhension des exigences des temps, dans la continuité de son action, que repose la raison du succès de « Scientia ».

La Revue publie toujours le Supplément en français, afin que ses articles, qui sont tous publiés dans la langue de leurs auteurs, puissent être lus et compris même par qui ne connaît que la langue française.

La constitution d'un large Comité Scientifique de la Revue, dont font partie des savants illustres dans les domaines les plus divers de la science, reflète, en le confirmant à nouveau, le programme de « Scientia », *qui est de considérer les diverses disciplines scientifiques comme les branches d'une science unifiée, de s'adresser aux savants de tous les Pays afin qu'ils deviennent les collaborateurs pour une recherche solidaire de la vérité, unissant ainsi les esprits dans une aspiration supérieure, dans une haute vision du monde matériel et spirituel, qui est aussi prémisse et gage de concorde et de paix.*

C'est au nom de ces idéals et de ce programme, que nous avons la confiance de pouvoir vous compter vous aussi parmi les abonnés de « Scientia », *contribution pour nous précieuse, acte de foi dans la collaboration, dans la coopération, dans la confraternité des savants, des hommes de science, des personnes cultivées de tous les Pays.*

La Direction

APPLIED GEOMORPHOLOGY IN INTEGRATED SURVEYS

Geomorphology is concerned with land forms and the processes that make them, both endogene and exogene. Landforms are subject to change in time, whereas the morphogenetic factors themselves are variable. Forms of the present are the result of processes from the past, which may differ from the presently active processes. The application of geomorphology in many aspects of life is to be considered in the light of the reduced time-scale. Apparently stable situations may result from a delicate and temporary balance in a situation that is, on a longer time scale, unstable. Disturbances then may trigger off adjustment processes that by far exceed the magnitude of the interfering force. In integrated surveys the manifold relations between geomorphology and other fields of science and technology to which it is applied, are most evident. Aerial survey is of a two-fold importance for geomorphology. Firstly, air photo-interpretation is the prime tool for the geomorphologist; secondly, many kinds of photo-interpretation are based on analysis of land forms. In many integrated surveys, aerial photo-interpretation takes an important role, and the air photo itself shows numerous elements of integration.

Introduction. — *Geomorphology* is defined as the Science of Land Forms. This includes description and classification of land forms, and the study of land sculpturing processes, both of the present and of the past. It is realized that the land forms of the present are the result of processes that worked in the (geological) past.

This realization is related to the principle of uniformitarianism: processes as they act in the present, are assumed to have acted in an identical way in the past, producing identical results as they do now, other things being equal.

The earth surface can be considered the plane of contact between the rocks of the earth (the lithosphere), and the earth-surrounding spheres of water (hydrosphere), plant and animal life (biosphere) and air (atmosphere). Or: between the exogene group of earth sculpturing processes, and the endogene group. The exogene factors are those affecting the earth from outside, the endogene factors act from within. Summarily, they can be grouped as per following table.

Structural events (mountain building, fault and rift formation, warping) may cause up and down movements of the earth's surface itself. Exogene forces act on that part of the earth's surface that rises above sea level, with a tendency to attack the lithosphere and lower it under influence of gravity. The attack is manifest in rock weathering, where minerals that are not chemically stable under atmospheric conditions, are katamorphosed to more stable compounds of lesser complexity. Rocks and minerals that are physically not stable under atmospheric conditions, are desintegrated under influence of thermal and mechanical forces.

EXOGENE FACTORS	Atmosphere	— precipitation — temperature — wind — radiation	rock weathering mass waste erosion
	Biosphere	– plant actions – animal actions – human actions	transportation
	Hydrosphere	– running water – percolating water – marine actions – ice – snow	deposition
	— earth's	surface —	
ENDOGENE FACTORS	Lithosphere	rock/mineral	composition resistance stability
		structure	active movements past diastrophism

The chemical decomposition of rock-forming minerals can only take place in the presence of water; ground water is usually of an acidic composition and thus much more agressive than pure water. The higher the temperature, the faster the reactions: chemical weathering reaches its maximal intensity in the humid tropics [1, 2]. In the various climatic belts of the earth, the weathering process takes different courses and intensities; the major climatic belts all have their own characteristic weathering features [3].

The resulting weathering products are subjected to gravitational mass movements and to erosional attack by running water, wind, moving ice, sea waves etc. As a result of the differential resistance of the lithosphere to the exogene forces, which themselves are largely variable, land forms are sculptured which vary from place to place.

Through the geological history of the earth, orogenic and epirogenic movements have afflicted various parts of the earth at different times; the climates of the past have been subjected to large variations even in the recent geological past. Thus, not only the land forms and the land sculpturing processes vary from place to place, they also vary from time to time.

The endogene and exogene processes need not necessarily be in balance of forces: commonly, and at any given time, they are not.

The earth surface, this plane of interaction between endogene and exogene forces, can thus be considered the momentary expression of an unbalanced field of forces. It follows that, in time, land forms which express this interaction will evolve towards a more balanced situation until diastrophic or climatic accidents produce a renewed unbalance [4].

The processes act slowly, and geomorphological time units are in the same order as geological time units. Changes in land forms observable during human lifespan are small in comparison to the over-all geomorphological development. Changes in land forms during historical times are bigger, though their observation or reconstruction is difficult. For the reconstruction of events on a longer time-scale, the geomorphologist employs largely geological methods.

The time scale in geological and geomorphological thinking is hard to grasp in relation to time scales in human life. Processes that acted in the more distant past of course have a lesser influence on the present morphology of the earth's surface than those from more nearby times. The imposing mountain belt of the Alps is young by geological standards; yet, its main phase of formation occurred some 15-25 million years ago. And it should be realized that in the formation of the chain itself, millions and millions of years were involved. Its morphology through these times, continually changing, expressed at any moment the unequilibrized balance between the endogene forces (tectonic compression, folding and uplift) and the exogene forces that attacked the uprising land masses that were to form the Alps: weathering by temperature changes, frost action, chemical processes in ground water, erosion by running water, ice, avalanches, denudation by landslides, rock falls and similar degrading processes.

The Rhine between Bingen and Bonn has cut its famous gorge into the uprising rocks of the ancient Rhenic Massif. This uplift took perhaps some 6 million years to accomplish, off and on, and if we take the incision of the river, which flowed there before the uplift started, at some 300 metres, then, very roughly speaking, we see that the Rhine has incised at the rate of about 0.005 cm/year, and maintained it, off and on, for at least 6 million years. Yet, such a process is fast by geomorphological standards. Faster still was the incision of the great Himalayan rivers in their antecedent gorges through the uprising Himalayan Chain. The Indus cut one of the deepest gorges on earth by maintaining its earlier established position as the land rose. This gorge is around 5000 metres deep. The uplift has taken place within the last 25 million years; that is an average rate of slightly over 0.02 cm/year. There are indications however, that the main uplift-cum incision took a much shorter time to accomplish; if we take it that the last 4000 metres might have taken only 2 million years to accomplish, even then the incision is no more than some 0.2 cm/year.

At the foot of the Himalayas, the rate of relatively recent uplift cum incision of the river system, could be established to have been at least some 900-1300 feet in the last 500.000 years, or about 0.05 to 0.08 cm/year [5].

The normal rate at which geomorphic processes act, is much slower; it depends on climate, structural and lithological conditions, which vary largely from one place to another.

The areal removal of material from the earth's surface by denudative processes, is slower still than the erosive incision of rivers.

APPLIED GEOMORPHOLOGY. — A point of fundamental importance in the application of geomorphology is the reduction of the time scale.

Land forms and the processes that make and change them are of consequence in many aspects of life, as in agriculture, in road construction and maintenance, in civil engineering practices in general, and in many more facets of everyday life. In these, time units are in the order of human lifespan, often shorter, and rarely more than a few centuries.

Though the geomorphologist thinks in time units of a geological order of magnitude, it would be a fundamental mistake to consider land forms static even at such short time units as human life span.

The dynamism of morphogenetic processes is projected against the unbalanced field of endogene and exogene forces. The natural setting thus is one in which apparent stability may be the result of a precarious and temporary equilibrium between forces that are in fact not in balance. The apparent equilibrium may just be the result of the long time scale in which the processes operate. It goes without saying, though, that there are really stable settings as well.

Interference by man — or by natural calamities — in this setting of precarious equilibrium may trigger off adjustment processes of a magnitude far exceeding that of the interfering force.

The application of geomorphological knowledge for practical purposes demands not only the recognition of process and change in short time-spans in relation to the existing situation; it also demands the projection of these into the future: the forecasting of natural phenomena and the prediction of reactions to human interference.

As examples, the following may serve.

1) In dam construction for hydro-electrical or irrigation purposes, slope stability in the reservoir area is to be investigated, also with a view on the changed conditions when water will be at the foot of the slopes. Potential landslides must be detected and brought under control in time. Small landslides may be harmful in accelerating the silting-up of the reservoir; big landslides may cause shock waves in the water causing overtopping or rupture of the dam, which may cause a major disaster.

2) Cuttings in potentially unstable slope zones for road construction may upset the precarious apparent equilibrium, and trigger off landslides that damage or destroy the road. The application of geomorphological knowledge is the detection of the potentially unstable slope — that is the recognition of the delicate balance in such situations between shearing forces and resisting forces — and the forecast of what will or may happen if this balance is disrupted by cutting in the slope.

These two examples deal with slope stability problems; similar examples could be given from many other fields of engineering and agriculture and other human activities. The following list does not aim at completeness, but at illustration:

— road and railroad construction
— harbour works
— building; settlement extensions
— land utilization problems in general
— drainage and irrigation
— flood protection; river training
— land reclamation
— even tourism, sports.

It is clear also to the non-geomorphologist, that in these activities the following geomorphic processes are involved:

— slope wash, denudation, landsliding
— coastal erosion, tidal scour, wave action
— rivermouth silting; offshore bar migration
— river flooding, bank erosion, river bar migration
— avalanche control.

From the foregoing it will be clear that the applied geomorphologist cannot work alone. The application of geomorphology mostly fits in with works of a technological or agricultural character, with resource exploration and exploitation, and more indirectly, with the economical and social consequences and restrictions inherent to the work or project at hand.

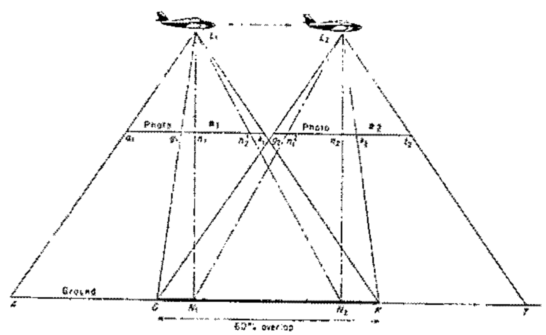

Fig. 1
Overlap of 60 % on two consecutive photos; from Miller [6].
Recouvrement de 60% entre deux photographies consécutives (d'après Miller [6]).

AERIAL SURVEY. — In aerial survey, data are gathered from aerial photography and also from other means of airborne collection of information such as airborne magnetometer surveys, thermal infra-red scanning and imagery, and airborne side looking radar scanning. In this paper, we shall only consider aerial photography; normal black-and-white panchromatic photography is at present the most common basis of aerial survey.

The camera is mounted in the aircraft so as to photograph vertically downward. Focal length of the camera lens and flying height are selected so as to produce the required scale of photography. As the aircraft flies along, photos are exposed at regular intervals, so that the area shown on each photo, overlaps the area shown on the preceding photo by about 60% (fig. 1). At the end of the run over the area to be photographed, the aircraft turns so as to fly the next flight line, usually in the opposite direction. This is chosen so that the area shown on the second run overlaps sideward the area shown on the first run, by about 30% (fig. 2). This way, the whole area to be photographed is covered (fig. 3).

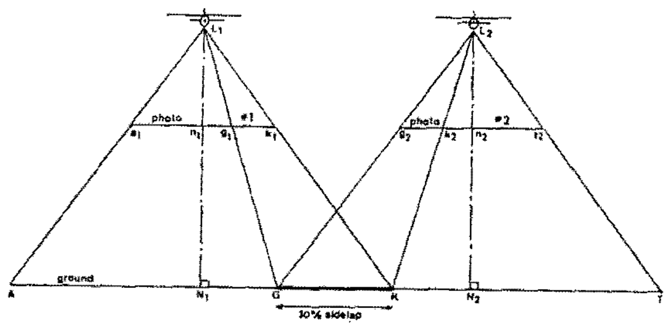

Fig. 2
Side lap of 30% on two adjacent runs; from Miller [6].
Recouvrement latéral de 30% entre deux parcours adjacents (d'après Miller [6]).

The 60% overlap on two consecutive photos shows the overlap area twice, but seen from two different positions, viz. the position of the camera in the air at the moment of the first photo, and that of the second (compare fig. 1).

The overlap area thus fulfils the requirements for stereoscopic observation: the same object is shown twice, from different viewing positions. The two photos are arranged under the stereoscope so that they are seen in the flying sequence and in such a way that the further technical specifications of photo and instrument are met, and then the overlap area can be seen in relief. Repeating the operation for photos No 3 and 4, then 4 and 5, and so on, the whole area photographed can be seen in relief.

The relief as observed on the air photo image in stereo-vision, is exaggerated as compared to the relief one would observe when viewing the area from the same height in the aircraft. This relief exaggeration is caused principally by the much larger distance between the two successive points of photography in the air, as compared to the interpupillary distance between the human eyes.

In the exaggerated relief image, it is first and foremost the relief *contrasts* that are exaggerated. This is a tremendous aid in the analysis of the relief — that is: the analysis of land forms, the geomorphologist's work.

In the exaggerated relief model, flat areas are still seen flat, but small escarpments, e.g. between terraces, stand out clearly. Slopes appear generally much steeper than they are in reality, but here again, breaks in gradient show up very clearly. Relatively small changes that are of importance but would otherwise escape notice, are now brought out clearly, which largely facilitates the process of photo-interpretation.

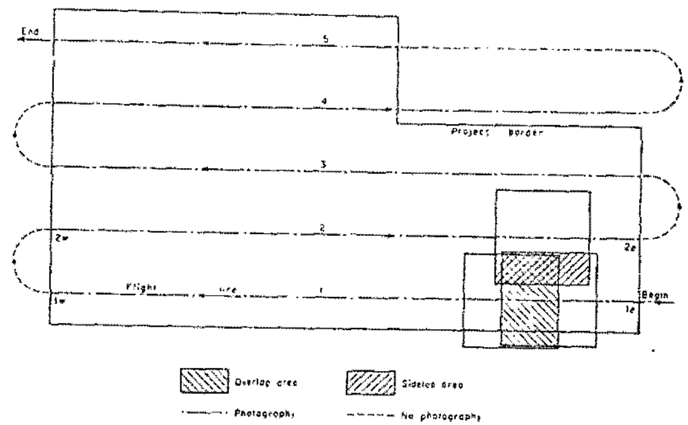

Fig. 3
Flight line planning to photograph a project area; from Miller [6].
Plan du vol pour relever une région donnée (d'après Miller [6]).

The air photo shows a central projection of the earth's surface, where the various objects shown are displaced along lines radiating from the centre point of the photograph. This parallactic displacement (fig. 4) can be measured both on a single photo and on the stereopair, and it is a yardstick for the heights and depths of the relief.

The scale in one and the same photo also varies owing to movements of the aircraft whereby the camera axis may not be exactly vertical at the moment of exposure. The air photogrammetrist deals with the rectification and the transformation of the air photo image to — principally — topographic and/or contour maps.

The photogrammetrist is primarily, thus, concerned with measurements on the photo images, and the rectification of the projection so as to eliminate distortions of various kinds and make the photo into a map of uniform scale.

The photo interpreter on the other hand seeks to abstract information from the photo image that cannot be directly measured. Photo interpretation is based on a large number of recognition elements like greytone and tonal variations on the photo — which again are controlled not only by the surface features on the earth but also by the combination of film and filter types used in the photography —; by the photo texture — infinitesimal changes in pattern brought about by unit objects which themselves are too small to be seen individually, like for instance the change from one type of grain field to another, and many more recognition elements. In practice, many of these are handled and combined subconsciously and photo interpretation is highly dependent on the experience of the interpreter.

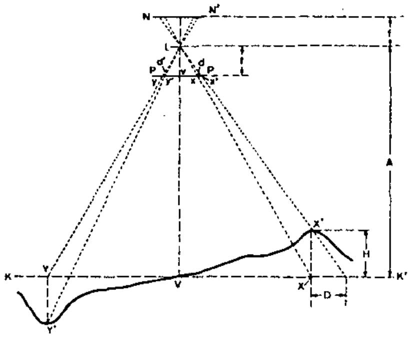

Fig. 4

Parallactic displacement due to topographic relief. Camera lens is in L; N—N' represents negative plane, P—P' positive plane. K—K' is datum plane. X' is a point on the surface above datum level, Y' is below datum level. X and Y are their projections on datum plane, and x and y the positions of these projections on the positive plane. The photograph shows, however, the points x' and y', which are radially dispaced w.r.t. the centre of the photograph: x' outward, and y' inward. x—x' and y—y' are the parallactic displacements; from Smith [7].

Déplacement parallactique dû au relief. L'objectif est en L; N—N' est le plan négatif, P—P' le plan positif. K—K' le plan de référence. X' est un point de la surface au dessus du plan de référence, Y' est au dessous de celui-ci. X et Y en sont les projections sur le plan de référence. La photographie montre comment les points X' et Y' sont déplacés radialement par rapport au centre de la photographie, x' vers l'extérieur, y' vers l'intérieur. x—x' et y—y' sont les déplacements parallactiques (d'après Smith [7]).

Land forms are directly observable on the air photo, often even better than in the terrain since many obstacles in the horizontal lines of sight of the field observer, do not exist for the aerial camera. The details observable vary with the photo scale: the larger the scale, the more the detail observable. However, with large scale photography, regional relationships and contexts may not be observed (fig. 5).

The air photo offers a wealth of information to the geomorphologist, and its extraction requires full familiarity with earth sculpturing processes and land forms. Most land forms as they now exist are plurigenetic, that is to say that their present appearance is the result of more than one morphogenetic process. In western Europe, for instance, fluvial activity has, in many parts, alternated with the morphogenetic

activity of continental ice sheets or large mountain ice caps. Four such glaciations have been recognized in the Alpine zone to have occurred during the last 1 million years; some investigations indicate that the time spell was in the order of only 700.000 years; others indicate five glaciations. Over the Scandinavian area, at least three major ice expansions have occurred. Each of these showed in itself a number of advances and retreats, known as stadials and interstadials. Though much has been investigated into the causes of these glaciations, there is no uniformity of opinions as to their causes. In any case, before the onset of a glaciation, climate changed, and the morphogenetic processes in the areas affected took on distinct periglacial conditions, comparable to tundra conditions of the present.

As a result of the accumulation of water, in the form of ice sheets, on the continents (similar glaciations occurred on the North American continent), ocean level fell, with a periodicity in phase with the glaciatons. These glacio-eustatic movements have been to as much as 80 metres below the previous stand. To complicate matters, these fluctuations were superimposed on a general fall of ocean level, traced back to Tertiary times [9, 10]. As a result of the fluctuations, the continental shelf seas fell dry during glacial periods, and this effect was not limited to the glaciated areas, but world-wide. When the ice melted, sea level rose and the then coastal areas were invaded.

If all the ice now present on earth (in the Antarctic and Greenland ice caps and the various glaciers of the earth) would melt, sea level has been estimated to rise by a further 40-60 metres [9].

The above serves to illustrate the changing exogene morphogenetic activity in various places: from fluvial to periglacial (that means, a.o., drier) and full glacial conditions and vice versa in some places, repeated two, three or even four times over, depending on how far the next glaciation extended; from land to sea and back to land in others, also with the possible repetitions, and all this with the transitional phases and sub-phases which differed from place to place.

This is not all: the glaciations caused (or: were caused by) large-scale changes in the general atmospheric circulation, which caused changes in the climatic regime of many areas not directly affected by the glaciations. Thus, parts of the present globe-spanning desert belt had a distinctly higher rainfall during glacial periods than they have now; other parts had a drier climate than at present. This, again, may have shown fluctuations to correspond with the rhythm of glaciations. Shifts in the pressure pattern and the tracks of depressions and westerlies seem to be the principal effects. Though it would be tempting to speculate some more on this matter, this is not the place to do so. The purpose is to elucidate the plurigenetism of land forms: these climatic fluctuations profoundly modified the exogene morphogenetic processes in the areas affected, and the combined results are

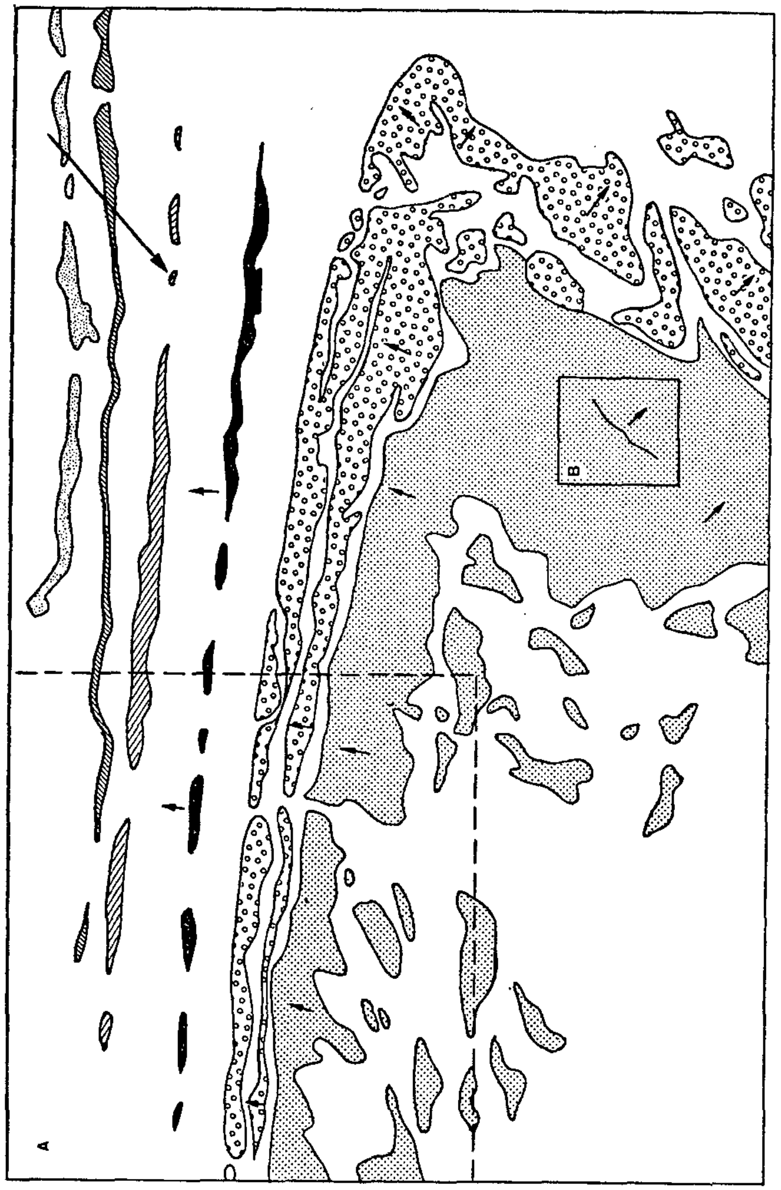

Fig. 5

Pitching anticline as revealed by photo interpretation. Large scale photographs (as in square B) showing only a small area are unfavourable for a rapid understanding of regional relationships. Small, uncharacteristic features (arrow) can still correctly be interpreted on the strength of their position in the structure; from Verstappen [8].

Anticlinal penché révélé par la photo-interprétation. Des photos à grande échelle (comme celui qui est dans le carré B) ne montrant qu'une petite portion du terrain sont défavorables pour la compréhension rapide des relations régionales. De petits accidents non caractéristiques (flèche) peuvent néanmoins être interprétés correctement, en raison de leur position par rapport à l'ensemble de la structure.

reflected in the land forms of today. Thus, in arid zones, relic land forms exist that have not originated under the present conditions of aridity; superposed on these, the arid processes (wind work, corrasion, pedimentation and the likes) have made their characteristically different imprint. Glacially sculptured or deposited forms exist in areas that are not now glaciated at all; superposed on them are the imprints of the agents active up to the present.

We have, thus, to do with land forms that reflect the processes that made them in the past period up to « yesterday » on the one hand. On the other hand we have to do with the processes that are to-day active, and that are underway to modify the land forms further.

The dynamism of the presently active processes, projected against the background of existing forms as a result of past events, not necessarily in equilibrium, is of the greatest importance in the practical applications of geomorphology.

In photo-interpretation, all this, and a lot more, comes to the fore in the analysis of land forms from the aerial picture. We shall not exhaustively discuss all the methodological aspects of photo-interpretation, though some general reference may be made.

The general sequence is:

a) detection and recognition
b) identification
c) analysis
d) interpretation.

Detection and recognition are associated with known objects, identification with unknown objects for which elements of recognition and detection contribute to their identification. Analysis is one step further on the way towards interpretation; in the latter, conclusions are drawn on the basis of the first three elements plus a number of indirectly attributed considerations. Some interesting considerations in this respect have been published: [11, 12].

In geomorphological photo-interpretation, the result is mostly represented in the form of a map. Once the mapping units have been analysed and interpreted, they are delineated on the air photograph under the stereoscope, or on transparent overlays, in the central parts of the photos which show the least distortion. The matching annotations can then be transferred into some form of base map, which may be a mosaic of air photos (with or without control or rectification), a base map made by photogrammetric methods from the same photos, or an existing topographic map.

Transfer instruments are often based on the camera lucida principle, and they are preferably so made, that the map image can be superposed — to scale for one level of reference at a time — in the stereoscopic photo image.

The terrain check for verification of the photo-interpretation is, of course, indispensable.

Geomorphological mapping then has a task to portray in suitable symbols the relevant geomorphological characteristics of the area under consideration. For mapping purposes, these can be phased in

morphographical
morphometrical
morphogenetical
morphodynamical
morphochronological

characteristics. The names speak for themselves. A geomorphological map need not necessarily place equal emphasis on all five characteristics, dependent on the purpose the map is made for.

Often, in the application of geomorphology to specific purposes, the selection will be for those characteristics that are specifically related to the purpose for which the survey is made.

There is, as yet, no systematic general geomorphological mapping in most countries; there is also no uniformity in approach and choice of symbols, though at present, some more specific efforts towards standardization are made [13, 14, 15, 16].

Geomorphological analysis and interpretation is a very direct kind of aerial survey. The air photo has become the prime tool of the geomorphologist; at the same time, the interpretation of air photos in various other disciplines of the earth sciences employs inference from the geomorphic observations on the photos.

Aero-geology and aero-pedology are both based to a considerable extent on the interpretation of geomorphological features observed on the air photo [17, 6]. Land forms reflect to a certain extent the lithological and structural properties of rocks; they may also reflect properties and, above all, horizontal boundaries of soil types. The application, direct and indirect, of geomorphological knowledge and observations is eminently manifest in these instances.

It must be stressed in the context of this paper, that aerial photo-interpretation is uniformly recognized as an aid, a tool, but that it can never be the aim in itself. One does not become a photo-interpreter by profession; one is a geologist, pedologist, geomorphologist etc. by training and profession, and one uses photo-interpretation as an implement. The survey therefore, in neither of these earth sciences, can be complete with photo-interpretation alone. Field control is always necessary, in many cases followed by laboratory analyses and renewed photo-interpretation.

Aerial survey is not limited to the earth sciences, though it is most prominent there. Widespread use of air photos is made in forestry surveying, and to a lesser extent also in land-use mapping, urban area analysis, vegetation survey and hydrology [18].

Integrated Surveys. — In recent years it has been recognized that effective information regarding development or construction projects, or assessment of resources and their exploitability, is best obtained from surveys — at specialist level — that are specifically aimed at the project while being interconnected with each other. Such types of survey, carried out by a team of specialists, have become known as Integrated Surveys.

« Integration is the term which has been widely adopted for the process of bringing together the appropriate sciences and technologies, where and when they are needed and in the right sequence » [19]. Various quarters hold different views on the nature and on the methodology of integrated surveys. Also, a very practical problem arises in that one has to bring together specialists from different disciplines who may be hard to locate.

In integrated surveys, several disciplines/specialists co-operate somehow towards a common objective; the methods of data collection and processing vary from one survey to the other, and standard procedures or definitions can hardly be given. So far, two principal lines of approach have become apparent.

In the first, the main emphasis is on the interrelation of phenomena and resources: any natural asset is influenced in its usefulness by other environmental factors. The survey of the environment in its totality thus becomes the principal aim of this method of integrated surveys.

The second approach is that of the integrated survey of all relevant aspects of specific development projects. Technical and scientific experts not only survey the project — whatever its nature, but also its interaction with other spheres of society.

In the first approach to integrated surveys, « Land » is considered the true resource: « the word land is used to refer to the land surface and all its characteristics of importance to man's existence and success » [20]. The combination of resource factors, rather than the individual factors, determine the usefulness of areas; finite areas can thus be recognized. Thus, a region under survey is segmented into areas with distinctive characteristics, and survey is carried on in those areas. A land system is defined as an area or group of areas throughout which there is a recurring pattern of topography, soils and vegetation. A land system is then considered to be built up of a recurring pattern of land units, each of which has its own characteristic topography, soil and vegetation [20, p. 242]. The degree of simplicity or complexity of a land unit is determined by the nature of the land form accepted as the unit of study.

This surveying system has primarily been developed by the Commonwealth Scientific and Industrial Research Organisation, Division of Land Research and Regional Survey, in Australia. It is largely based on aerial survey followed by field control and large areas in Australia have been surveyed this way [21]. In this Australian Land Research Approach, equal emphasis is given to all significant factors: land form, soil, vegetation, drainage, climate, and impact of man. The surveys are carried out by simultaneous field visits of the team of experts; this ensures on-the-spot exchange of views and information. This exchange and feedback of data is an essential requirement in all integrated surveys [22].

The second main line of approach in integrated surveys has developed through the years of practical resources survey work, as examplified by the works of the United Nations Food and Agriculture Organization (F.A.O.), and many consulting engineering and surveying firms. These surveys are in the first place oriented towards developing countries, and therefore invariably linked up with development projects.

Appraisal of resources is most pressing in the developing, often newly independent countries: with expanding population (exploding would be a more appropriate word in many countries) and straggling food production, stock-taking of resources and their development and exploitation are urgently needed.

« Within the developing countries the range of environmental and social conditions is too vast for any valid generalization to be made on the type of survey most urgently needed. Such problems can only be considered in relation to specific areas » [23]. Two broad categories of resource appraisal in developing countries are to be recognized: one that is concerned with exploratory surveys of areas in which little reconnaissance has been carried out; the other is concerned with more complex investigations into means of intensifying resource usage. The latter have largely been carried out as specialized technical surveys, and the need for integration of data and surveys has been recognized as experience with these surveys increased [23, p. 42].

The tendency now is to have the relevant experts in the team during that phase of the survey in which their services are most useful. This may be the full period of the survey for some, certain part(s) of it for others, while still others may be sub-contracted as consultants. Integration, and the indispensible exchange and feed-back of data, is achieved by setting the expected results of the survey beforehand as an aim; at regular intervals the progress made towards the aim is reviewed in the various aspects involved in the execution of the survey [23, p. 44]. In other words: by evaluating the survey at regular intervals during the survey itself.

It should be realized that there are a great many organizations and institutions practizing some form or other of integrated surveys. Their approaches may all be different in detail as well in principle. This will be understood as conditions differ from country to country, from project to project and from organization to organization.

In fact, the composition of the teams determines the approach to the problem to no small extent. Apart from the professional capabilities of team members and the logistical organization of their survey, the personalities of the team members are of key importance. This holds all the more for the team leader or project manager who ultimately is left saddled with the team and has got to make it work [24].

Some further relevant points on integrated surveys were formulated by Batisse [25], who remarks that the concept of natural resources is essentially an economic one. The study of the natural environment — in the form of eco-systems — should find its integration with technology and socio/economics [25, p. 23]. This is in fact the recognition that a form of bridging the gap between the two main lines of approach distinguished in the preceding paragraphs, should be found.

Application of Geomorphology in Integrated Surveys. — After the paragraphs on applied geomorphology, and on integrated surveys, it will be evident where the principal applications of geomorphology in integrated surveys lie. Though it is, of course, not the only surveying technique employed, air photo-interpretation takes an important place in almost any type of integrated survey. In the aforegoing it has been pointed out that geomorphological photo-interpretation forms the basis for further specialized extraction of information, as in geological surveys and soil surveys. In the land research system, the land form even is the basic unit of the whole survey. It is clear that these are important applications, both direct and indirect, of geomorphology in integrated surveys.

In surveys of an integrated character, geomorphology is also applied in other ways.

Considerations in road planning are often of an economic nature, especially in developing areas [26]. Once the decision has been arrived at that the road is to be made, then the terrain conditions — along with other factors — dictate where it is best located. All this has to bear relation with the cost of road construction and the places and purposes it has to serve. In studying slope stability, flood risks, bank erosion — terrain suitability in general —, in the first instance from the air photo, and later on the spot, the geomorphologist at all times has to keep touch with these aspects in order to give a usable advice on the road's location.

As another example we may quote the application of geomorphology in hydrological surveys, where morphometrical analysis of a drainage network is a most useful tool in determining runoff characteristics [27, 28]. These in turn find their application in engineering practices and in agriculture. In this type of morphometrical analysis, the

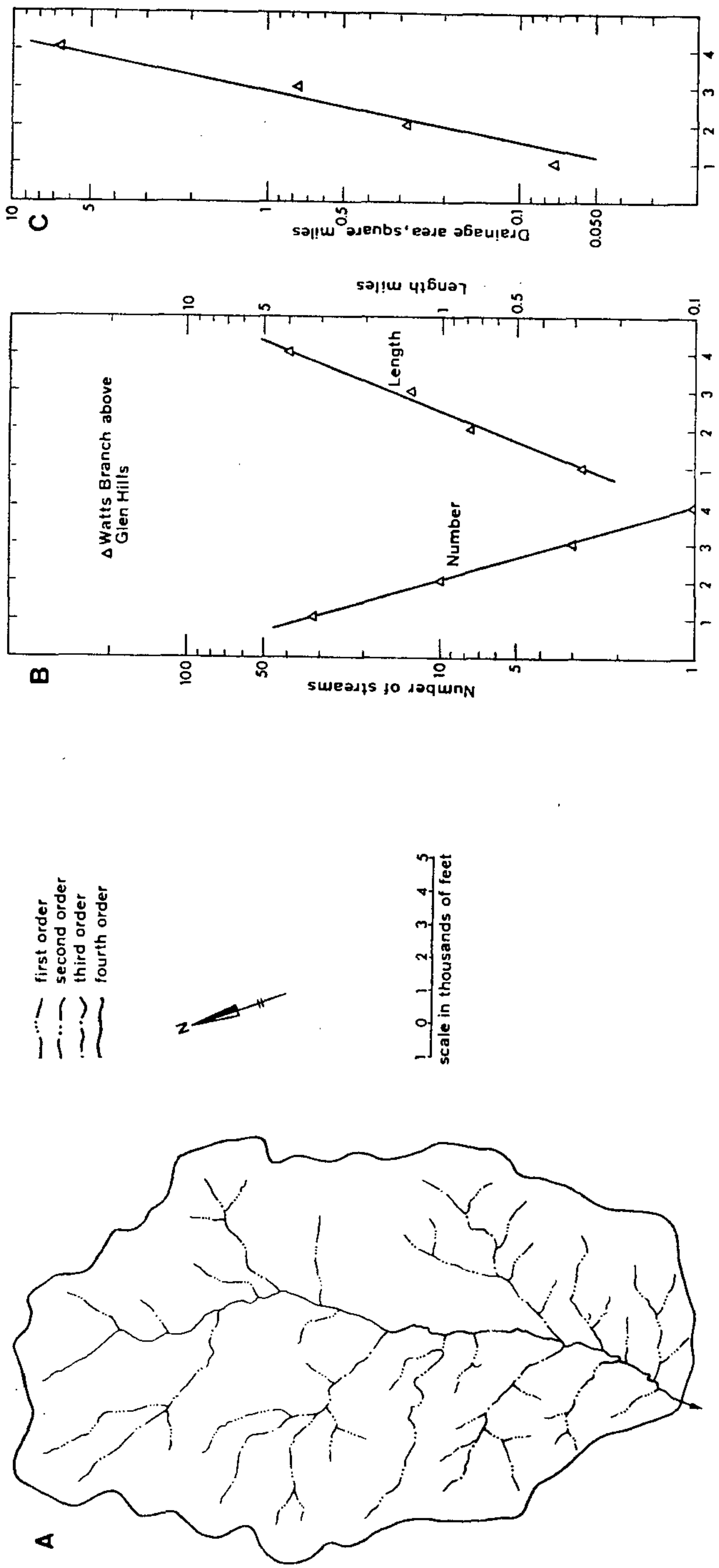

Fig. 6

A) Planimetric map of a drainage basin showing stream orders; B) relation of average length and number of streams to stream order; C) relation of stream order to drainage area; from Leopold, Wolman and Miller [27].

A) Carte planimétrique d'un bassin de drainage montrant l'ordre des cours d'eau; B) Relation entre la longueur moyenne des cours d'eau et leur nombre d'une part, leur ordre de l'autre; C) Relation entre l'ordre des cours d'eau et la surface drainée (d'après Lepold, Wolman et Miller [27]).

stream network per basin is grouped by order: first order streams are those that receive no tributaries; second order streams receive only first-order tributaries; third order streams receive only second and first order tributaires, and so forth. Horton [28] showed that stream length, stream order, drainage area, and further characteristics of the drainage system and basin are related by geometric or exponental relationships, which have turned out to be important aids in runoff computations (compare fig. 6).

Of an integrated nature also are the investigations for the choice of locations for settlement extensions, construction sites and the like. Slope stability studies, based on photo-interpretation [29] and pursued in the field, flooding risks and similar surveys, are contributions that the geomorphologist makes in this context [30]. It may be stated in general that settlements located in unstable terrain run constant risks of damage by slope movements. At best, this induces recurring heavy expenditure for repair and maintenance, which had been avoidable; at worst, it causes disasters. Potentially unstable terrain is hardly recognizable for those not trained in the analysis of the geomorphic setting and of the morphogenetic dynamism.

Concluding remarks. — The aerial photo itself is an evident element of integration in surveys, eventually from the stage of topographic map-making down to very detailed photo-interpretation [31].

But apart from the systematic interpretation in the various sciences and technologies involved in the survey, the air photo also offers a good deal of information on the inter-relationships between the features observed. It also shows relations between these and factors that cannot be directly observed on the air photo, like economical, sociological and similar aspects. Though, in modesty, we should concede that not all of these can be surveyed from air photos, still the analysis of these inter-relationships on the aerial photo is an important facet in integrated surveys and here, too, applied geomorphology has its part to play.

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