OBSERVATIONS ON THE SOILS OF CENTRAL CHILE (1)

by A. Charles S. Wright (2)

INTRODUCTION

The geographic similarities that exist between Chile and New Zealand are well-known to all. Scientists who have worked in both countries have, from time to time commented on the apparent similarity existing in the soils and their problems, and in the use of the land.

This present work gives some impressions of the first New Zealand pedologist to visit Chile. The author is a Senior Pedologist in the Soil Bureau of the Department of Scientific and Industrial Research of New Zealand, and his visit to Chile took place between November 1954 and January 1955.

This study was made possible by courtesy of the Ministry of Agriculture of Chile and the field work was carried out under the direction of Srs. Manuel Rodríguez Zapata and Carlos Díaz Vial of the Departamento de Conservación de Recursos Agrícolas.

During the period of three months, visits were paid to each of the field parties working between Santiago and Puerto Montt, and in addition a visit was paid to the island of Chiloe, a region in which Charles Darwin described conditinos typical of the Southern part of New Zealand.

PART I

SOILS ENCOUNTERED ALONG A TRANSECT FROM COAST TO CORDILLERA BETWEEN LATITUDE 33º S. & 34º S.

This transect covers the region between Valparaíso and San Antonio on the coast and extends inland towards the Chilean-Argentinean border at the summit-line of the Andes. Santiago, the capital of Chile, occupies a more or less central position in this transect.

Range of Environment:

Climate along this transect shows decreasing winter (May to September) temperatures from the coast inland; but from October to March the central plain (on which lies Santiago) often experiences tem-

---

(1) Report written in 1955.
(2) A member of the Soil Bureau of the Department of Scientific and Industrial Research of New Zealand.

peratures some 6º F. to 9º F. higher than localities on the coast. The mean annual temperature gradient shows a slight rise as far inland as the foot of the cordillera. (Coast, 40º F; central plain 42º f). On a seasonal basis, the coast is warmer than the central plain in winter, and the latter is a little warmer than much of the coastal region in summer. Mean annual rainfall is in places higher on the coast than on the plain, mainly due to extra rain during the winter months; total precipitation along much of the coast is about 2 to 3 inches higher than at Santiago. The coastal uplands receive about 30 in, per annum, and a similar amount is experienced over the lower foothills of the Andes, but with increasing altitude, precipitation increases slowly to a maximum of about 60 in., and much of this occurs as snow in winter. The air of the coastal region is consistently more humid than that inland throughout the year. The coastal regions have a mean annual humidity of about 80% with seasonal range of probably not more than 10%. Humidity at the coast is considerably influenced by a bank of cloud and mist that often rolls in from the sea as the land cools during the night. Humidity figures for Santiago show a mean annual humidity of less than 70%, with a range from 56% to 80%. Humidity data may often be an important factor in soil formation in regions where the rainfall is relatively light.

The original *vegetation* along this transect has been modified by at least eight centuries of fairly intense human activity. Casual burning by nomad tribes, inhabiting this part of South America, probably destroyed much of the vegetation for several centuries prior to the arrival of more stable forms of farming, introduced by Inca colonists. However, despite the great modifications in the natural vegetation caused during these centuries of intermittent burning, it seems generally agreed by botanist that there are traces left of five main environmental zones, as follows:

— a strip of evergreen and semi-evergreen forest, extending in places up to 5 miles inland from the coast —

— xerophytic woodland with patches of open woodland rich in xerophytic species on the northern and eastern slopes of the coastal ranges, and a more compact type of low woodland of mixed xerophytic species, including both evergreen and decidous trees, on the southern and western slopes of the coastal range, —

— grassland with patches of Acacia *cavenia* woodland occupying much of the central plain —

— xerophytic shrubland and dense scrub along the lower Andean foothills, merging into low scrub and herb-field in alpine belt —

— above which begins the subalpine and alpine herb-field.

Gallery forest accompany the course of the rivers across the central plain and also through the coastal range, but apart from these forests, and the strip of evergreen forest along the coast, it is possible that very little *closed* forest cover was ever present in the region covered by the transect.

Soil forming *parent materials* present along the transect range from granitic and highly metamorphosed sedimentary and igneous rocks of considerable age, to Quaternary marine sediments. The latter are to be found only along the coast. Much of the lower-lying land is mantled in glacial detritus, some undisturbed since the last cycle of glaciation, but in many places resorted and redeposited, along with recent alluvial and colluvial material. Terraces and terrace remnants of pumiceous volcanic material are also found in the region.

Throughout the transect, great diversity of *topography occurs*. The lowest lying areas are of level to slightly undulating relief, often bordered by a strip of rolling landscape produced by the mature dissection of terraces. Isolated hills arise from the central plain, but hilly landscapes are largely confined to the coastal ranges and to the lower foothills of the cordillera. Part of the summit region of the coastal range consists of strongly rolling uplands forming, in some cases, a well-defined system of dissected plateaux. Ascending the Andean cordillera, slopes steepen abruptly, and many of the small towns of the foothills are set in mountainous topography.

It is quite evident that the *time* factor in soil formation has been comparatively short over much of the transect. None of the soils of the Andean foothills or the central plain can be older than the last glacial period, and none of the soils of the lowlands along the coast can predate early Quaternary uplift. Thus the oldest soils are likely to be found on the remnant plateaux surfaces of the coastal range.

Evidence of zonal impress in soil profiles:

A soil surveyor entering an unfamiliar environment is concerned, first of all, with locating evidence from which he can judge the strength and direction of current soil forming processes. He seeks out the oldest soils on the most stable land surfaces for an expression of the maximum zonal impress, and compares these soil profiles with others of less stability and greater youthfulness, paying particular attention to profile features normally associated with the processes of leaching and weathering. Experience has taught him to restrict, if possible, his investigations to a comparatively narrow range of soil parent materials, and, where possible, to consider only those of somewhat siliceous nature (i. e., excluding materials abnormally rich in ferro-magnesian minerals). Care must also be taken to exclude from the initial analysis polycyclic profiles (profiles in which changes produced by currently operating soil processes are wholly or partially obscured by features which have persisted from an earlier environmental cycle). With such a formidable list of restrictions, frequently only a very small part of the landscape is well suited for studies of this type. Occasionally, as in the case of many small Pacific islands of basic volcanic origin, there are no really suitable soils available for easy estimation of the strength and direction of the current zonal impress, but even in these cases experience and careful interpretation of the soils by field examination will usually permit a reasonable estimate. This estimate is of considerable importance because it underlies much of the critical dynamic relationship between plants and soils (hence crop production, land use consideration, etc.).

In the case of the transect under discussion, the range of soil parent materials is wide, but parent materials of desirable low ferro-magnesian content unfortunately occur over only a small part of the environmental range. Furthermore, anycomparatively stable sites located in the foothills of the cordillera must have soils no older than the last glaciation, while soils in equivalent sites in the coastal range may well have been developing over a longer period of time. Indeed many of the stable soils derived from the granitic rocks do show profile features suggestive of an earlier, warmer paleo-climate, and hence maybe are polycyclic in origin. There is therefore little chance of making a close evaluation of current soil forming processes along this transect using only the stable soils. The alternative is to try for an approximate estimation based upon a study of the somewhat less stable soils developed on one of the more widespread types of parent material available: preferably one that extends throughout the full environmental range of the transect.

This was attempted by making a comparison of soils formed from metamorphosed sedimentary rocks containing volcanic ash of moderate ferro-magnesian content (mainly hypersthene and augite). To obtain a wider range of soils for this study it was necessary to include soils on strongly rolling to hilly relief (slopes between 16º and 24º). From these field studies, it could be estimated that at least five pedogenic regions are present along the transect. Along the coast and extending for two or three miles inland, weathering appear to be slight-to-moderate and leaching moderate and probably strongly influenced by the presence of cyclic salt. Somewhat further inland, i. e. over much of the coastal range, the intensity of weathering is slightly lower than on the coast, but the intensity of leaching is somewhat higher. The latter appears to fall off quite sharply on the inland side of the range (before reaching the central plain). Over most of the central plain itself, weathering is weak-to-very slight and leaching is the weakest of any part of the transect. (1) Similar conditions exist along the outer margin of the foothills; but with increasing altitude, weathering increases slightly for a time and then decreases again at the highest levels.

(1) This, of course, excludes soils that have been under irrigation over a long period.

By contrast, leaching is slight in the lower foothills but becomes more and more pronounced in the upper foothills (i. e. above 2,500 ft.).

The overall range between the least leached and most leached, and between the least weathered and most weathered profiles in the sequence, is small, and only relatively minor pedological differences separate the members of the sequence. With increasing altitude, soils of the Andean foothills show increasingly fine aggregation, and at the higher elevations the soils become loose and powdery in the topsoil and develop strong brown to yellow-brown colours in the subsoil. The strong differentiation between topsoil and subsoil colours is found only at the higher elevations in the cordillera; at lower elevations both topsoil and subsoil are brown to dark brown.

It must be emphasized that these field studies were made largely on soils developed on moderate slopes, where there is insufficient stability to show clearly the impress of soil forming processes. The more stable soils examined suggest that the soils of this sequence might be approximately correlated with the weak-to-submoderately weathered Brown Granular Clays developed from andesitic rocks in the eastern half of the South Island of New Zealand. Somewhat similar soils are found in parts of the southern interior of British Columbia in places where intermediate rocks predominate, and these are regarded as belonging to the Brown Wooded soils of the Canadian classification. In California, soils with similar profiles have been included in the Non-Calcic Brown soil group.

Soil patterns:

Analysis of the intensity of the zonal impress is one thing, and presenting an accurate picture of the soil pattern is often quite another thing. In the transect in question, the actual area of the soils considered suitable for pedogenic analysis is probably considerably less than 1% of the whole area included in the transect. In most cases the profiles studied represent soils that occupy too small an area to delineate as units on the soil map. Pedogenetic analysis in itself often poses many problems, but an even greater challenge to the acumen of the soil surveyor is that presented by the problem of pedologic synthesis, — the grouping together of the many soil units detectable in the landscape, so that the ultimate soil map will present an accurate resume of soil conditions in any area. In many Chilean landscapes there is so great a diversity of topography or parent materials, and so great a disparity in age between soils, that any regional impress exerted by the climate, and its ally, the plant cover, becomes almost totally obscured in the picture presented on the final soil map, unless the map legend is carefully constructed to bring out hidden regional relationships, — which are often of great significance in agricultural practice.

Consider, for example, the soil pattern of the more elevated part of the present transect: the upper foothill region of the cordillera. Here the dominant soils are unstable lithosols and steepland soils. These persist over a large part of the lower foothill region of the Andes; and, in both upper and lower regions, the most significant feature modifying the appearance of the soil profile is the presence or absence of calcium carbonate in the parent rock. This is particularly important in the lower foothill region where steepland soils and hill soils occupy a proportionately greater part of the landscape than lithosols, and where there is a greater accumulation of outwash fan and colluvial material giving rise to soils on the valley bottoms and along the foot of the slopes. Very many of the soils formed by accumulation contain a large amount of free lime as a result of leaching from above. The region as a whole may be characterized as one of weak-to-slight weathering and leaching (such as is normally associated with the development of *Non-Calcic* Brown soils) but owing to the sporadic occurrence of calcareous rocks in the landscape, and owing to concentration of the weathering products by accidents of topography, the soil pattern actually shows an exceedingly large area occupied by *highly calcareous* soils.

The soil pattern over the less elevated part of the Andean foothills, included in the transect, shows a complex association of calcareous and non-calcalithosols, steepland soils, and hill soils, with outwash fans, stream alluvium an older alluvial terraces; and many of these soils are partly or wholly calcareous in nature.

On the central plain, both calcareous and alkaline soils are common. There is a sprinkling of more leached soils where pumiceous or gravelly terraces occur, but the soils of the surrounding rolling to hilly terrain are frequently highly calcareous. There is often a well-marked topographic soil catena, with dark brown soils on the upper part of a slope, grading into grey-brown, then dark grey and black soils at the foot of the slope. It is likely that calcium, released by solution of limestone present in the glacial drift or by weathering of basic minerals, moves down slope with the drainage water to reappear as calcium carbonate in the lower members of the catena where the soils dry out in summer. In regions of weak weathering and weak leaching, such occurrences are to be anticipated. Non-calcic brown soils may be present, but only as a minor component in the soil pattern.

That part of the central plain near the main rivers is occupied by recent alluvial soils, commonly light grey or brownish-grey gravelly sands over rounded river gravel. These soils are similar to those found on the Canterbury Plains in New Zealand, and, where irrigated, are very productive. Complexly associated with the well-drained alluvial soils are other less freely drained soils showing weak to moderate mottling. Heavier textured gley soils occupy a part of the bottomland, and most of these are very alkaline, (e. g. near Batuco).

Amongst the more interesting soils of this part of the central plain are those formed on the pumiceous terraces. The origin of the pumice is obscure but since the terraces have been built up by the Mapocho and Maipo rivers, the volcanic material is likely to have originated from a vent near the source of these rivers. Near Melipilla township, the pumiceous subsoil is cemented to form, when dry, a strong, rigid pan which appears to follow the minor undulations of the surface of the terrace and may possibly be a pedological feature (i. e. one not present when the pumiceous materials were emplaced) ; although other aspects (i. e. lack of consistent correlation between soil depth and thickness of pan) suggest that this phenomenon may turn out to be primarily a geological attribute. The nature of the cementing material is uncertain, but may well include silica as a bounding agent, supplemented by accumulation of iron and manganese (derived by leaching from the soil above) as a thin layer coating the upper surface of the pan.

A large part of the coastal range is formed from granodioritic rocks. Road tunnels cut through this rock confirm that the first stages of rock decay have penetrated to a depth of 250 ft. The outer layers of this weathering zone are much more strongly decomposed and give rise to soils with a conspicuous reddish-brown subsoil colour. These reddish colours, taken in conjunction with the depth of penetration of rock weathering, have given rise to suggestions that since the coastal range escaped the later cycles of glaciation, the soils may have originally formed by soil processes associated with a period when the climate was warmer and wetter than at present. However, it must be remembered that granites are in most cases very old rocks, and their coarsely crystalline structure, that could be expected to disintegrate deeply in the course of time, irrespective of climatic conditions. The appearance of reddish colours in the soil could likewise be due to the addition of small amounts of basic volcanic dust to the soil mantle. Topsoils are usually grey to pale grey sandy loams or sandy clay loams, contrasting sharply with the reddish-brown sandy clay subsoils which are compact and usually show prismatic and columnar structures. In the superficial features many of the granitic soils of Chile resemble the Red-Yellow Mediterranean soils of Río de Janeiro State, Brazil.

In the coastal region, some very interesting soils are found on the older of the marine terraces. The marine sediments forming these terraces appear to be a mixture of granitic and basic volcanic detritus. The soils developed in them show a sharp differentiation between the dull grey-brown structureless loamy sand topsoil and the brown heavy clay of the subsoil. Further investigation may show that topsoil and subsoil materials are not always of identical origin. In many places the subsoil is very strongly mottled. An influence of salt spray from the sea (cyclic salt) on soil development is strongly indicated.

PART II

SOILS BETWEEN TALCA (LAT. 35º 30' S.) AND LOS ANGELES (37º 30' S.)

Most of the area visited was already covered by reconnaissance soil maps, although the area in the vicinity of Linares was in process of being mapped.

The detail shown on these soil maps and the standard required for reconnaissance surveys is somewhat similar to that in use in New Zealand. Indeed the reconnaissance soil maps of Chile can be readily comprehended by a New Zealand pedologist. In both countries, the soil boundaries on the reconnaissance maps embrace units which are in most cases larger than soil types and often larger than soil series. The mapping units are sometimes composed of genetically related soils, but quite often they represent an *assemblage* of soils related only through their geographic distribution on a particular type of landscape. As in New Zealand, the publishing scale is 1:250,000; which inevitably requires considerable condensation of soil knowledge. In New Zealand, the published mapping units have been referred to as "soil sets" implying that they are an utilitarian grouping. On reconnaissance soil maps it is rarely possible to depict the soils exactly as they are: the patterns are too complex and the range of topography over any given area of land, too great. In such regions the use of grouping such as soil "sets" is almost obligatory on maps of reconnaissance scale. In Canada, British Columbia is facing the same problem. Both New Zealand and Chile, have kept, when ever possible, some clear thread of genetic relationship in assembling the soil "sets".

Two conventions in general use in New Zealand which might be used in Chile to make soil maps more effective pictorially are, (i) the use of a basal stippling to indicate normal hill soils on slopes that are to steep for ploughing and (ii) the separation of lithosols and steepland soils on very steep slopes asentirely separate soil groups. On maps prior to 1956 the soil boundary of the "Cordillera series" really represented the boundary at which soil mapping stopped, for within the "Cordillera series" there is a considerable area of valley bottom, hill slope, upland plateaux, sub-alpine and alpine soils, all worth mapping and many of which are actually being farmed. If the hill soils of cordillera foothills were stippled to show their relationship to normal soils developed on adjacent land of more gentle relief; and the truly steep soils of the cordillera separately differentiated (perhaps as a Cordillera lithosol set) a better picture might be achieved. The presence or absence of volcanic ash mantling the lithosol set is also worth showing. Exactly the same problems had to be faced when mapping the North Island of New Zealand and the draughting technique finally selected is well shown on sheet 4 of the provisional soil map of the North Island of New Zealand.

The volcanic ash soils of the region:

To a New Zealander the chief interest of the region lies in the presence of volcanic ash as a widespread soil forming material. The ash gives rise to the group of soils known in Chile by the name "Trumao" soils. They are unquestionably similar to the "Yellow Brown loam" group as defined in the New Zealand soil classification. Should New Zealand ever have to find a better name, the name "Trumao" would be highly suitable. "Trumao" is an Araucanian word descriptive of the light, powdery nature of the material, and its origin by accumulation.

Trumao soils as recognized in Chile, are soils formed from the more recent accumulations of light and powdery volcanic dust. However, they are not the only volcanic ash soils in Chile. Reference has been made (in Part I) to the presence of rhyolite pumice deposits in the Santiago area. There are also beds of older volcanic material, of heavier texture than Trumao at their present stage of weathering and of redder hue. Soils from these beds belong to a broad suite known as "Collipulli". These soils have been variously described as derived from loess, glacio-fluvial deposits and alluvium containing much ash. However, many of the features associated with the Collipulli soils are more consistent with origin from volcanic dust whose main period of accumulation seems to have been contemporaneous with the end of the last period of glaciation. There is evidence that this dust was accumulating at a time when many of the slopes of the cordillera were free of ice but when many of the valleys were still ice-bound. In some places glacial drift and large boulders are buried by typical ash while in other placse (i. e. on the lower slopes of some valleys) there is drift and boulders but no ash at all. Occasionally, one may even find a tongue of flacial drift sandwiched between beds of typical Collipulli ash.

Much of the Collipulli-type ash appears to have been washed from the slopes of the cordillera, thereby contributing to colluvial deposits on the plains; and, in mixture with other alluvial materials, to alluvial deposits and even lake deposits. All of these have a characteristic bright red-brown colour and are related to the soils mapped under the names — Collipulli, Mirador, etc. At times the mapping of the Collipulli and related soils may have been a little uneven. The presence of Collipulli ash on the upper slopes of the cordillera near Bullilleo (Parral) would justify the creation of a hill soil category within the Collipulli suite. Similarly the presence of a layer of Collipulli ash of even depth faithfully following the relief of strongly rolling slopes near Los Angeles would justify a "loma" sub-category.

The source from whence came the Collipulli ash is obscure. It may represent ancient dust accumulating from several volcanoes in more or less simultaneous action along the cordillera; each contributing their quota of dust. Chillan volcano seems to have contributed particularly strongly, but some of the material may have originated from any one or more of the following five or six vents lying immediately to the south, namely Antuco, Copahue, Tolhuaca, Lonquimay or Llaima. In the present advanced stage of weathering there is little field evidence to indicate if there was any significant difference between the ash originating from the different volcanoes, — if indeed there *was* any difference originally.

Turning now to consideration of the less weathered ash soils known as "Trumao", there does appear to be some slight difference in the nature of the ash from separate vents. What is needed is some petrographic investigation of the sand fractions. However, differences may prove to be so small that it may be possible to regard most Trumao soils as belonging to one common suite; or, on the other hand, several suites may need to be recognized.

Interesting soil patterns are encountered near the western limit of the Trumao soils, particularly where the Collipulli ash beds extend westward beyond the limit of the Trumao beds. Chilean soil maps usually show the Trumao soils ceasing at the point where the ash is still a uniform mantle of some 12 or 20 inches in depth. There is a good reason for this, for a thin veneer of Trumao ash is not easy to differentiate from the topsoil of the Collipulli soils. Moreover on slopes over 50º, the lighter dust seems to have washed off almost as fast as it fell. Thus, to the east of Parral, Trumao soils are absent from slopes of the cordillera which are deeply mantled by Collipulli ash to a depth of 3 ft., yet Trumao may be present on land of easy relief in the same area. In New Zealand it is customary to try and locate the 3 inch or 6 inch boundary of each ash shower but in Chile this boundary becomes highly conjectural without the services of a mineralogist. It is however necessary to find some way to mark on the soil map, the fringe or transition zone of Trumao soils, particulary where this falls in a region of Collipulli soils. In the simplest form this can be done by using double symbols or numbers on the soil map; but it is often more satisfactory to indicate the transition by noting changes in topsoil textures, i. e. Collipulli clay becomes, in the transition zone, Collipulli fine sandy clay loam. Sometimes the transition zone may show an intricate pattern of Collipulli clay with islands of Trumao represented by fine sandy clay loam, and this may justify the creation of a zone referred to as Collipulli complex; clay and fine sandy clay loam. Whichever of these three techniques proves to be best suited to local conditions, it is nevertheless advisable, in some way or other, to show the transition zones on the reconnaissance soil maps. They are important soil entities and are usually recognized as such by the farming community. For verification of the real depth of the Trumao ash before erosion removed some of it, it is usually necessary to search the flatter parts of the summits of the island hills that are occasionally present in the plain. In a few places slight traces of Trumao ash can even be found on the rounded plateau landings of the coastal range, although it seems certain that most of the coastal range in this part of Chile lay outside the main zone of Trumao ash accumulation.

Profile differentiation in the ash soils is interesting. The range of climate and vegetation in the region between Talca and Los Angeles is not so great (total annual rainfall ranges from 30 ins. to 50 ins. and the original plant cover formerly ranged from "Espinos" scrub to light broadleaf forest). By extending the investigations into the foothills of the cordillera, the environmental range can be widened to include regions with a total annual rainfall of over 100 ins. and a closed forest in which Nothofagus sp. and Laurelia sp. predominate. In well-drained sites, Collipulli soils show two main types of profile; differing mainly in the degree of clay shift, subsoil structures, apparent mobilization of iron, and also in apparent fertility. The least developed profiles are found in the lowlands near Linares where by New Zealand standards the stage of development would be referred to as "late immature". More developed profiles are found in the cordillera east of Parral where the stage of development would be recognized as "mid to late semimature".

Trumao soils in well-drained sites also show two distinct types of profile. One is knows as the Santa Barbara type and is typically representative of an immature Yellow Brown Loam of the New Zealand classification. The other is a semimature profile found at higher altitudes in the cordillera. This latter soil may turn out to be a northward relative of Puerto Octay soils, mapped more extensively in Llanquihue Province. Strongly gleyed profiles were not seen in Trumao soils in this region, and the main indication of increasing soil moisture was in the deep, dark brown topsoils developed where the soils were occupying depressions.

The Soils derived from granitic and metamorphic rocks:

The coastal range in these latitudes is largely composed of granitic rocks. Total annual rainfall lies between 40 ins. and 70 ins., and only a few of the higher hills receive about 100 ins. The original vegetation as far south as the river Bio-Bío ranges from coastal scrub to broadleaf forest. However, soil profiles do not appear to show a great deal of differentiation between these environmental extremes, and problems of pedogenesis are overshadowed by the speculation as to what makes these granitic soils predominantly red-brown or reddish in their subsoil colour. As mentioned earlier it has been suggested that the reddish coloration is due to soil processes operating in these soils during warm, dry period in inter-glacial times. The difficulty with this theory is that the soils are by no means uniformly reddish, — many of them are quite a pale yellow-brown colour and, if the reddish coloration is present, it varies greatly in depth, sometimes extending down deeply into the weathering rock. The deeper zones of the weathering rock itself is not reddish. There is some possibility that the reddish subsoil colours in many granitic soils are caused by admixture of volcanic ash in the topsoil. This cannot yet be entirely ruled out in explaining the colour variations in such soils as Cauquenes soils. Field evidence is somewhat unsatisfactory. For instance, many places on the broad upland plateaux where ash must surely have lodged when volcanic dust was falling in this region seem to be free of ash; although a shallow drift of ash is fairly common on some of the gentle eastern slopes of the coastal range in the about latitude of Chillan.

The peculiar thing about granitic rocks as a soil parent material is that weathering appears to proceed in two stages. In the first stage part of the mineral assemblage weathers — usually to very great depth — leaving soft, rotten rock. This stage of weathering does not produce any marked reddish coloration; the rotten granite is only slightly yellowish or brown stained. Most granitic rocks (perhaps the majority of those present in Chile) seem to undergo a further stage of weathering during soil formation, and in the course of this the red coloration is produced. This may be in some way associated with the development of the organic cycle during soil genesis. The building up of soil humus and the increase in the quantity and in the variety of organic acids circulating in the upper soil horizons may bring about the decomposition of iron-bearing minerals which are comparatively resistant to decomposition by carbonic acid, hydrolysis and related inorganic agencies. It is well known that iron and alumina phosphates can be dissolved by certain groups of organic acids commonly associated with the soil organic cycle, and it may be that in this fact lies part of the explanation of the production of red subsoil colours in some granitic soils. In the case of granitic soils which do not show red subsoil colours, this may correlate with petrological variability of the parent materials: i. e. the presence or absence of a particular mineral group of minerals. Likewise differences may be associated with the path taken by percolating rainwater carrying down organic compounds. Red colours at depth are not so common and appear to be associated with zones of shattered rock where groundwater can move comparatively freely. It is also noticeable that local concentrations of plant organic matter, — as when a tree root forces its way through rotten granite — are usually accompanied by the development of reddish colours. It is a problem worth further study.

The importance of organic matter in releasing plant food from rock minerals is well demonstrated on the flood plain of the Laja river. Where this river debouches from the Cordillera, there is a wide plain composed of andesitic and basaltic fine gravel and sand. Lower down the valley, there are grey sand dunes flanking the river, and the same type of sand (somewhat mixed with quartz from granitic rocks) makes up the recent dune accumulations on the coast. All these parent materials are potentially valuable soils because they contain a comparatively large reserve of plant food in their mineral assemblage. This food reserve may be released but slowly during inorganic weathering, but release is likely to be greatly accelerated when the soil acquires an efficient organic cycle. Experimental *Pinus insignis* plantations on the Laja gravels will probably prove to be very successful for their organic by-products appear to be attacking the finer mineral fraction in the soil and thus releasing plant foods at ever increasing rates. The long channels of more strongly weathered material following the path of roots penetrating the gravel beds bears witness to this. In the same way, the older sand dunes lower down the valley may become excellent farming soils once an efficient humus-building system of soil management has been adopted.

Granitic soils to the west of Los Angeles show less and less red coloration in their profiles; and near the southern limit of the granitic soils, the great majority of the soil profiles are pale brownish yellow and show moderate to strongly leached, moderately weathered profiles. Thus there is a gradual change from reddish granitic soils in the north in plant cover associated with exposure may be involved. The occasional, presence of red colours at depth in the deep zone of decomposing rock to yellowish granitic soils near the southern limit of the range of these rocks. There may be a correlation with a change in the mineral assemblage, produced during the granitization of this continuous mass of rock, or it may be a reflection of the gradual change in climate and vegetation from North to South.

Soils derived from mica-schist occur to the west of Los Angeles. These normally weather deeply, like granitic rocks, but to produce a fine sand rather than a coarse sand. In this material, many of the soil profiles take on a light vermillion-brown or pinkish-brown colour.

The presence of a wide range of red-brown and brown-red soils formed from granitic rocks and mica-schist (sometimes partly covered with a mantle of reddish-brown Collipulli ash) makes mapping by remote inspection a somewhat chancy busines. In particular, deep inspection pits may be needed to resolve the soil pattern in the zone where Collipulli soils are complexly associated with soils derived from mica-schist.

A HYPOTHETICAL CHRONOLOGY OF SOIL FORMATION IN THE MIDDLE SECTION OF THE CENTRAL VALLEY

The history of soil formation in the middle section of the Central Valley may have been approximately as follows:

(I) At the time of the last glaciation the longitudinal valley had attained, more or less, its present shape: — a longitudinal depression flanked on the west by the coastal range of granite, granodiorite and mica schist; and by the Andean cordillera in the east. Bouldery deposits (possibly formed either as lateral moraines of an earlier cycle of glaciation, as boulder beach deposits around ancient lakes, or littoral debris during ingression of the sea in warm inter-glacial times) were present at the foot of the Andean slopes, and very probably also along the inner flanks of the coastal range. The floor of the valley was occupied mainly by boulder clays, sands and gravels of fluvial glacial and glaciolacustrine origin. Some of these were inter-leaved with beds of volcanic ash and cemented "tosca" layers. The ancient valley floor was a plain of subdued relief, broken in places by rolling hillocks representing remnants of terminal moraines of former glaciers. Several large lakes may have been in existence at various times.

(II) The limit of the ice during the last glaciation seems not to have extended far out on to the valley floor from the Andean Cordillera. No signs of any recent glaciation was seen in the coastal range. Terminal moraines from these lateral glaciers and deposition of boulders were probably the most significant contribution of this last cycle or refrigeration to the geomorphology of the central valley.

(III) Before the ice had completely melted from the Andean valleys an event of importance occurred. This took the form of a steady, slow rain of fine basic volcanic dust. This seems to have occurred over the whole of the eastern half of central Chile, — from Parral in the north to the far south. Several vents may have contributed to this dusting of ash. However, no clear difference can be seen in the macroscopic features of this ash over the whole range of its extent.

(IV) Much of this ash became redistributed about as soon as it fell. The climate may have been such that the ice mantle was melting fast and turbulent streams and rivers were building steep cones of gravelly alluvium mixed with ash on the floor of the central valley. In places ash was moved by sheet wash to give deep beds of colluvial ash which are almost free of stones. Meanwhile the drifting dust continued, possibly covering parts of the landscape to a total depth of some 10 ft.; in places covering the earlier resorted ash, and ash-alluvium deposits, with a new mantle of the sub-aerial dust. Strong winds would be likely to move some of the ash, like loess, forming low dunes, and filling in shallow depressions in the topography.

(V) At the end of this period of ash deposition, there appears to have been a fairly long interval with only minor volcanic activity. During this time, the Andean rivers extended their alluvial cones across the plain and, swinging from one course to another, removed much of the earlier "alluvial fan" deposits and isolating other patches so that they now appear as remnants of old terraces. A new series of younger, stony sediments came into existence on the floor of the plain, and in these the proportion of ancient volcanic ash is much diluted.

(VI) At some point in this period, ash deposition recommenced. These younger volcanic dusts are of an andesitic type, and, whereas the pattern of deposition strongly suggests that this material could be in some cases related to individual vents or to groups of volcanoes, there is little difference in the composition of the ash detectable by simple examination in the field. There were possibly at least four major centres of ash production but the volcanic activity of all four was probably contemporaneous. The nature of this activity probably involved intermittent explosions which produced coarse shower deposits in the vicinity of the vent, and a rain of fine ash over the surrounding country side. Much of the dust is likely to have fallen in Argentine territory.

(VII) As a result of this later period of ash deposition, the rivers became over-loaded with ash and broke out from their established channels, depositing water-sorted ash over a wide area of the central valley. Subsequent floods carried down ash mixed with miscellaneous alluvial materials, giving rise to a further set of mixed alluvial and Trumao soils.

(VIII) At the end of this last cycle of ash deposition, the rivers settled in their new courses and normal alluvial accretion was resumed.

The foregoing account deals only with the general processes which helped to build up the landscape. In addition, there have been a number of specific local phenomena which have played a part in soil formation in certain places. The development of impervious pans, locally known as "tosca", is one such example.

Tosca layers found in this part of Chile appear to be of at least four types.

(I) Near Temuco, some of the central plain land is covered with resorted Trumao, but below the ash bed there is a cemented horizon of coarse dark gray scoriaceous gravel. The gravel is angular but fairly fine. This cemented horizon is peculiar to the plain and is absent from the nearby hills, and therefore it cannot be derived directly from a volcanic shower. The gravel is too angular to permit the suggestion that it is an alluvial deposition, and the most feasible suggestion seems to be that it represents a gravelly mud flow the breaching of some glacial lake nearby.

(II) Over part of the foothills, in the Cordillera, prominent beds of gravelly scoria are encountered. These are often cemented, but they are clearly of normal sub-aerial origin and follow the curve of the present landscape.

(III) Yet a third type of tosca is that associated with a rapid flow of incandescent scoria. One such flow appears to have swept down the Laja valley from a vent near Antuco. It would appear that a swift-flowing river of incandescent gravel filled in many of the depressions in the plain between Chillán and a point just south of the Laja falls. The lip of the Laja fall is composed of material belonging to this tosca layer, here some 10 ft. in depth. This type of tosca is very strongly cemented and much resembles a fine breccia.

(IV) Another type of tosca is produced by the cementation of fine and coarse glacial material.

The agency cementing the various kinds of tosca described above is likely to be varied. Iron and humus are responsible for cementation in the case of some toscas, but often the cementing agents cannot be identified in the field. It is suspected that, in some cases, the cementing agent may be colloidal or hydrated silica. Cementation by deposition of calcium carbonate was noted in a few cases.

Correlation of New Zealand soils and Chilean soils of this region:

Many of the soils of this region of Chile correspond fairly closely to soil types in New Zealand, yet the land use practices do not. This is due mainly to differences in the distribution of rainfall. The total rainfall and the mean temperatures have about the same annual ranges in both countries, but in this part of Chile there is a marked period of summer drought: much of the land between the coast in the foothills of the Cordillera experience 4 to 5 months with less than 2 — 4 inches of rain. No region of New Zealand consistently has such a long dry summer, except possibly parts of central Otago. In occasional summers the climate of the Canterbury plains region in New Zealand, might approach fairly closely that of Chillán. This means, for instance, that the volcanic ash soils of Chile cannot support New Zealand types of pasture unless irrigated, and this may explain, to a large extent, why the Trumao soils of Chile are at present, less productive than their New Zealand counterpart. The total environment measured as annual rainfall temperature may be rather similar in both countries, but seasonal conditions are not as closely comparable as they might at first appear.

The chief differences visible in the soil appear to be due to differences in the intensity of soil weathering; Chilean Trumao soils are mainly less weathered and less rapidly weathering, than most New Zealand *Yellow-Brown loams.* To a New Zealand pedologist, Chile provides examples of a range of weak to *slightly weathered* Yellow-Brown loams, such as might have been developed in the South island of New Zealand had these beds of volcanic ash been present in this region. As it is, many of the Chilean Trumao soils have a striking resemblance to some loess soils on the Southland plain and in the Catlins ranges of the southern region of New Zealand. This resemblance increases if comparison is made with the Trumao soils of Chiloé Island.

Because of this difference in stage and intensity of weathering it is hard to find precise New Zealand equivalents for Trumao soils of this part of Chile *Egmont* and *Otorohanga soils* are related to Santa Bárbara Trumao soils, but the relationship is not a close one.

The red-brown Collipulli and related ash soils of Chile resemble in some respects certain of the basalt soils of North Auckland, New Zealand (especially those of the dolerite suites), and show other features relating them to the *Hamilton soils* of New Zealand.

The alluvial soils of the central valley are very like some of the recent soils of the New Zealand Canterbury plains; for instance, the gravelly recent alluvium of the Laja valley and the "Arenales" series are, superficially at least, like many South Island alluvial soils. Differences may become more apparent with time, when the alluvium becomes more weathered, for the Chilean materials are predominantly andesitic, while those of New Zealand are usually less rich in ferromagnesian minerals.

Recent ash such as that mantling the slopes of Volcán Chillán is normally a dark grey sand, much resembling the Ngaurahoe soils on the slopes of Mt. Ngaurahoe in New Zealnad.

Distribution of volcanic ash:

This part of Chile is relatively heavily mantled in volcanic ash and the great majority of the soils are derived from this type of parent material. Thick beds of volcanic ash, showing clear banding due to difference in the particle sizes and mineral composition of successive showers, extend right to the coast in the province of Valdivia. Upland plateau located in the coastal ranges are often fairly thickly plastered with ash, although "windows" where the soils are formed from the underlying rock do occur here and there. In these southern provinces, the familiar granitic rocks which formed much of the coastal range as far south as Angol gives way to mica-schist. Correlating with this change in the underlying geology, there is a marked alteration in the proportion of lithosols and steepland soils in the landscape. Up to a point this also applies to the foothills of the cordillera from Osorno northwards; fully 50% of the soils of the ranges and foothills could be classed as hill soils, and less than 5% as lithosols. The amount of ash plastered on these slopes varies greatly, and in some cases the soil pattern is intricate and will probably have to be mapped as a complex of ash and non-ash soils.

There are at least thirteen volcanic cones along the cordillera between the latitudes of Los Angeles and Puerto Montt, and several of these have been in eruption during the present century. Deep vertical sections seen in road cuts show that, in the past, there was considerable diversity in the ejecta from different centres, but later deposits show some measure of uniformity. There may be some possibility of identifying ash material from the different centres by means of soil minerological studies, but in the field there appears to be little difference from the younger ash near Antuco volcano in the north and that from Osorno volcano, some 4 degrees of latitude to the south.

Most of the volcanic material consists of beds of fine ash and well-marked shower horizons are conspicuous by their absence — at least as far as the lowlands of the central plain and the coastal range are concerned. Shower layers, indicative of a sudden explosive phase, are slightly more common along the foothills of the cordillera, a feature which is related to an increasing proximity to the actual vents. There are very few prominent shower horizons like that described by Auer, ("Las capas volcánicas como base de cronología post-glacial de Fuego Patagónica", Revista de Investigaciones Agrícolas, Vol. III, Nº II, Buenos Aires).

Auer refers to a conspicuous layer of pumice near Lake Todos los Santos and Puerto Montt, and has suggested that the point of origin might have been Osorno volcano. There is a deep pumiceous shower horizon, resembling the one described by Auer, in the ash beds near Villarrica but it may well be that Villarrica volcano is the source of this material and not Osorno. Auer considers that this shower is not less than 10.000 years old. The Villarrica pumice appears to lie in the middle of sandy ash beds whose dark brown colour is flecked with a white weathered mineral. This enveloping ash bed is not greatly dissimilar to some dark brown sandy ash beds seen on Chiloé Island. These beds enclose a sandy horizon, probably due to a mud eruption. The soil known as Puerto Octay appears to be derived from these same dark brown sandy ash beds. The stratographic relationship between these conspicuous dark brown ash beds and the more weathered underlying ash which gives rise to the reddish-brown clays and loams of Fresia and Mulpun soils (which are in some respects not unlike Collipulli soils) was not resolved during the brief time available. This same reddish-colored, heavy, strongly weathered ash material was also found at depth on Chiloé Island, but did not appear to be soil forming on that part of the island visited.

The youngest (uppermost) ash beds show great variability in thickness even on landscapes of subdued relief. For instance, near Valdivia (a point fairly remote from any obvious centre of volcanic activity) the ash appears to be several feet in thickness; contrasting strongly with the situation near Osorno where, on landscapes of similar relief, the latest ash beds are comparatively thin although situated geographically much closer to centres of eruption. This type of irregularity in the thickness of the ash beds is by no means uncommon in this part of Chile, and when the actual soil pattern is studied in some detail, there is more than a suspicion that it is due to some local factor which determines whether the ash would stick or blow away at the time of deposition. Auer, from his studies in southern Argentina, confirms that the post-glacial climates in this region showed the normal rhythm from Boreal to Atlantic to sub-Boreal to sub-Atlantic and that vegetation changes occurred in sympathy with climatic oscillation. It is at least possible that the plant cover over this region of Central Chile showed a complex pattern of forest and grassland at the time when ash deposition was most active. Fine ash drifting down on forested country would be less susceptible to wind erosion than ash falling on grassland or near-barren land. If this was so, then it is conceivable that the ash beds would come to lie thickest in the regions of higher rainfall, as indeed they do in western Valdivia province.

A somewhat similar problem arises in connection with the thickness of ash overlying the level, gravel filled, bottom-land occupied by ñadi soils. Ñadi soils are soils derived from volcanic ash developed in situations where there is a high watertable. Nowhere on the plains does the ash lie as thickly as on the surrounding hills, and it is the presence of strongly cemented horizons in the underlying gravel that produces the high, perched water-table that has so strongly influenced soil development. If the ñadi soils were developed only from ash beds resulting from a later series of eruptions, it would be easy to postulate that infilling by gravel of the bottomland had occurred at a comparatively late stage in the sequence of events; but unfortunately the ash overlying the gravels shows much the same vertical stratification as is present on the adjacent land of rolling relief. The only difference is that each different layer on the flat land is only a fraction of the depth of the same material on the rolling land. It would thus appear that ash material which was able to persist on rolling country, failed to persist on the level bottomland. The cementing material in the gravel appears to be largely ferruginous and may well represent a pedological pan formed long ago, and perhaps was responsible for turning much of the bottomland into a seasonal lake; one which may have dried out in the summer. Under such conditions, no effective plant cover would be able to develop and any ash falling on these bare flats might be susceptible to wind erosion during the summer. It might be possible to demonstrate that the thicker ash beds on the rolling land and terraces adjacent to the flats are partly of windblown (i. e. loessial) origin.

Soil processes in Trumao soils:

Certain of the gravel ridges emerging from the plain are devoid of ash and these soils show podzol horizons or show other indications that they are very strongly leached. In some cases the subsoil shows a cemented iron pan and the soil horizons above are strongly gleyed. In New Zealand, such soils are called Gley podzols, and elsewhere might be regarded as Humic or Groundwater Podzols. They are analogous to the "pakahi" soils of the west coast of the South Island in New Zealand, where they are recognized as being very difficult soils to farm. This is sufficient indication that the intensity of leaching in this region of Chile is very strong.

However, many Trumao soil profiles do not show such an intense degree of leaching. For one thing they are younger than the gravels. A significant factor may lie in the relatively basic nature of the volcanic ash. Much of the material in the ash is likely to have consisted originally of finely comminuted ferromagnesian minerals and basic volcanic glass which are more susceptible to weathering than the gravelly material. Although the intensity of leaching may be strong, the rate of weathering in the ash beds may be adequate to maintain the soils in a comparatively youthful stage of development. Few of the well-drained Trumao soils would be rated at more than a "semi-mature" stage of development by New Zealand standards, and some are still in the "late immature" stage. It must also be remembered that, in general, most Trumao soils in Chile are developing under a weaker weathering regime than the Yellow Brown Loams of New Zealand.

Trumao soils in the highest rainfall region of south-central Chile (esp. Valdivia) show an interesting range of profile development. Many profiles, even in places where the total annual rainfall of more than 100 in. do not show podzolization but possess a subsoil horizon which is powdery, without cohesion, bright orange-brown in colour and sometimes shows development of soft ferruginous concretions. These soils are unquestionably strongly leached but, as in many soils derived from basic parent materials, the form of the iron in the soil seems to preclude easy movement by leaching. Another member in this development sequence is found near Villarrica, where leaching is fairly strong and profiles are intermediate between Valdivia and Santa Bárbara soils. Brighter colours in the Villarrica soils and a tendency to form large, slightly firm aggregates in the subsoil are the main characteristics of this particular stage of development. This profile is frequently encountered between Rucumanqui in the north and Lake Ranco in the south, and probably should be differentiated from surrounding Santa Bárbara soils.

Only a few of the volcanic ash soils of New Zealand are developing in situations with a high watertable, and so ñadi soil profiles are not widespread in New Zealand, although some of the soils near the town of Invercargill, on the Southland plain, are not greatly dissimilar. The downward movement of iron mobilized during the season when ñadi soils are saturated, and the subsequent movement and oxidation of this iron in the underlying gravels, must surely contribute to a steady and gradual worsening of drainage conditions in these soils.

Patches of soil showing podzol horizons which can be related to individual coniferous trees of slow growth habit are not as common in this part of Chile as on the nearby island of Chiloé. Nevertheless, there appears to be some difference in the conditioning effect of the various tree species. This is a well-know phenomenon in New Zealand, and it would make an interesting subject for research to compare the relative podzolizing intensity of the various Nothofagus species in Chile and New Zealand; and also to compare the effect of Podocarpus, Dacrydium and Libocedrus, and other genera which are common between the two countries.

In this region of Chile, it would appear that Nothofagus Dombeyi, N. antarctica and N. pumilio are more potent accelerators of soil development than other members of the Nothofagus genera. Dacrydium sp. and Libocedrus sp. appear to have about the same influence in soil formation in both countries, but the few species of Podocarpus found in Chile appear to be roughly the equivalent of P. spicatus (New Zealand Black Pine) which has a weaker conditioning influence on soil development than most other New Zealand podocarps. Alerce, the large and long-lived Chilean conifer (Fitzroya sp.) appears to be nearly as potent a force in the conditioning of leaching as the kauri (Agathis australis) of New Zealand; but Araucaria, another very interesting Chilean conifer seems to have a rather weak influence on soil development. It is clear that both countries have in common a very interesting field for studies in soil-plant relationships.

Sufficient still remains of the natural forests in this part of Chile to make ecological research of this type very rewarding. However, the natural forests of Chile are dissappearing quite rapidly and many of the best examples are not easy of access. Some time was spent in a visit to the Araucaria forests high in the foothills of the cordillera, inland from Cunco. This forest is growing on recent soils from volcanic ejecta of the volcano, Llaima. Some of this volcanic scoria, is quite recent and may be found in the junction between branch and trunk of some of the older trees.

Recent soils from volcanic ash:

The younger ash beds remote from the centre of the eruption are largely unstratified, but on approaching the centre of the eruption along any radius, stratification soon becomes apparent and textures become more coarse. Textures at a distance may be fine sandy loam, and there is usually a progression through sandy loam to loamy sand and coarse sand, with increasing admixture of fine and coarse scoria. On the actual slopes of the volcano, the material is often thinly stratified fine and coarse scoria, and the commonest soil texture is gravelly sand. In a like manner, soil colours change from brown to brownish-yellow to dark grey on approaching the volcano. Recent volcanic soils are usually dark grey or grey-brown near the actual vent and the minerals in the material are but little weathered. On the slopes and plains in the immediate vicinity of the vent the soils are deep, dark grey and very scoriaceous, showing little signs of profile development.

These recent volcanic soils in site are closely related to river alluvium composed of the same cindery material carried down from the slopes of the volcano and deposited on the lowlands many miles distant. Both kinds of recent volcanic soil should be differentiated on soil maps because they represent a large reserve of plant foods, and are often very good soils for afforestation projects, although subject to the hazard of potential destruction by reawakened vulcanism. On many of these soils it is apparent that tree growth can be extremely fast: both Araucaria and Libocedrus trees were noted to be showing very good annual increment in girth and length.

PART IV

SOILS OF CHILOE ISLAND IN LAT. 42º 30' S.

The soils of Chiloé Island are of interest to New Zealand because they are forming under a typically New Zealand type of forest, composed of a mixture of broadleaf trees with Podocarpus and related species, and Nothofagus. The visit to Chiloé Island was made partly to ascertain whether the soil micro-pattern shows a vegetation mosaic, wherein different tree species can be associated with different stages of soil profile development.

Soil parent materials available for study within a 15-mile radius of the town of Castro are as follows:

(I) Fluvio-glacial deposits (fine gravel and coarse sand, with occasional andesitic pumice).

(II) Marine and glacial lacustrine beds, consisting mainly of sand and fine gravel.

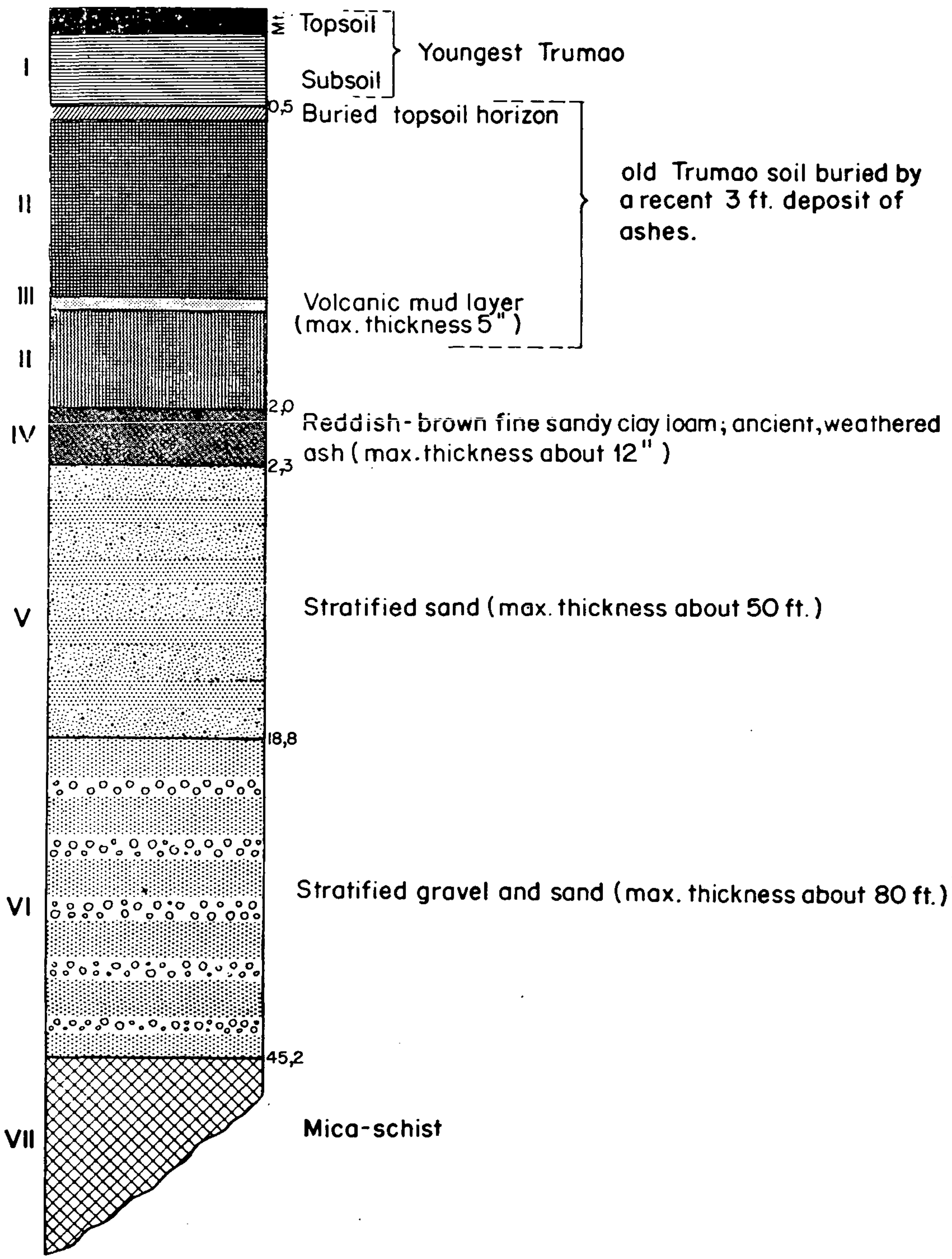
(III) Volcanic ash beds with at least four well-defined periods of deposition.

(IV) Mica-schist, the basement rock in this region.

One or other of these materials may be absent at any site due to local erosion. For instante, the older (lowermost) ash beds are very commonly missing north of Castro. The middle, usually the thickest, ash bed (shown as layer II in the diagram below) usually shows a thin but very-conspicuous layer of volcanic mud (III) at about the centre of the bed. This probably represents a brief period when there was a violent eruption from some lake-filled crater, throwing out the muddy sediments from the bottom of the lake. This explosive interlude occurred during a period when the ash accumulation was more of the nature of a steady drifting down of volcanic dust.

A buried topsoil can sometimes be seen in the uppermost part of the penultimate ash bed, suggesting that there may have been a long period of quiescence between the end of this period of accumulation and the beginning of the next. The ultimate stage, the youngest ash on the landscape (I) is somewhat similar to the andesitic material which gives rise to Santa Bárbara soils further North. On Chiloé Island, this material is seldom more than 20" in thickness, whereas on the mainland it is usually deeper. For instance, on Chiloé, in many places this type of ash may give rise to little more than a thin silt loam topsoil, whereas the subsoil has developed from the older dark brown ash beds below.

A typical vertical sequence in a deep section is as follows:



Of the various layers noted; I—is commonly soil forming on all but the steepest slopes; II—is commonly soil forming on the slopes of the marine terrace levels which make up most of the eastern half of the island of Chiloé; III—is the parent material for a few of the soils on the steeper slopes; whereas IV — was not found forming soil, although it will undoubtedly contribute to the profile of the hill soils to the west of Castro; V—forms the soil on the steepest of the marine terrace slopes north and west of Castro (where repeated potato cropping in rows up-and-down the slope has caused greatly accelerated erosion), while VI—and VII—take part in soil formation only on the slopes of the western ranges.

In mapping the soil pattern on Chiloé Island it will be necessary first to make careful study of the various parent materials, so that genetic differences in the soil profile can be separated from differences caused by stratification of the parent materials.

The mantle of the young Trumao ash covers almost all the more stable situations in the landscape near Castro. For reconnaissance purposes, the Trumao soils of central Chiloe may be considered to be of two kinds. Over the eastern part, the profiles are but slightly developed (Castro soils) ; while further to the west profiles show clear signs of leaching (Chiloé soils). By comparison with related soils in New Zealand, the Trumao soils near Castro would be recognized as "early semi-mature" stages of development and the Western Chiloé Trumao soils would represent a late semi-mature or weakly podzolised stage. The comparison cannot be exact because the Chilean soils are developing in a weaker weathering environment than the majority of New Zealand's Yellow Brown Loams. The nearest New Zealand equivalents are to be found on Chatham Island, a small island off the coast of the South Island of New Zealand. It is also interesting to find many features in the Chiloé soils which more nearly correspond to the soils of the Southland region of New Zealand, although these are not derived from volcanic ash but from loess. The climate of Southland much resembles that of Chiloé, but there is no question that the Chiloé ash beds are true ash beds and not loess, — the various layers follow the strongly rolling topography far too closely for loessial origin, and the composition of successive layers varies far too widely.

The Trumao soils near Castro have the following general profile:

0 — 7 in. dark brown silt loam; very soft crumb structure, powders readily;

7 — 10 in. dark brown silt loam with weak yellowish-brown mottling;

10 — 15 in. yellow brown silt loam; firm aggregates with a slight reddish-yellow crust, moderate compaction;

15 in... on yellow brown to brownish-yellow silt loam, slight compaction.

This profile appears to have been developed under a cool to cold climate, with a rainfall of about 80 in. per annum (no dry months) and under a mixed Nothofagus — Broadleaf forest. Little of this original forest now remains near Castro, but one site was discovered with a good stand of Nothofagus Dombeyi. Here the profile showed a litter layer (Ao horizon) two inches in depth, composed mainly of compressed layers of Nothofagus leaves and small twigs. The A_1 horizon is strongly melanized and has a much better structure than the adjacent soils which have been subjected to 80-100 years of farming. The lower part of the A_1 horizon has weaker aggregates than the upper part. The B horizon is not sharply differentiated from the C, and the only sign of mobilization of Fe is in the presence of rust-colored particles lining old root channels. In a nearby road cut the B horizon shows very weak columnar structure.

By contrast, trumao soils of Western Chiloé show the following general profile:

4 — 0 in. well decomposed forest litter (dark brown loamy peat);

0 — 4 in. very dark brownish-gray (peaty) silt loam with crisp crumb structure;

4 — 8 in. grayish-brown silt loam, almost structureless;

8 — 9 in. dark brown, slightly mottled reddish-yellow heavy silt loam;

9 — 11 in. bright (reddish) brown silt loam with soft yellowish-red aggregates scattered through this horizon, and occasional a few harder concretions;

11 in... on yellow brown silt loam.

This profile appears to be associated with slightly higher rainfall (100-120) in, more cloud, and cooler and more humid conditions than experienced in the environment producing the trumao soil profiles seen near Castro. The forest contains a fairly high proportion of taxads (Podocarpus sp. and Dacrydium sp.) and a fair amount of Nothofagus sp. as well as many broadleaf species (notably Laurelia).

It is interesting to note that some of the larger individual taxads are having an appreciable influence on the soil in which they are growing. Beneath many of these trees, the rate of leaching has been sufficiently rapid to promote the development of a distinct but thin podzol horizon in the soil profile. As in New Zealand, the chief factor appears to be the building up of a cone of litter beneath each tree, through which passes an augmented stream of rain water (the result of extra water collected by the catchment formed by the branches and trunk of the tree which has the effect of concentrating rainfalling in the vicinity on to a relatively small area at the base of the tree). Furthermore the effectiveness of leaching is likely to be much increased by the potency of certain organic compounds produced by the slow decomposition of the mound of litter. The most maturely developed profiles seen on Chiloé Island showed distinct podzol horizons.

8 — 0 in. dark reddish-brown loamy peat; somewhat fibrous;

0 — 2 in. dark gray-brown (peaty) silt loam;

2 — 3 in. pale brownish-gray silt loam;

3 — 5 in. brown, slightly peaty silt loam;

5 — 7½ in. strong brown, faintly mottled silt loam;

7½ in... on yellow-brown silt loam.

Profiles similar to the one described above were found only beneath large taxads. In New Zealand, such a profile would be recognized as the "sub-mature" stage in the sequence of soil development. There is therefore evidence of a vegetation — soil erosion in the soil pattern of this part of Chiloé Island.

It is likely that profiles of this description become more general on the western side of the Chiloé Island. Aerial reconnaissance showed that the proportion of Podocarpus and Libocedrus species in the forest increases to the west. At the same time it was noted that many of the upland plateaux of the coastal range were clothed in low windswept scrub and tussock grassland. In places, this grassland appears to be in process of being rapidly invaded by young Dacrydium forest. There is a possibility that the thin volcanic ash was not entirely successful in maintaining its position on these exposed ridges and that the soils here may be developed directly on basement rocks. If these are siliceous they would be expected to podzolize much more readily than volcanic ash. Changes in vegetation may be related to progressive soil deterioration as is known to occur in New Zealand. An equally likely hypothesis, however, is that the present vegetation patterns has been produced by repeated burning.

In New Zealand terminology, the soils of Chiloé Island could be characterized as weakly weathered Yellow Brown loams, ranging from moderately leached to weakly podzolized; locally strongly podzolized.

Exact correlation with actual New Zealand soil types is more difficult. Morphologically, the Chiloé soils have almost exact counterparts in the Catlin region of the Southland District of New Zealand. Management practices under (both farming and forestry) also seems to follow closely the pattern. Known seen in the Catlin area. In Chiloé, dairy and sheep pastures are common, and potatoes and cereals are the main arable crops. The quality of pastures is not good and management is often very poor with a high proportion of the area reverting to low bushes (as was the case in the Catlin area of New Zealand in about 1938). It would take very little effort to transform Chiloé into a major dairy and meat producing area, equal to the Southland — district in New Zealand — one of the best farming areas in New Zealand. In Chiloé, lack of roads, transport and capital for land development are obstacles not easy to overcome. However, once the process is started, there is little doubt that successful pasture establishment and grass management techniques could be adapted from experience gained during the development of similar soils in New Zealand.

PART V

DISCUSSION

Since its inception in 1946, the soil survey of Chile has examined, in varying degree of detail, most of the agriculturally important soils. The more detailed of these soil surveys and their derived maps (single factor maps showing texture, or depth, or drainage properties, or fertilizer requirement, etc.), have found a large measure of acceptance amongst agriculturalists and foresters and the demand for this type of information is steadily increasing. At the same time, members of the soil survey group are aware that they need to extend reconnaissance soil mapping to cover the whole country, in order that soils *potentially* well suited for agricultural and sylvicultural development, by means of modern technology can be located, and a complete pictures of the soil resources thereby obtained. From this latter, will emerge the final scheme for the classification of the soils of Chile. The present investigation has shown that genetic relationships may be fairly clearly discerned in many Chilean soils and it is very likely that this type of classification will be well suited for correlating the soil resources of Chile and will eventually prove as valuable tool for furthering agricultural and forestry research as it has in New Zealand and other countries where soil forming factors are equally dynamic and operate over comparable ranges.

An attempt at preparing a generalized map showing the genetic relationship of the soils of Chile might be well worth while, — particularly in respect of trumao and related volcanic ash soils (Collipulli ñadi, etc.) where important nutritional differences may be observed by similarity of texture, depth, structure, colour, or drainage, etc. The volcanic ash soils of Chile might well be made the subject of a comprehension study to decide genetic relationships.

The foregoing account has mentioned some of the more obvious problems awaiting further work. These include:

1. To what extent has regional volcanic activity added ferromagnesian and other basic minerals to the soils developing on the older land surfaces of the coastal cordillera and coastal lowlands as far north as Valparaíso?

2. What is the geographic origin and pedogenesis of the pumice soils in the vicinity of Santiago?

3. To what extent can the various phases of deposition of subaerial volcanic material be related with contemporaneous glacial phenomena? For example, Collipulli and related basic volcanic material may occur below, within and above materials emplaced during a late glaciation.

4. Does the Collipulli-types ash have a consistent mineralogical composition throughout its wide range? If so, where was the source of this material?

5. To what extent can the trumao soils be related to individual sources? If mineralogical differences exist, is the pattern of deposition similar in each case?

6. How should trumao soils be mapped near the periphery of their range? In some cases there appears to be a complex of two or more types of ash, whereas in others it is more of textural intergradation.

7. If major and minor suites can be established for the trumao soils (i. e. defining the various *inherited* soil characteristics) what are the profile characteristics *acquired* in the course of soil development under the different weathering and leaching environments, and over the various periods of time?

8. Is the presence of varying amounts of volcanic ash a significant feature of the soil pattern in the desert areas of northern Chile?

9. What is the origin and development of "tosca" layers in volcanic ash? Which are inherited features and which are acquired during soil development?

10. What is the origin and development of ñadi soils? Why are they often relatively thin soils in landscapes that are otherwise thickly mantled with ash.

11. The meaning of the fluctuations in thickness of sub-aerial deposits of volcanic ash? How much volcanic dust remains in *sites* and to what extent does redistribution take place? Do variations in the plant cover affect this?

12. Assessment of the intensity of leaching in volcanic ash soils is relatively simple in high rainfall districts where the original dust was moderately siliceous, but what are the significant soil profile features in regions of lighter rainfall or where the ash beds are markedly basic in nature?

13. What are the major differences between the soil process in the volcanic ash soils of Chile, and those of New Zealand? To what

extent do Chilean ash soils have a higher reserve of plant foods (represented by weathering soil minerals) and in which environmental regions does the rate of loss by normal soil leaching overtake the rate of release of soil nutrients through weathering? Does this provide an essential clue for equating agricultural practices in the two countries?

14. New Zealand can provide many examples of the successful application of modern farm management to volcanic ash soils but, to what extent may these be applicable on fairly similar soils under Chilean conditions?

Some of the above problems can be resolved through additional field work, and some will require laboratory research. In this latter respect, it is comforting to know that the Chilean soil survey will be equipped to undertake mineralogical studies and microscopic examination of soil sections with personnel trained in these respective fields. Close collaboration between field and laboratory groups should eventually lead to a classification of the volcanic ash soils of Chile which will prove to be of great value to farmer and forester alike, and one which will prove to be of great value to farmer and forester alike, and one which will permit more precise correlation with the volcanic ash soils of New Zealand, North-Eastern Asia and North-West America. Here is a Pan-Pacific problem in which Chile has much of value to contribute.