THE VOLCANIC ASH SOILS OF CHILE(*)

The distribution of volcanic ash soils in Chile (Fig. 6)

Soils derived from volcanic ash fall into two well-defined divisions: those with a significant amount of amorphic material in their clay fraction, and those either without amorphic clay or with such a small amount that it has no practical significance for both the farmer and the soil scientist. Soils of the latter division are found where the volcanic ash has been deposited in regions with arid or semi-arid climates, and they also occur under the very cold conditions prevailing in very low latitudes or at very high altitudes. In Chile, such soils are widespread in the northern deserts, at the margin of the Patagonian desertic region, at high elevations in the southern Andes and, most probably, in Antarctica Chilena.

The distribution of volcanic ash soils in Chile can best be discussed under two headings.

- in the arid and semi-arid regions
- in the sub-humid and humid regions.

In the arid and sub-arid regions

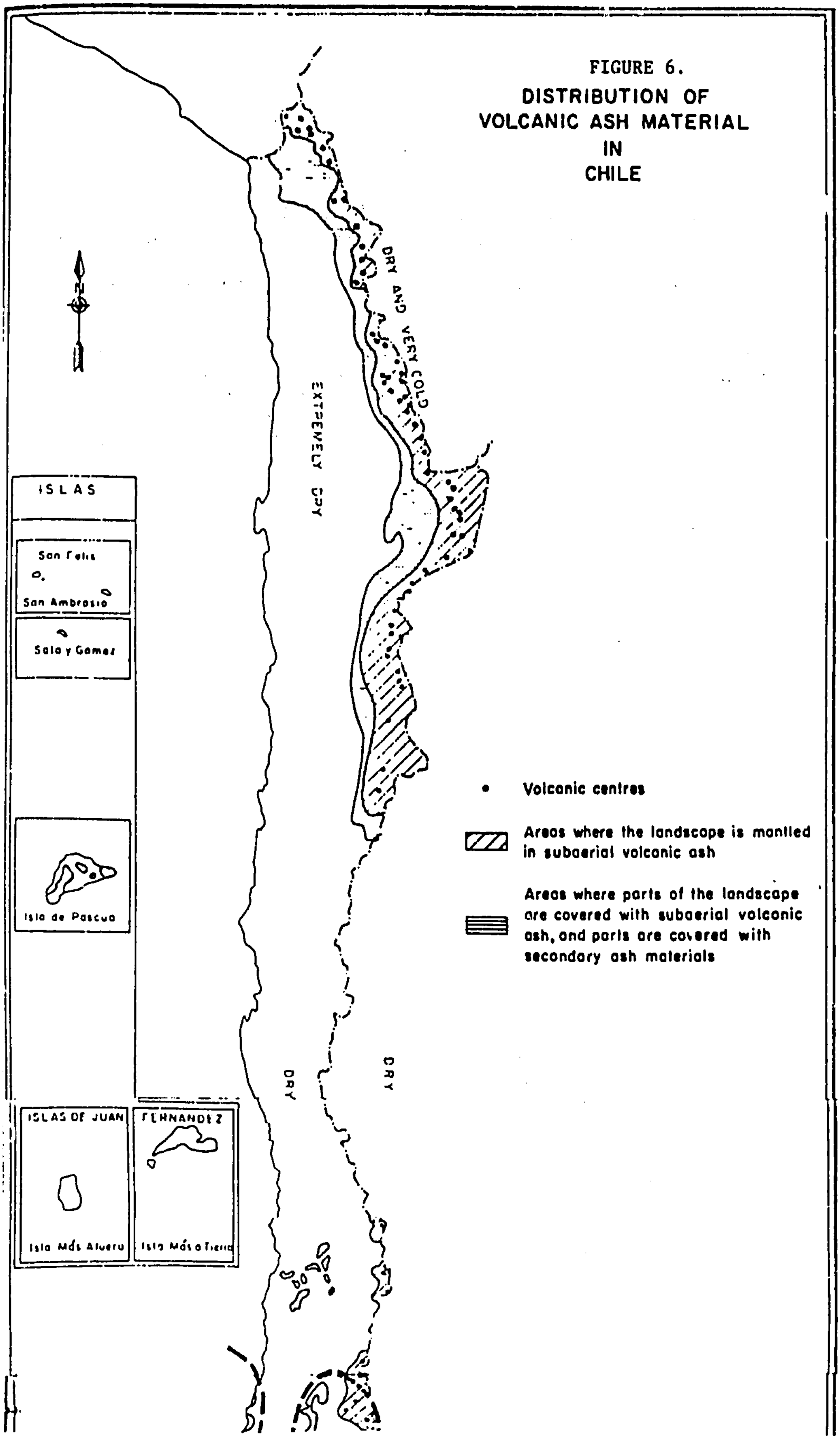
In this kind of environment the soils are subject to minimal weathering and leaching, but may become strongly enriched by the upward movement of soluble salts. Furthermore, the organic regime (as defined by Taylor, 1949) is exceedingly weak. With weathering at such a low intensity, and under the intensely dry conditions that prevail for most of the time, the volcanic glasses in the parent material disintegrate very slowly, and if amorphous allophane is formed at all, it certainly does not remain long in colloidal form. Since the weathering environment is saturated with cations, most probably clays such as montmorillonite, illite and vermiculite are formed in place of allophane. In any case, extremely small amounts of clay are formed in these desertic soils.

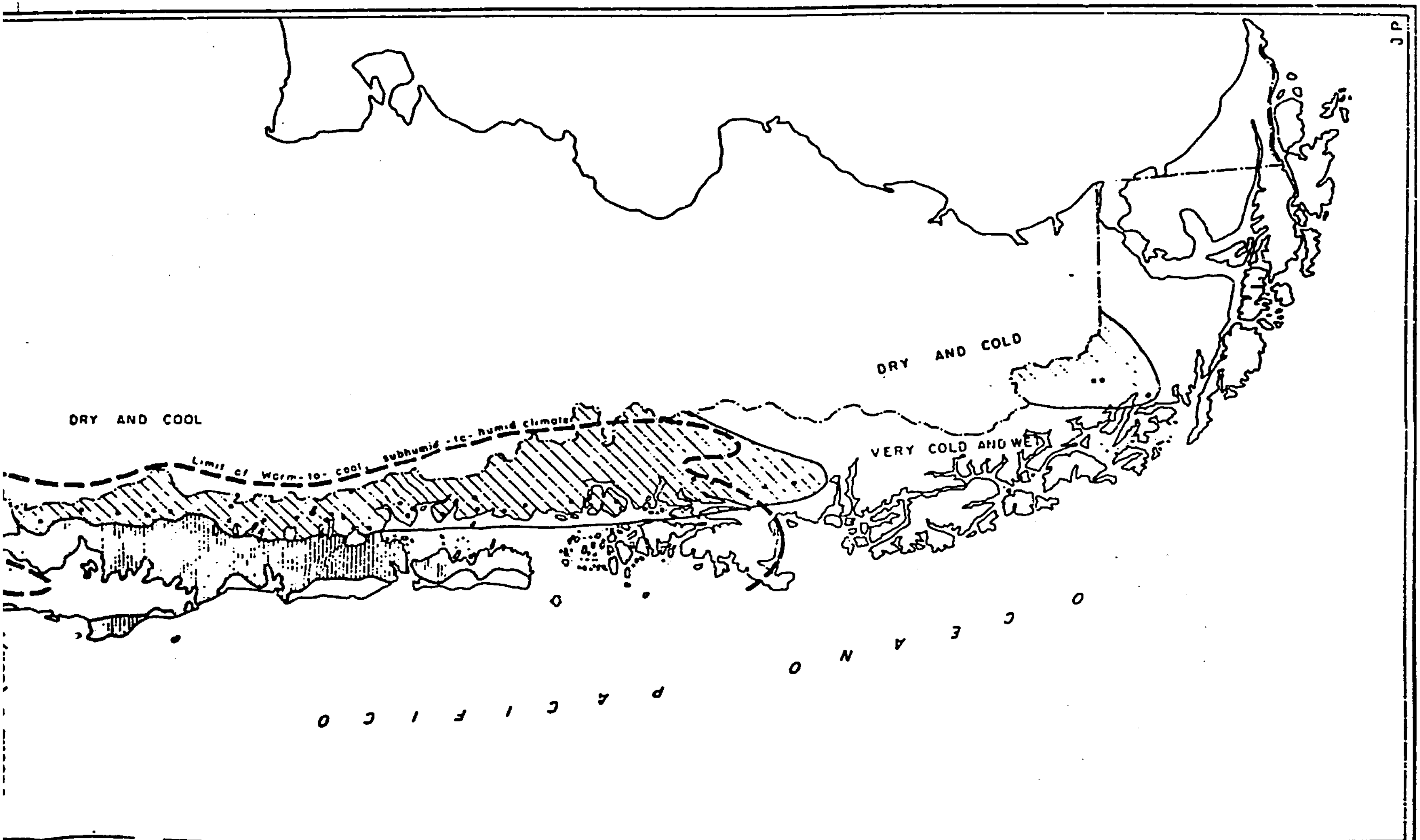
In quite a number of these soils, silica released during the weathering process may move slowly and bring about silica cementation of subsoil horizons. This is particularly noticeable in some desert soils formed from siliceous rhyolitic ash.

However, in general, there is little to differentiate the soils derived from volcanic ash from other soils in the arid landscape. Under extreme desert conditions, only the highly pumiceous ash soils stand out, and then mainly because of the presence of the white pumice gravel. Under slightly less desertic conditions, weak silica cementation often occurs in pumiceous soils, yet be absent from other soils in the landscape. Under semi-desertic conditions, soils derived from both

(*) Extracted from: Charles A. Wright, 1965. The volcanic ash soils of Chile. Report N° 2017. FAO, Rome, 201 p.

FIGURE 6.
DISTRIBUTION OF VOLCANIC ASH MATERIAL IN CHILE




DRY AND COOL
Limit of Warm-to-cool subhumid-to-humid climates
DRY AND COLD
VERY COLD AND WET
OCEANO PACIFICO
JP

acidic and intermediate kinds of volcanic ash may show a minor amount or amorphic clay formation, but this takes the form of silt rather than clay. Possibly the amorphous alumina colloid shrink to form clusters under the long interval of very dry conditions that follow the brief period when rain has moistened the soil enough to permit operations of the weathering processes, forming silt-sized compound particles which appear to be rather resistant to further wetting.

In the subhumid and humid regions

In Chile, one of the regions of very intense volcanic activity from Quaternary time onward was along the western flanks of the Andes in the south-central sector of the country. Most of this region lies well within the humid zone; and as a result post-glacial deposits of volcanic ash are at a stage of weathering marked by great abundance of amorphic clay. The soils forming in these ash beds therefore disply almost all the typical characteristics of soils rich in amorphic clay and the agriculturalists of Chile recognise a distinct region of volcanic ash soils. The great majority of these are called "trumao" soils from ar Araucanian Indian word implying lightness or dustiness. A smalle group, on low lying land and with a seasonally perched watertable, are known as "ñadi" soils, which is another Araucanian word connoting land that is swampy, but possessing a firm subsurface so that it is transitable with care. In referring to volcanic ash soils of the subhumid and humid regions of Chile in this report, these indigenous and widely used local soil names will be employed. Trumao soils are essentially freely drained soils: ñadi soils are seasonally waterlogged (Wright, 1959, ii).

On the flanks of the Andean cordillera, and on some of the high plateaux, volcanic ash has accumulated as a direct subaerial deposit during the actual period of the eruptions. Since the prevailing winds are from the west and southwest, much of the ash clouds settled to the east of the Andean divide, and only a relatively small proportion was deposited in Chilean territory. Nevertheless, the lower foothills and high terraces of the Chilean side of the Andes do show a very heavy mantle of ash materials. Much of this is undoubtedly a secondary deposit derived from volcanic ash that was carried far out over the plains of the Central Valley by the large braided river systems and was, subsequent to deposition as volcanic alluvium, picked up by the strong westerly winds and drifted back over the foothill region. This ash material has been called "volcanic loess" to distinguish it from the subaerial volcanic ash of direct deposition. The name is open to question by those who wish to retain "loess" for the finer by-products of glacial action, but short of coining a new name ("aeolium"?) there is little to be done about it. The volcanic loess is usually somewhat more uniform in composition than subaerial ash, and often contains some rounded quartz grains and plant opal. Volcanic loess occurs not only on the Andean foothills, but appears at intervals on the western face of the coastal range where it is presumably derived as drift material from nearby coastal terraces and beaches. A similar aeolian material has also been found in areas where sedimentary rocks containing volcanic glass are being abraded by the wind.

In some parts of south-central Chile, the swift-flowing transverse rivers carry fresh volcanic ash (as well as eroded volcanic loess) right to the coast. Here it is picked up by the north-flowing current and eventually deposited along the beaches. This volcanic alluvium, as well as estuarine and coastal deposits with a high proportion of volcanic minerals, are comparatively commonplace in south-central Chile. In places, rivers overloaded during a particularly intense period of volcanic activity have built up high banks, changed their courses, and formed long, sloping alluvial fans. Steeper alluvial fans are common along the foot of the Andes: some of these originated as giant mudflows and sludge-like deposits, still besprinkled with enormous boulders (resembling glacial erratics) that were floated into position in a medium of high density (Wright & Espinosa, 1962). Volcanic ash lies very thickly on all but the steepest of the Andean slopes, although the thickness of this mantle often diminishes in the inmediate victinity of the volcano. It is apparent that where hot volcanic ash or noxious gases destroy the native forest, erosion subsequently strips away the ash; in areas where the vegetation is not killed, the fine ash is permitted to accumulate from one eruption to the next and ash beds several meters in thickness have been recorded from slopes in excess of 45°. These steepland volcanic ash soils (steepland trumao) erode rather rapidly when the forest is felled and young colluvial soils of mixed ash materials accumulate near the foot of the slopes. The stripping of the ash mantle from deforested slopes may assume catastrophic proportions when triggered by seismic movements (Wright & Mella, 1963, i and ii).

The distribution of volcanic ash and related materials in the subhumid and humid regions of Chile covers a range in latitude of about 20°; commencing with the appearance of small scattered areas in the Andean cordillera inmediately north of the Maule River (latitude 35°S). Thence, proceeding southward, trumao soils occur with increasing frequency in the foothills of the Andes, until they form an almost complete mantle in about latitude 36°30'S. On the lowlands, scattered patches of trumao-like soils of alluvial origin appear in latitude 35°30'S; and these grow more extensive to the south, until in about latitude 39°S almost the whole of the land between the Andean ranges and the sea is occupied by trumao or trumao-like soils. Further to the south, the ash mantle on the Andean ranges is very thick and complete, but does not extend (except in a few places) to the coastal ranges; in these latitudes, the ñadi soils appear on the plains and terraces of the Central Vale. This pattern is continued on the Chiloé Island, while on the very steep and dissected mountains of the Andes on the mainland opposite, the sub-aerial ash mantle continues unbroken, except where removed by, in historic times, man-induced erosion. At the latitude of the southern port of Aisén (latitude 45°S), the trumao soils still cover the undisturbed hill and mountainsides, and further extend westward into Argentina where their amorphic clay properties diminish owing to increasing dryness and coldness of the Patagonian climate. Trumao soils continue well below latitude 50°S, but are somewhat restricted to a narrow more humid foothill region on both sides of the Andean chain. At high elevations, and on the western Patagonian pampa, conditions are too cold or too dry for the formation of amorphic clay in significant amounts in the soils. On the hills east of Punta Arenas (latitude 53°S), there are podzolised soils which are in part formed from volcanic ash, but the amount of amorphic clay in their profiles is very small. In these latitudes, most bog soils have layers of volcanic ash clearly preserved in the peaty profile (see also Auer, 1950). By studying the extent of these ash layers it is possible to be certain that volcanic ash constitutes a part of all the soils in the Magallanes Provinces. Yet amorphic clays are not a significant feature of any of these soils.

This brief resumé of the distribution of volcanic ash soils in Chile would be incomplete without mention of the soil parent materials of Easter Island; the westernmost outpost of Chilean territory, 2000 miles from the Arauco peninsula, the nearest point on the South American mainland. The volcanic soils of Easter Island (Díaz, 1949, 1951; Wright and Díaz, 1963) are somewhat older and more basic in origin than most of the volcanic ash soils of the Chilean mainland. They occur mainly on the old volcanic cones where they are in part mixed with weathered scoria. Related soils, possibly formed from a type of loess rich in volcanic minerals, rasped from the steep cliffs surrounding most of the island by the persistent trade winds, occur in patches throughout the island.

There are many volcanic ash soils in the sub-humid and humid zones of Chile that do not achieve recognition as trumao or ñadi soils. These are all from older volcanic ash, in which the weathering process is more advanced and amorphous clays have been largely replaced by semi-crystalline and crystalline clays like halloysitic and kaolin. These soils no longer have the morphological, chemical, physical, nor the farming or engineering, attributes of trumao and ñadi soils: in Chile they are known collectively as the "red volcanic clay" soils, and they fall outside the terms of this enquiry; although some intergrades between these soils and trumaos are mentioned.

There are important pedological and farming differences amongst the various kinds of trumao and ñadi soils. However, before closing this introduction, it is well to remember that from time to time, almost the whole of the Chilean atmosphere must have been charged with fine volcanic dust, and every soil in the country likely contains some minerals of volcanic origin and that are not representative of the local rocks. The proportion may be small, as judged by the remaining resistant minerals (see also León, 1962); but the total contribution over the centuries may be considerable, and may account for some degree of similarity that may be observed throughout the Chilean soil assemblage. This may be even more true of the soils of Argentina, a patient land that has accepted without protest many million tons of volcanic dust blown across from volcanoes on the Chilean side of the Andes.

The common properties of Chilean amorphic volcanic ash soils are discussed in Section of this report, together with a brief summary of the main kinds of trumao and ñadi soils occurring in Chile.

A. Andosols[1/] of Chile: General characteristics, formative environment and main kinds of soil

1. Trumao Soils

(a) General characteristics

The general characteristics of the andosols of Chile are as follows:

i) The whole soil profile tends to be mellow and friable, usually with clearly distinguishable depositional stratification, and with a distinct colour difference, sharply defined, between the topsoil and the subsoil. Occasionally one or more of the subsoil layers may be pumiceous and cemented.

ii) Topsoils range from brown to nearly black, and the natural colour (as visible under the natural plant cover) persists for a long time after the onset of farming, even where no particular effort is being made to sustain the organic matter content of the surface soil. Textures are usually loam, with varying amounts of sand and silt.

iii) Subsoils are noticeably more yellowish than the topsoils; in extreme cases yellowish-brown or yellowish-red in colour; ranging in texture from loam to clay loam, and usually with a high content of silt (part of which may be aggregated clusters of dried amorphous allophane). When completely dry, the powdered soil behaves like fine sand and is slow to rewet, but often the soil is only apparently dry and when squeezed firmly between finger and thumb, there is an abrupt sheering sensation, and the soil becomes moist, with a rather "slippery", "soapy", or "greasy" feel. Naturally moist soils have an easily recognised greasy feel, and under pressure they become "smeary" or, when rubbed strongly for some time in the palm of the hand, the soil material may almost become liquid. All of these are useful tests for the presence of allophane in appreciable quantities.

iv) Deeper subsoil horizons are nearly always depositional strata, and may vary widely in nature; their boundaries are often very distinct and marked by abrupt changes in texture, compaction, consistance etc.

v) Seldom, if ever, are the qualities of stickiness or plasticity pronouced in the topsoil or upper subsoil horizon of trumao soils.

1/ The name "Andosol" is used by C. Wright to embrace both "trumao and "ñadi" soils.

If these appear in the lowermost strata, it is usually an indication that the passage of time has permitted the change of allophane clay toward meta-halloysite or one of the other structurally orientated clays.

vi) The whole soil has a very low bulk density, expressed as a notable "fluffiness", has low volume weight, and the peds are usually quite porous. When thoroughly dried, peds are often difficult to rewet, and may float briefly when thrown into water.

vii) The upper soil horizons have a high water-holding capacity, and a high water retaining capacity when once thoroughly wet. The upper subsoil horizon may develop very prominent shrinkage fissures on drying. Both topsoils and subsoils form long ice pillars and needles where roadside cuts are exposed to heavy frost; frost heaving of the topsoil is commonplace on ploughed land in winter.

viii) There is usually intense fibrous root development in the topsoil but relatively few tree roots penetrate into the deeper subsoil layers.

ix) The clay fraction is dominated by amorphic mineral compounds, usually allophane, which, lacking a permanent charge or possessing a high variable charge, causes the soils to be strongly buffered against changes in pH and gives the soils an apparently high base exchange capacity. Thus soils commonly have a base saturation seemingly inconsistent with their pH values. Chilean trumao soils range in acidity from around pH 6.7 to pH 4.5, but their base status may lie between 90 percent and 2 percent.

x) Trumao soils have characteristically a high base exchange capacity, a high anion exchange capacity, and a very high rate of phosphate "fixation".

xi) The soils are difficult to disperse properly for textural determination. Soils that are essentially clays by definition in properly dispersed material have field textures no heavier than silt loam or even fine sandy loam. Proper dispersion may usually be achieved by treating the soils with hot dilute peroxide solution, washing on a Buchner funnel first with water and then with N/20 hydrochloric acid, then again with water, and dispersing finally in sodium hexametasulphate solution at a strength of 3 grams per litre (Birrel, pers. comm. 1960).

xii) Total nitrogen is high to a remarkable depth in these soils, and this is often accompanied by such a high total carbon content that the C/N rations are commonly unusually high for a considerable depth down the soil profile.

xiii) On analysis by X-ray and D.T.A. equipment, and from inspection of electron microscope photographs, Chilean trumao soils (Besoaín, ibid, 1958; 1961; 1963, in press) have allophane as the dominant mineral in the clay fraction. Besoaín also reports that many Chilean trumao soils have considerable quantities of gibbsite present, even in the upper part of the subsoil horizon. In this, the Chilean soils differ from New Zealand amorphic soils where gibbsite appears mainly in the lower horizons and strata. In the lower strata of some trumao soils, where weathering of the older depositional materials is more advanced, kaolin and amorphous silica have been found along with halloysite, hydrated halloysite, gibbsite and hydrous oxides of iron.

xiv) The variable charge mechanism also poses problems for, where the pH is below 5.0, the soil should, in theory, become electropositive and release of active alumina should increase. Many trumao soils have been shown to contain a high proportion of exchangeable alumina, and free alumina compounds have also been detected quite frequently. These latter are quite toxic to alumina sensitive crops, such as sugar beet.

(b) The formative environment

Within the general limits of humidity (subhumid to perhumid) and temperature (warm to cool temperate) outline in the opening remarks, the trumao soils of Chile occupy a number of well-defined kinds of environment. The formative environment is thus somewhat varied but the approximate range in climate, topography, parent materials and natural plant cover is set down below. These are not only of interest to scientists studying soil genesis, but have considerable bearing on land use practices.

i) Climate

Precipitation: at the dry extreme, allophanic soils occur under a precipitation of somewhat less than 1000 millimeters per annum, with a very unequal distribution in that there are no less than five continuously dry months (in which the monthly rainfall is less than 60 millimeters), although rarely does any month have less than 10 millimeters. In this area evaporation rates during the dry summer months are very high.
At the other extreme of their moisture range, trumao soils occur under a precipitation of over 4000 millimeters par annum, with no well marked dry season. Some areas regularly experience winter snowfalls up to 3 meters in depth, lasting on the ground for one or two months; other areas are virtually frost free (e.g. parts of Chiloé Island) throughout the year.

Temperature: the average mean annual temperature ranges from about 15°C to less than 8°C; with a winter (July) range of less than 1°C to about 8.5°C; and an average summer (January) range of around 13°C to over 20°C. Freezing and thawing phenomena are characteristic of some areas, absent in others.

ii) Topography

Trumao soils may be found on almost any type of relief, from the extremely rugged and precipitous slopes of the Southern Andes, to the flat plains and terraces of the central vale. The topography perhaps most characteristic of the Chilean trumao soils is the strongly rolling to undulating "ceja de montaña" strip of foothill country extending along the face of the Andes from Chillán to near Villarrica. This is a most important farming region, but here the soils are only in part derived directly from subaerial volcanic ash: mainly it is a region where soils derived from re-sorted and re-deposited volcanic loess. The true subaerial volcanic ash soils are found further in towards the volcanoes, usually on steeper hill slopes, and as steepland soils amongst the ranges. On the plains of the central vale, trumao soils are mainly derived from volcanic loess and from volcanic alluvium; and along the coast there are some areas of rolling landscape covered with trumao-like soils derived mainly from loess originating from coastal drift materials.

iii) Parent materials

The most obvious difference in the soil parent materials lies in the presence or absence of pumice fragments and the proportion of angular or rounded quartz sand.

Pumiceous and conspicuously sandy volcanic materials are more common in the south of the trumao soil region (from Llanquihue Province southwards), but highly pumiceous areas also occur in the high cordillera at several places north of this limit. There is also a visible coarsening of the ash materials along any radius towards a volcano, ending at the point where all ash is obscured by coarse scoria and similar large ejecta or by recent lava. Stratification of the ash beds also increases along any radius towards the volcano. At some distance from the vent, where all ash is of a fine grade, stratification of the beds is sometimes very difficult to make out without laboratory investigation of selected samples.

General observations show that the great majority of the ash beds in Chile are of intermediate to acid origin: basic volcanic sands are comparatively rare, occurring chiefly in the Los Angeles area where they originated from Antuco volcano, and descended on the lowlands as a sudden sand flow connected with the rupture of a lava barrier across the front of Laguna del Laja; also over smaller areas near Llaima volcano; and in the vicinity of some of the more southerly groups of volcanoes, including several areas in Aisén Province.

iv) Natural plant cover

To a Chilean, the typical natural plant cover associated with trumao soil is the roble (Nothofagus obliqua); but this is true only over a limited part of the whole extent of trumao soils, - the sector between Chillán and Puerto Octay, along the face of the

Andean cordillera. Elsewhere, trumao soils are associated with broadleaf evergreen forests (the "laurel" forests with abundant Laurelia sempervirens, Laurelia serrata, Drimys winteri, Aextoxicon punctatum, and, especially in the south, Eucryphia cordifolia); with mixed forest containing podocarps such as the maño (Podocarpus nubigenus) and coigüe (Nothofagus dombeyi); with alerce forest (Fitzroya cupressoides), - although this magnificent timber tree has been cleared from most areas of trumao soils; with "north Patagonian rainforest (Schmithüsen, 1956) dominated by coigüe, but with associate species of Weinmannia, Saxegothaea, Laurelia and Nothofagus nitida; with ñirre forest (Nothofagus antarctica); and with lenga forest (Nothofagus pumilio). In addition to the above types of forest cover, trumao soils also may be found with savanna-parkland natural vegetation in which the ground cover is grass, with numerous scattered bushes of Acacia caven ("espino") and large isolated roble trees; and under a continuous low shrub vegetation dominated by maqui (Aristotelia sp.). In coastal areas, some small patches of trumao carry evergreen forest with abundant litre (Lithraea caustica), boldo (Peumus boldus), etc.

(c) The main kinds of trumao soils

There are six major subdivisions within the trumao group[1/], each characterized by a measure of difference in the degree of weathering, degree of leaching, and intensity of melanisation (humus incorporation). These are environmental factors operating during soil formation, and they operate not only on trumao soils but on all the other kinds of soil in the vicinity. Thus, by studying these other, somewhat older soils associated with trumao soils, one is able to get a more comprehensive idea of the regional environmental impress on soil formation than if the, generally younger, trumao soils were studied alone. By thus extending the scope of the enquiry, one can delimit with greater surety the approximate boundaries over which the present strength of the weathering, leaching and melanising factors are operating with about equal force.

There are six principal weathering categories: slight, slight-to-moderate, sub-moderate, moderate, and moderate-to-strong, and strong-to-very strong. The latter category is restricted to Easter Island. Within these six categories, the soils show varying degrees of leaching and melanisation; which accord fairly well the recorded rainfall data, temperature data, and age of the soil, and other factors influencing the intensity of the soil process.

i) In the first weathering category belong the scattered patches of trumao in the Andean foothills of the provinces of Talca and Linares; their derived alluvial and colluvial associates on the Central Vale; a very small area of related soils, somewhat pumiceous, around Laguna del Maule (at an altitude of 2.100 meters); a few patches of volcanic loess along the coast near Tregualemu; and some small areas of trumao at the margin of the Patagonian

1/ C. Wright emphasize that at the moment when he wrote this paper there was no adequate laboratory information to make possible a precise statement on the limits of the main kinds of trumao soils.

pampa between latitude 45°S and 46°S. These soils are all of minor extent, but they are all no more than slightly weathered, and they all exist under relatively weak weathering environment; although they differ amongst themselves rather widely in age, in degree of leaching and in degree and type of melanisation. These are the "extreme northern" examples of trumao soils in Chile.

ii) In the second weathering category, where the present weathering impress is slight-to-moderate, we have the main area of trumao soils of the Andean foothills and ranges stretching from north of Chillán to south of Los Angeles; together with their derived alluvial and colluvial associates. Patches of recent volcanic ash, in which weathering is only just commencing occur near certain volcanoes; but apart from these, the degree of weathering appears to be fairly uniform over the zone, and the main variations in the soils are due to leaching and melanisation. These soils represent the "northern" group of trumao soils.

iii) In the third category, where the present weathering impress is submoderate (i.e. rather more than in the preceding zone but less than "moderate"), we have an important area of trumao soils centred about the Province of Cautín. In this zone, trumao soils extend from near the coast right to the Argentinian border, and include soils derived from volcanic loess, volcanic alluvium, coastal drift (volcanic) loess, and subaerial volcanic ash, some of which is markedly pumiceous. Soils range from slightly leached to very strongly leached, and from weakly melanised to strongly melanised. These soils represent the "modal" or "central" group of trumao soils in Chile.

iv) In the fourth category, where the weathering impress can be described as moderate, are the trumao soils of Valdivia, Osorno, Llanquihue and part of Chiloé Provinces. Here again, there are trumaos of various age and origin, ranging from slightly leached to strongly leached, and from slightly melanised to very strongly melanised. These soils represent the "southern" trumao soils.

v) In the fifth category, where the weathering impress is moderate-to strong, we have soils in the south of the island of Chiloé, in "Chiloé continental", and in the southern province of Aisén. Here most soils are fairly strongly leached and melanised, although the type of melanisation varies rather widely. These soils are the "extreme southern" type of trumao ash soil in Chile.

vi) In the six and last weathering category, we have only the soils developed near the volcanic cones on Easter Island, and their related loessic volcanic soils. These soils represent the Chilean "tropical" trumao soils.

With the exception of the sixth category, in which near tropical temperatures have markedly accelerated the rate of weathering, the remaining five categories cover a relatively small range in mean annual temperature (from about 15°C in the north to about 8°C in the south; and the weathering environment is clearly controlled more by the mean condition of soil humidity and by the pattern of the rainfall than by mean air temperatures or by the total precipitation. The five weathering categories correspond quite well with the mean length of the summer dry season; the somewhat cooler but continuously moist soils of the southern part of the trumao range are continuously moist soils and are thus subjected to considerably more weathering than the rather warmer soils of the northern sector where the soils are relatively dry for nearly half the year.

Admittedly, this subdivision of the trumao soils of Chile is still largely an experimental one, and much essential laboratory data still needed but, does accord reasonably well with land use practices and with farming experience. In some cases, the suggested subdivision of the trumao soils cuts across soils that, up to the present time, have been mapped as a single pedological unit; - for example the old San Bárbara trumao soils have been divided into two parts, the northern part carrying the old name and the southern part being provisionally named Cautín trumao soil.

2. Ñadi Soils

(a) General characteristics

Ñadi soils have many of the physical and chemical characteristics of trumao soils, but differ rather conspicuously in their morphology. They are essentially similar to "pseudogley" soils, in that they are seasonally waterlogged due to impeded drainage and the development of a perched watertable at from 18 to 36 centimeters below the surface. Unlike pseudogley and gley soils, subsoil mottling is rare or non-existent. The conspicuously dark topsoil colour of the trumao soils is usually present, but the subsoils are often a more pronounced yellowish-brown, and become brownish yellow or yellow in the zone most affected by the perched watertable. Thin, discontinuous iron pans or a layer of hard nodules often occur at the base of the ash layer, inmediately above the cemented glacial or alluvial gravel. On drying (as when drained), the upper part of the profile may develop strong vertical fissures of sufficient regularity to give the appearance of massive soil columns.

Ñadi soils are usually less "fluffy" and are more consolidated than trumao soils, and are often slightly more sticky and plastic when moist. Many of their chemical characteristics seem to be the same as trumao soils, although some of them tend to be intergrades to soils that do not have a significant amount of amorphic clay.

(b) The formative environment

i) Climate

Towards the northern limit of the "ñadis", the mean annual rainfall lies between 1.200 millimeters and 1.500 millimeters with up to two months with less than 100 millimeters, but in the region where the ñadi soils attain their maximum development, the mean annual rainfall lies between 1.500 millimeters and over 3.000 millimeters with no months in the year with less than 100 millimeters. In this latter zone the precipitation during the three winter months frequently exceeds 1.000 millimeters. Over the whole range of the "ñadis", the mean annual temperature lies between 10°C and 12°C. The warmest month (January) lies with the range 14°C and 17.5°C; while the coldest month (July) lies within the range 7°C and 8.5°C (Almeyda, 1958).. Cloud cover averages 60 per cent over the year. According to Papadakis (1961), annual evapotranspiration lies between 25 and 50 centimeters per annum, so that the excess precipitation theoretically available for leaching through the soil is in the range of 175 to 200 centimeters per annum. No actual evaporimeter data are available for the region of the "ñadis"; but field observations suggest that in some cases the removal of the forest results in the soil conditions becoming wetter than formerly, and hence water lost by direct transpiration may considerably exceed that lost by direct evaporation.

ii) Topography and parent materials

Any study of ñadi soils must begin by considering the origin of the typical landforms associated with these soils, and the probable manner of emplacement of the volcanic ash on this landscape. Recent drilling by petroleum exploration groups has shown that the shape of the bottom of this sector of the great Central Valley of Chile varies markedly. Usually the bedrock is micaschist, and this is covered with from 100 feet to over 4.000 feet of sediments, mainly sandy and gravelly. The uppermost part of this filling material is clearly of glacial origin (Weischet, 1958), and the ñadis occur on flattish to very gently undulating landforms between morainic debris. There is evidence to suggest that the parent materials of the ñadi soils were emplaced subsequent to the last glaciation; although buried ñadi-like soils, probably dating from earlier glacial periods, have also been found.

Not all ñadi soils are associated with glaciated landscapes. Those of the northern sector (e.g. Pitrufquen soils) are found on old terrace landforms, while some of those in Chiloé Island are also associated with terrace formations and even with local lacustrine deposits. None of these landscapes are likely to be older than the ultimate glaciation. All ñadi soils occur on flat or very gently undulating landforms.

The stratigraphic column of ñadi soils is much abbreviated as compared with adjacent trumao soils on more strongly rolling landforms, and there is usually no recognisable correlation of the stratigraphic sequence between the latter soils and ñadi soils in the vicinity. There is also the problem of the method of deposition of the original volcanic materials. Usually the material is free of stones and gravel; although on Chiloé Island, ñadi subsoils often contain very fine rounded quartz pebbles, especially common in the lower horizons. In Chiloé, it is easy to think of the soil materials as being emplaced by water, yet, apart from the fine rounded gravels there are no other indications of their possible alluvial origin. Moreover, the materials usually show a notable thickening toward the edge of the terrace which is difficult to contrive solely by deposition from water; and is almost impossible to imagine when there are several levels of terraces all apparently covered with the same kind of ash deposition and more or less following a common pattern of stratification.

A more feasible explanation is that the soil parent material was probably deposited mainly in the form of "loess" rich in volcanic glasses on the wide outwash plains of a periglacial zone. The presence of occasional rounded fine quartz pebbles in the material may indicate nothing more than the force of the wind, and the probability that the land surface was periodically frozen allowing the pebbles to roll for some distance. The source of these pebbles is never far distant; they are usually to be found in the sandy morainic deposits of the vicinity. A few cases have been noted where these pebbles have clearly been resorted by very local water movements, and this also is entirely feasible in a frozen landscape subject to periodic thawing and even solifluction.

The discrepancy between the depth of the volcanic materials on the ñadi plains and that on the trumao-covered downland is probably a matter of distortion of wind currents by the latter topography, allowing thicker deposition of the wind-borne volcanic dust for more turbulent air. The fact that weak stratification is visible in the ñadi parent materials, and very marked stratification is visible in the nearby trumao parent materials, serves as an indication that the source of the dust was not consistent over the whole period of accumulation. Well-defined shower layers also occur in the trumao soils, and in a few cases these shower layers can be traced, without break, into the ñadi stratification, where it is found to be much reduced in thickness but virtually of the same basic composition.

As a tentative theory, then, one would be inclined to suggest that the ñadi soil parent materials are mainly of aeolian origin, and that the great majority of them were deposited not earlier than date of the last withdrawal of the ice from this part of southern Chile. Older materials deposited in the same way at the end of earlier glaciations have been almost entirely destroyed by erosion of the lowland landscape associated with the cutting of new drainage channels during the various interglacial periods.

The process of loessic accumulation did not cease inmediately on the final retreat of the glaciers, but continued through the early part of the post-glacial period when the landscape was intermittently re-frozen; and was further prolonged, in some areas, to allow loessic deposition on the first alluvial terraces. The process probably finally ceased when the land was again clothed in vegetation.

Fragments of older ñadi-like soils, some very rich in organic matter (and perhaps containing valuable pollen remains), are occasionally preserved in cemented ash beds included in morainic debris. Cemented ash beds of this type are thought to represent ash materials that fell on the glacier surface, gradually becoming incorporated in the glacial ice. This ash was subsequently re leased when the glaciers retreated, the deposited material cemen ted (apparently by silicates of calcium and magnesium), permitting the preservation of other materials present in the glacial ice. Amongst these were relatively large and irregular patches of fro zen soil, ploughed up from the pre-glacial land surface by the advancing snout of the glacier. These are not so common in the moraines of the last glaciation, which was a relatively minor one, but are very common in the morainic materials of the penul timate glaciation. Thus, still cemented in relatively unweathered ash materials, we can still find soils dating from at least the penultimate interglacial period. Some of these fossil soils are so well preserved that it is possible to re-construct their ori ginal orientation (some are inverted and some are now at right-angles to their original position), and to find the thin iron-pan of the original "B" horizon still intact. Many such relicts are not simply fossil volcanic ash soils, but are clearly fossil ñadi soils. They deserve much greater investigation than they have had up to the present time. Still older soils are preserved in cemented ash materials associated with the second glacial period; they must represent fossil remnants of the landscape that existed during the first interglacial period, and are even more worthy of study.

iii) Natural plant cover

In the north, where they first appear, the patches of "ñadi" ve getation are conspicuous as being something different in the lands cape; in the center of their range, they are the dominant feature of the landscape; and at their southern limit they merge into peat bogs and cool temperate, very humid rainforest. Throughout this climatic range, no single plant species can be said to be characteristic of "ñadi" vegetation; and the dominant trees vary from north to south, and also vary with local soil conditions. By comparison with surrounding forest communities, the "ñadi" fo rests are, however, conspicuous for a preponderance of plants with xerophilous characteristics. The "ñadi" flora is rich "in Myrtaceae, Ericaceae, Berberidaceae, Juncaceae and Cyperaceae. The general aspect is of a stunted thicket, relatively dense, with a very dense herbaceous lower stratum of an abundance of mosses, especially sphagnum, and ferns" (Rodríguez, 1948). A further feature of the "ñadi" forests is the extreme shallowness of the root systems of the trees. Species commonly found in "ña di" vegetation include *Drimys winteri* ("Canelo"), *Tepualia stipularis* ("tepu"), *Embothrium coccineum* ("Ciruelillo"), *Ovidia pillopillo* ("pillo-pillo"), *Aristotelia chilensis* ("Maqui"), *Lomatia ferruginea* ("Fuinque"), *Lomatia obliqua* ("Radal"), *Berberis buxifolia* ("Calafate"), *Gunnera chilensis*, *Verbena corymbosa*, *Lomatia sp.*, *Baccharis saggitalis*, *Oldenlandia uniflora*, *Isolepsis vivipara*, *Juncus procera* and *Juncus planifolius*. Less common generally, but sometimes of great local importance, are such species as *Myrceugenia planipes* ("patagua valdiviana"), Myrceugenia pitra ("pitra"), Myrtus luma ("Luma"), Podocarpus nubigenus ("mañío"), Saxegothaea conspicua, Pilgerodendron uviferum, Gevuina avellana ("avellano"), Eucryphia cordifolia ("ulmo"), Desfontainea spinosa ("taique"), Fitzroya patagonica ("alerce"), Weinmannia trichosperma, etc. In many areas, the most prominent tree is Nothofagus; colder situations favour N. antarctica ("ñirre") the more swampy situations favour N. nitida, while N. pumilio ("lenga") and N. dombeyi ("coigüe") are more common in the cooler and higher rainfall areas. Between Puerto Montt and Lake Llanquihue there formely existed an area of "ñadi" entirely dominated by very large Fitzroya trees.

In the case of the ñadi soils, where soil processes are in part strongly influenced by seasonal waterlogging, low oxigen content and the seasonal development of soil gleying processes, they can be regarded as poorly drained soils related to specific trumao soils of their particular weathering region. Ñadi soils first appear in the third weathering zone, reach their maximum expression in the fourth zone, and dissappear as a distinct entity in the fifth weathering zone; it may therefore be more convenient to regard them, as is the present policy in Chile, as a group quite distinct from the trumaos. In the southern half of the Province of Llanquihue, where the rainfall frequently exceeds 2.000 millimeters per annum, excessive accumulation of acid forest litter produces a distinct peaty topsoil in many of the localities with ñadi soils. Still further to the south, on Chiloé Island (in about latitude 42°00'S), peaty topsoil conditions become a general feature of all ñadi soils in their natural state. In about latitude 42°25'S, near Mocopulli on Chiloé Island, in some of the flatter lowlands areas some ñadi soils begin to show marked peat accumulation; and the forest vegetation becomes replaced by sedge communities, by Gleichenia - Pernettya - Baccharis associations, scattered Donatia cushions and with typical wet bog species such as Sphagnum, Tetroncium and Marsippospermum. In the extreme south of Chiloé Island, the distinctive pattern of the "ñadis" become lost, - completely submerged in the "north-patagonian rainforest" (Schmithusen, 1956) dominated by Nothofagus dombeyi. In this latitude, (i.e. at about 43°00'S) the "ñadi" concept is no longer applicable; it is no longer possible to identify specific seasonally swampy areas since, with a rainfall in excess of 3.000 millimeters per annum evenly distributed throughout the year, all the soils in the landscape are characterised by abundant humidity at all times.