VEGETATION AND SOILS IN THE SOUTH CHILEAN ISLANDS

By M. W. HOLDGATE

Scott Polar Research Institute, Lensfield Road, Cambridge

INTRODUCTION

South of Puerto Montt (41° 30′ S., 73° 0′ W.), the country between the Cordillera of the Andes and the Pacific is a maze of mountainous islands and fiords stretching southwards for nearly a thousand miles (1610 km) to Cape Horn (Fig. 1). This region has long been famous for its rugged terrain, extremely oceanic climate (Table 1) and waterlogged vegetation and soil (Barclay 1926, Butland 1957, Darwin 1845, Murphy 1936, Rudolph 1934, Skottsberg 1911).

Table 1. *Climatic data for a series of places in southern South America*

The numbers in the left hand column refer to Fig. 1, where the location of the stations is shown. All data ultimately based on records kept by the Chilean and Argentine Meteorological Offices.

Locality	Latitude	Annual rainfall (mm)	Mean temperature (° C) January	Mean temperature (° C) July	Source
1 Ancud (Chiloé)	41° 47′	2032	13·75	7·7	South America Pilot (1956)
2 Melinka (Guaitecas)	43° 50′	3175	13·5	7·7	Butland (1957)
3 Puerto Aisén	45° 20′	2870	13·5	5·0	Butland (1957)
4 Cabo Raper (Taitao)	46° 49′	2088	11·1	6·2	South America Pilot (1956)
5 San Pedro (Gulf of Penas)	47° 45′	4725	11·1	5·5	Butland (1957)
6 Islas Evangelistas	52° 24′	2845	8·4	3·3	South America Pilot (1956)
7 Bahia Felix (Isla Desolacion)	52° 57′	5080	8·9	4·0	Butland (1957)
8 Ushuaia (Tierra del Fuego)	54° 49′	561	9·1	1·1	South America Pilot (1956)
9 Navarino	54° 52′	457	8·8	1·6	Butland (1957)

Godley (1960) has re-defined the five main vegetational regions of southern Chile from 40° S., and the distribution of these can be related to climate. Evergreen forests range along the whole western side of the Cordillera, where the rainfall is heaviest. The species-rich Valdivian forest dominated by *Eucryphia cordifolia*, *Laurelia serrata*, *Weinmannia trichosperma*, *Amomyrtus* spp. and *Nothofagus dombeyi* extends as far south as the Gulf of Penas (48° S.). Beyond this inlet there is a species-poor Magellanic forest dominated by *N. betuloides*, which gives way in the most exposed and wettest outer island zone to Magellanic moorland. This has discontinuous patches of evergreen woodland among boggy herbaceous formations. East of the Andes, in the drier zone, there is a belt of deciduous woodland, dominated by *N. pumilio* and *N. antarctica*, while farther eastward still and towards the driest extreme of the rainfall gradient this is replaced by scrub and then by the Patagonian steppe.

Practically no observations have been made on the soils of this region. Butland (1957) proposes a broad preliminary division of Aisén and Magellanes Provinces into two soil regions separated by the 20-in. (51 cm) isohyet. West and south of this line there are said to be podsols, peat bogs and expanses of almost soil-free rock: east and north of it the soils are derived from glacial deposits and vary widely in type. Habit (1954) similarly distinguishes two soil provinces in Magellanes, separating the soils of the Cordillera, which are derived by *in situ* weathering, from those of the steppes and foothills which consist basically of deposited sediments. According to Habit, the western zone is also characterized by thick superficial organic layers, and over more than half Magellanes

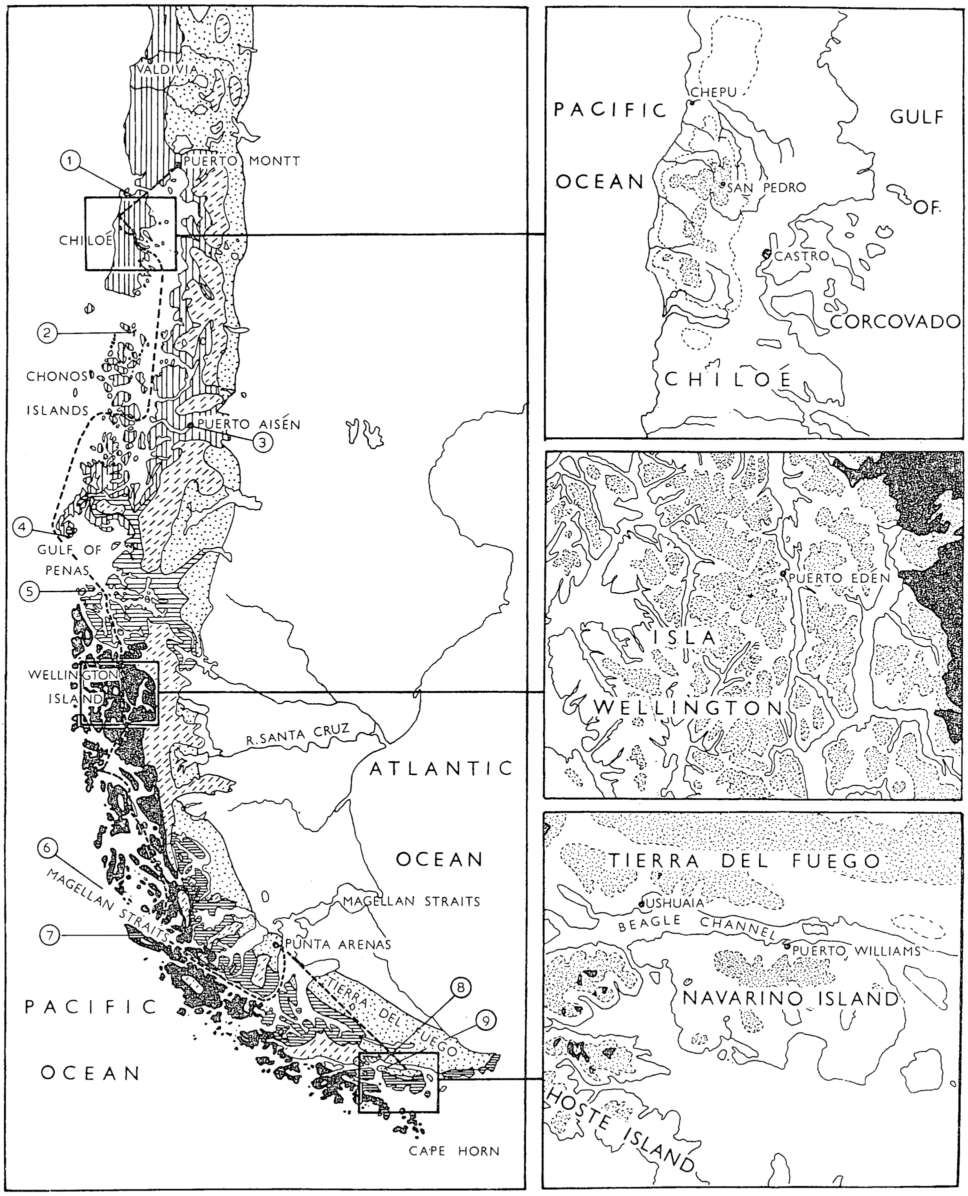

Fig. 1. Southern Chile. The three main study areas are shown in the insets enlarged on the right: in these maps areas over 500 m are stippled and ice-cap is shown black. In the left hand map solid black tinting represents areas of Magellanic moorland; close horizontal shading, Magellanic forest; vertical shading, Valdivian forest; stipple, deciduous forest; and broken oblique shading, ice-cap and forest-free uplands. The unshaded area on the east is the Patagonian steppe. The encircled numbers refer to the stations for which climatic data are cited in Table 1.

these layers exceed 30 cm in depth. Vogel (1957), in a subdivision of Chiloé Island into nine different soil types, again makes the nature of the parent material, the situation, and the drainage, the bases of his classification. None of these authors gives any details about profiles, composition, or the precise vegetational relationships of the soils. It is the aim of the present paper to provide some new information about some of the less accessible parts of the western Chilean island zone.

Observations were made in three regions (Fig. 1): Chiloé Island (42° S.), Wellington Island (49° S.) and Navarino Island (55° S.), while the author was a member of the Royal Society Expedition to southern Chile 1958-59 (Holdgate, 1960). The vegetation of these areas will be described in detail by the botanist of the expedition, Dr E. J. Godley. The field work at Chepu, Chiloé, was done between 1 October and 5 November 1958; at San Pedro, Chiloé, between 8 and 22 November; at Puerto Edén, Isla Wellington, between 28 November and 21 December; and at Puerto Williams, Navarino, from 7 January to 18 February 1959.

METHODS

Soil profiles were examined using an auger. Attention was concentrated on determining the depth of the superficial organic-containing layers: in many places deep probing to establish the presence or absence of pans was impracticable owing to the resistant nature of the substratum.

Water content and *organic content* were determined on samples of about 25 g weight collected in the field into clean, polythene-stoppered glass tubes and examined as soon as possible after return to field base. An improvised steelyard was used for relative weight determinations. Samples were handled in light aluminium dishes, and dried slowly on an oven: for ashing they were transferred to a small iron dish and heated to red heat over a primus flame. After combustion had ceased the material was carefully tipped back into the original aluminium container and re-weighed. Because of the improvised nature of the equipment, all figures are to be regarded as approximate, but the results obtained seem consistent for samples of the same type.

pH determinations were carried out using an Analytical Measurements portable pH probe (kindly loaned by B.D.H. Ltd.). The samples were placed in clean glass columns and agitated with a standard quantity of de-ionized water. Barium sulphate was added to clear the suspensions. The meter was checked against standard buffer solutions (pH 4·0 and 7·0) before and after each series of determinations, and the cell was washed out with de-ionized water between each single measurement. At least two, and often three measurements were made of the pH of each sample, and the meter was further checked from time to time by parallel colorimetric determinations.

OBSERVATIONS AROUND CHEPU (CHILOE)

Topography and vegetation

Chepu (Fig. 2) lies on the Pacific coast of Chiloé island and in the region of the Valdivian forest. Its rainfall is probably slightly greater than that of Ancud (Table 1), and in the range 2000-2500 mm, while its mean annual temperature is probably around 10-11° C. The country is undulating and in its lower parts covered by fluvial or fluvio-glacial deposits. Estuarine terraces occur at 4·5 m, 15 m, 25 m, and 75 m above present sea level.*

* The map in Fig. 2, and the description in the text, are based on conditions prior to the severe earthquake of May 1960. This is known to have caused a shock wave on the coast of Chiloé, rising some 5 m above normal tide limits, and permanent changes of level of the order of 2 m are reported. The configuration of the Chepu estuary is likely to have been affected by these events, and the flimsy wooden house at Chepu, sited only 2 m above high water mark, has probably been destroyed.

Most ridges and drier slopes support a *Eucryphia cordifolia-Laurelia serrata-Weinmannia trichosperma* forest, except near the coast, where *Aextoxicum punctatum* becomes dominant. Badly drained ridge flanks and hollows are covered by a second forest type

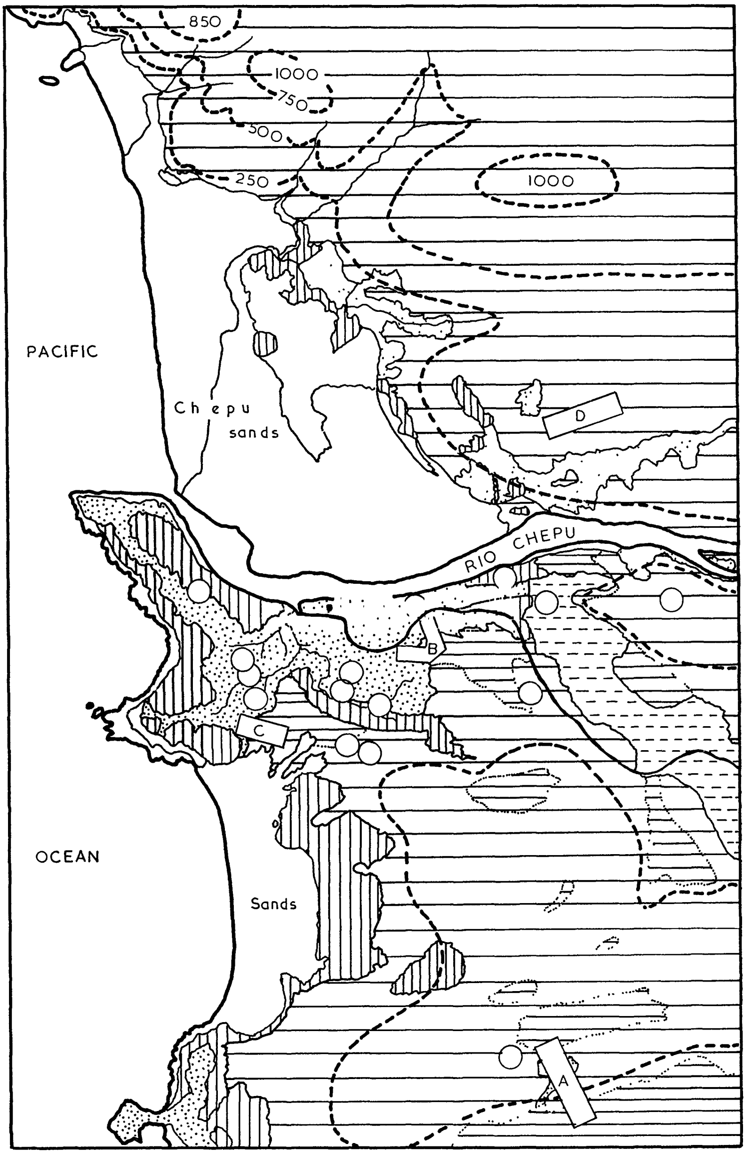

Fig. 2. The Chepu estuary. Lettered insets A to D refer to sample areas discussed in the text, and blank circles to sites from which samples were obtained for analysis. Wide horizontal shading represents natural *Eucryphia* and *Aextoxicum* forests: close horizontal shading areas with less irregular canopy, mostly 'tepual'. Vertical shading indicates secondary scrub, broken horizontal shading bog, stipple grassland, and absence of shading coastal sand and rock. Based on aerial photographs and field notes: heights in feet.

dominated by *Nothofagus nitida* and *Tepualia stipularis*. Near Chepu clearance by cutting and burning has created areas of grassland, and understocking has allowed large tracts of this to revert to a secondary scrub in which bamboo (*Chusquea quila*), shrubs (*Berberis* *buxifolia*, *B. darwinii*, *Embothrium coccineum*, *Myrceugenia* spp., *Ovidia pillo-pillo*, *Raphithamnus* sp.) and young forest trees (especially *Drimys winteri*) are prominent. The wettest parts of the fluvial terraces east of Chepu provide the only natural open ground, in the form of bogs largely dominated by *Leptocarpus* and *Sphagnum* spp. (Fig. 2).

Soil profiles of ridge and hollow vegetation

Fig. 3 illustrates the distribution of vegetation and the general appearance of the soil along a transect across a typical ridge and hollow system north of the Rio Toigoi, 5 km south from Chepu (A, Fig. 2).

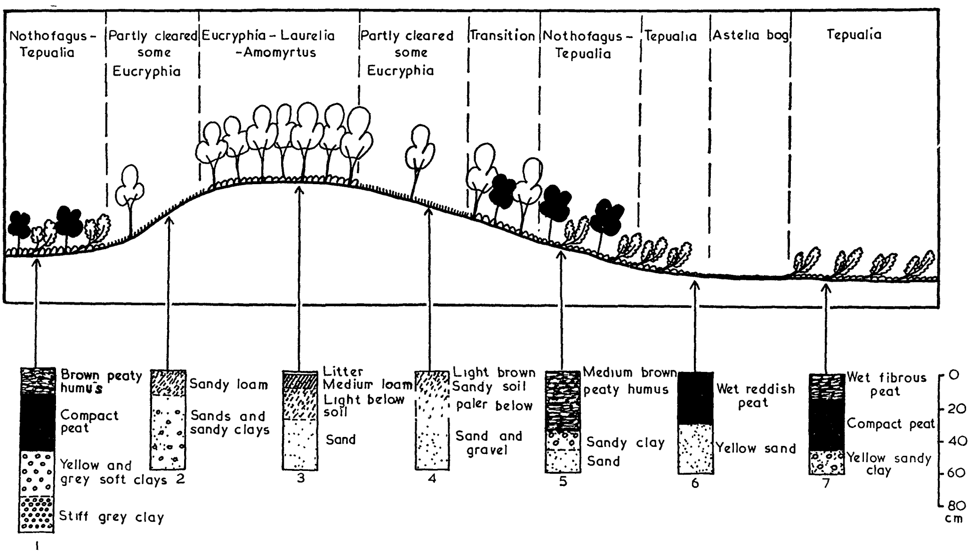

Fig. 3. The vegetation types and soil profiles across a ridge and hollow system near Chepu (area A on Fig. 2).

On the ridge crest the soils, even near the surface, contain little organic matter, a medium to light brown loam giving way at 15-30 cm to a sand, sandy gravel, or sandy clay which is probably little-altered fluvio-glacial outwash. The upper humus-containing layers were best represented in core 3, which was taken in an area of uncleared *Eucryphia* forest retaining a 5 cm superficial litter layer, and in another untouched forest area not plotted in the diagram. Despite the recentness of their clearance the other ridge sites showed far less organic matter, suggesting that its destruction by oxidation and leaching is very rapid in such well-drained, light, soils.

The flanks of the ridge are characterized by more organic soils. Cores 1, 6 and 7, in *Tepualia* forest, *Astelia pumila* bog and *Nothofagus-Tepualia* woodland, all revealed an uppermost 30-50 cm of waterlogged, reducing, peat passing below through a very narrow transition layer into sands, sandy clays, or clays. Core 5, in *Nothofagus-Tepualia* woodland on a gentle slope, appeared intermediate in showing a superficial 35 cm of medium-brown peat which was distinctly drier in appearance than the saturated peats of the hollows.

The general picture revealed by this series was confirmed elsewhere. On the ridge north of the Rio Chepu a series of five cores in *Eucryphia* forest with two small *Nothofagus* patches (area D, Fig. 2) had the following features:

Eucryphia forest

1. 0-30 cm light brown, paling to base.
   30-60 paler, yellowish.
   60-125 yellow clay.
   125- coarse yellow sand.

2. 0-30 light to medium brown with gritty fragments and clay nodules.
   30-110 stiffer pale clay with stones.
   110- gritty.

3. 0-20 medium brown soil, locally almost peaty.
   20-30 paler, more mineral.
   30-80 stiff, gritty yellow clay.
   80- wet yellow grit.

Nothofagus patches

4. 0-30 medium brown soil.
   30-35 grades into yellow clay.
   35-110 wet yellow clay.
   110- gritty material.

5. 0-30 dark wet organic, paling downwards.
   30-80 grades into yellow clay with sandy nodules.
   80- gritty material.

Rather more organic soils were observed in *Eucryphia* forest 2 km east of Chepu, where the samples analysed and plotted in Fig. 4 were obtained. Here about 2-5 cm of leaf litter overlay a medium brown, moderately organic loam. Somewhat comparable brown-earth soils of varying organic content appear to be characteristic of coastal *Aextoxicum* forest in the Chepu district.

Soil profiles on the estuarine terraces at Chepu

Whereas the vegetation pattern described above can be clearly correlated with the topography, that seen on the fluvial terraces south and east of Chepu is less evident in its relationships. Here the only remaining natural forests are patches of 'tepual' (*Nothofagus-Tepualia* association), locally incorporating many of the species of the richer ridge forests. They are flanked by secondary scrub and cleared grassland which lies at much the same level but is conspicuously drier.

Fig. 4A illustrates the marked change in soils which accompanies the transition from forest to cleared ground on the 4·5 m terrace (area B, Fig. 2), and Fig. 4B shows that the same pattern prevails on the upper terrace (25 m) (area C, Fig. 2). All the forest sites examined had about 5 cm of litter overlying anything from 15 to 60 cm of wet peat: below this lay yellow sand or sandy clay. In almost all the profiles it was noted that the peat became smoother and more compact basally, and in some places it graded downwards into the mineral material in a manner suggestive of some downwashing of organic matter into the upper mineral soil horizons. In general these forest soils therefore show a clear resemblance to those of the *Nothofagus-Tepualia* woodlands in the Rio Toigoi basin. Similarly, the adjacent scrub and pasture overly free-draining loamy or sandy soils with a definite similarity to those of the *Eucryphia* ridge forests. But these two types lie at the same level and, as Fig. 4 suggests, appear to grade into one another, the wet reducing forests peats seeming stratigraphically equivalent to the drier humus-containing layers of the pastures.

This pattern might be interpreted in two ways. Possibly clearance has been preferential, the drier less peaty soils remaining from *Eucryphia* or *Aextoxicum* forest and never having been as wet or as organic as those of the adjacent 'tepual'. A few *Aextoxicum* trees still grow at the higher seaward end of the terrace west of Chepu and so support such an hypothesis. Alternatively, it may be that clearance accompanied by burning and destruction of litter and obviously accelerated oxidation, might itself lead to the conversion of

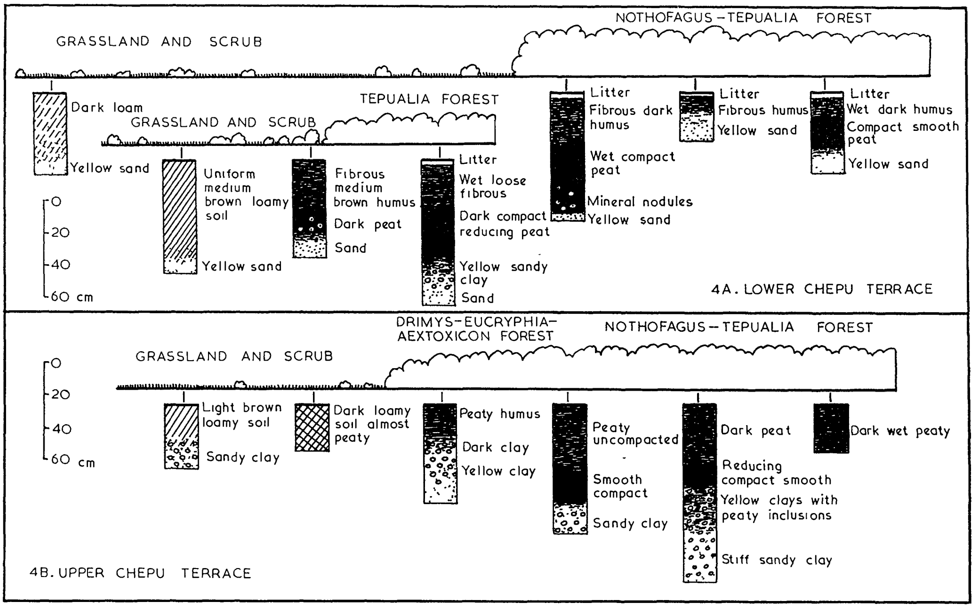

Fig. 4. The vegetation types and soil profiles on the fluvial terraces near Chepu (areas B and C, Fig. 2).

wet forest peats into dry loams. Certainly the *Nothofagus* forest is being cut back behind one new house on the lower terrace, and pasture overlies deep peats on the margin.

Determination of water content and organic content

Samples for these measurements were taken from two levels in the soil profiles; firstly from the upper humus-rich layers, usually at about 10 cm and in any case below the surface litter, and secondly from the basal sands or clays. All the results are plotted together in Fig. 5, from which the relationship of the two parameters is immediately apparent. Of natural vegetation types, the *Eucryphia* ridge-forests are as a group characterized by soils whose upper layers have around 30-45% organic content, while *Nothofagus* and *Tepualia* woodlands have progressively wetter and more organic substrata. While measurements of the total annual addition of organic matter to the surface soil layers have not been made, it was obvious in the field that the production of such material was high in all forest types. Indeed the broad-leaved *Eucryphia-Laurelia* forest probably produces more litter than a canopy of the microphyllous *Tepualia*. The differences between the soils depend on the preservation, not the production of organic litter, and here the degree of waterlogging of the ground is of prime importance. This in turn affects the soil fauna, which is noticeably richer in all species, including oligochaetes, in the *Eucryphia* forest.

The other two vegetation types represented in Fig. 5, secondary scrub and grassland, are noteworthy for having drier and less organic soils than any natural forest. Even assuming their derivation from *Eucryphia* woodland on initially well-drained ground, it is evident that clearance has been followed by considerable destruction of organic matter. In some grassland areas these processes have gone so far that the upper dark-stained soil layers contain little more organic matter than do the deeper sands and clays. Podsolization is evident in some of these sites, where 5-10 cm of humus-stained material overlies a very dry, pale mineral soil. Where such pasture flanks the Rio Chepu and is eroded a deep iron pan seems to be exposed in places.

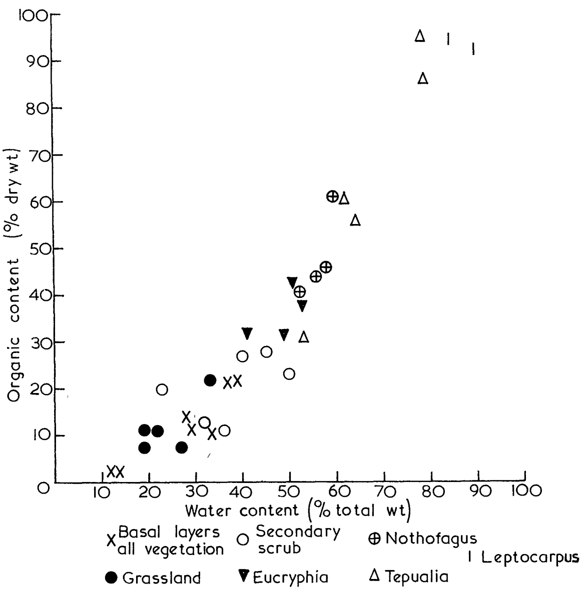

Fig. 5. Water content and organic content of soil samples from the Chepu district.

pH values

Results of pH determinations on soil samples from the upper and deeper layers beneath all vegetation types are set out in Table 2. It is evident that a broad correlation exists between organic accumulation in the upper layers and soil pH. It is also clear that the basal sands and clays from all areas have a more or less similar pH which is higher than that of the humus containing upper layers and shows no correlation with it.

Table 2. *pH of soils in the Chepu district*

Each figure is the mean of several determinations. Unless otherwise stated all samples are from the upper humus-containing layers.

Vegetation	pH				Mean	Mean organic content %
Eucryphia forest	5·2	5·2	4·7	4·4	4·9	36
	5·3	4·4	4·7	5·3		
Nothofagus forest	4·2	3·6	3·9	4·2	4·0	43
(with *Tepualia*)	3·9					
Tepualia forest	3·5	3·8	4·0	4·1	3·8	66
	3·7	3·9				
Secondary scrub	4·8	5·4	5·1	4·8	4·9	20
	4·7	4·7				
Grassland	4·7	6·0	5·0	4·6	5·0	12
	4·8					
Leptocarpus bog	4·4	4·6	4·3	4·2	4·2	94
	4·2	4·0	3·8			
Basal sands and	4·6	4·7	5·2	5·0	5·0	11
clays, all vegetation	5·1	5·0	5·8	4·9		

Discussion of the soils of Chepu and lowland Chiloé

The present observations around Chepu agree broadly with the findings of Skottsberg (1916) for the district near Ancud. There a *Eucryphia cordifolia-Myrceugenia apiculata* association is said to be typical of porous, permeable, soils, *Aextoxicum punctatum* of sands, *Nothofagus dombeyi*, *Myrceugenia apiculata* and *Laurelia serrata* of moist but fertile soils, and *Tepualia stipularis* and *Pilgerodendron uviferum* of boggy ground with impeded drainage. It is rather more difficult to correlate the present results with the classification proposed for the whole of Chiloé by Vogel (1957). The latter does, however, state that the best timber trees, including 'ulmo' (*Eucryphia cordifolia*) are characteristic of the undulating lower ground over deposits of glacial sand, and that 'coighue' (evergreen *Nothofagus* spp.) is only occasionally present here. In contrast, level ground with an impermeable subsoil is characterized by very dark, incompletely decomposed organic layers and by a vegetation of beeches.

As a generalization it therefore seems valid to state that the species-rich *Eucryphia-Laurelia-Weinmannia* forest of Chiloé is typical of well-drained situations and that its soils have a brown-earth profile. Like most brown-earth forest soils these show a rapid incorporation of litter into the upper layers, they are not very acid, and they have a fairly rich soil fauna. In contrast the valley bottoms and areas of impeded drainage with a 'tepual' vegetation have a thick superficial mat of acid humus or peat which shows only a moderate degree of downwashing of organic material into the mineral substratum.

The distinction between these two vegetation and soil types is of interest because the former community is generally regarded as the 'typical' Valdivian forest. Southwards, and upwards in the hills, it gives way to a variety of *Nothofagus*-dominated associations, and ultimately to the *N. betuloides* woods and *Astelia pumila-Donatia fascicularis* bogs of the Magellanic zone. At Chepu the correlation of Valdivian and *Nothofagus* forest types with a soil drainage catena suggests that increasing rainfall and increasing impermeability of the substratum may be important in determining forest transitions from region to region within the evergreen belt, and that the north-south variation need not depend solely on temperature.

OBSERVATIONS IN THE CORDILLERA DE SAN PEDRO, CHILOÉ

Topography and vegetation

The uplands of northern Chiloé are a dissected schist dome or peneplain with little or no superficial glacial deposits. The highest summits of the Cordillera de San Pedro and Cordillera de Pichihue rise to 700-800 m as gentle undulations from a broad tableland whose eastern lip is at about 540 m. Field observations left no doubt that these hills are wetter and colder than Chepu, which lies 16 km north-west (Fig. 1). The annual rainfall is probably around 3050 mm (120 in.) and the mean annual temperature around 6·5° C.

The species-rich *Eucryphia-Laurelia* forest does not reach these uplands. The lower and eastern part supports a *Nothofagus nitida-Saxegothea conspicua* forest which seems to occupy a distinct altitudinal zone (Godley 1960), while the highest levels are more open. Here, isolated beech clumps (in which the Magellanic evergreen species *Nothofagus betuloides* is often prominent) are flanked by stands of *Pilgerodendron uviferum* and separated by tussocky grassland, low scrub of *Baccharis* sp. or bog dominated by *Astelia pumila*, *Donatia fascicularis* and plants of like habit. In the wettest places there are patches with *Sphagnum* spp., *Tetroncium magellanicum* and *Marsippospermum grandi-*

florum. The natural vegetation patterns have however been greatly disturbed by burning during an abortive attempt to make sheep-pasture.

Soil profiles on the San Pedro plateau

Three series of borings were carried out in the search for edaphic variables which might be correlated with the vegetation patterns and the topography. The results are presented in Fig. 6.

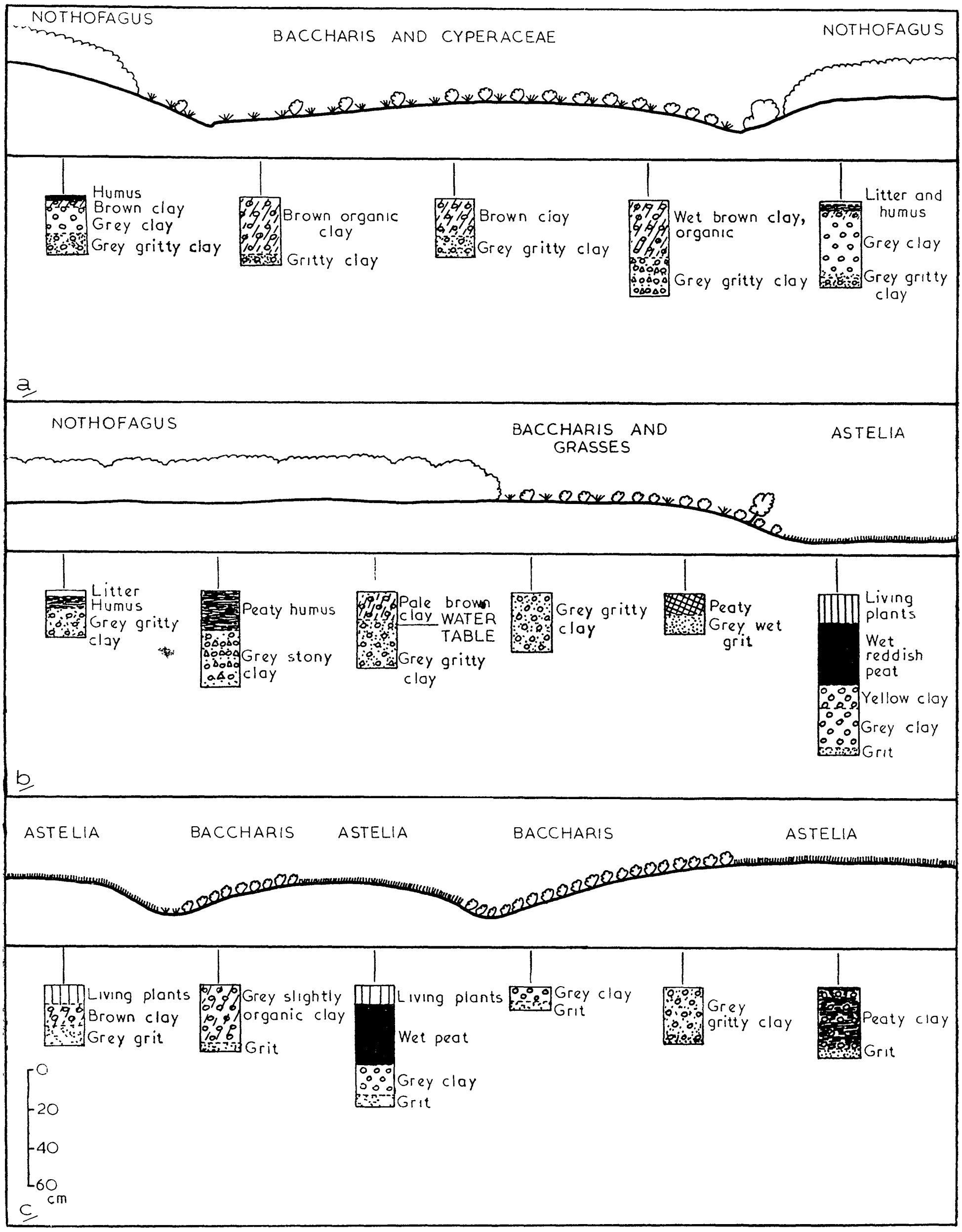

Fig. 6. Vegetation types and soil profiles on the Cordillera de San Pedro.

In series 6a and 6b patches of woodland were examined. In both instances their soils were incomplete contrast to those of lowland forests. The sites in series 6a had a few centimetres of leaf litter grading into 5-10 cm of *mor* humus which was unevenly distributed over the surface and rested abruptly on a grey, only slightly humus-stained clay beneath. Similarly, the three cores in series 6b had respectively 10 cm, 20 cm and 0 cm, of humus resting on grey gritty clays. This picture was confirmed by cursory examination of other sites in the adjacent woodlands.

Baccharis scrub grows on the higher levels of the slope examined in series 6a, on the knoll adjoining the forest in 6b and on the steeper flanks of the ridge and hollow series in 6c. Many of these areas were distinctly wetter than the adjoining woods, and in series 6a large *Schoenus* tussocks become increasingly abundant as the slope dips to a soakway and a stream. In all these *Baccharis* scrub patches there was no surface litter or well-defined *mor* layer: instead there was a superficial 20-30 cm of brownish, wet, fairly organic clay grading downwards into a grey gritty clay comparable with that below the forest patches. In the wettest places up to 30 cm of a reddish somewhat peaty material was encountered. Conversely, on the steeper ridge flanks *Baccharis* was found to be growing on 5-30 cm of grey clay with no evident organic content, which rested upon a wet, coarse grit.

Blanket bog dominated by *Astelia pumila* carpets was the third vegetation type examined in these series. In 6c these bogs evidently occupied ridge crests, and in one place an obvious soakway on a slope otherwise supporting *Baccharis* and grasses. Most of these *Astelia* carpets over lay definite peat from 10-30 cm deep, but in two places they were growing on a grey gritty clay with organic accumulation restricted to the plant mat itself. Possibly these areas had been recently recolonized after burning. In contrast, the soakway crossed in series 6b had 15 cm of surface vegetation and roots above 20 cm of reddish peat.

Determinations of water content and organic content

In Fig. 7A the organic content and water content of the upper humus layers and lower clay layers of the forest soils are plotted: the clear separation of these layers noted in the

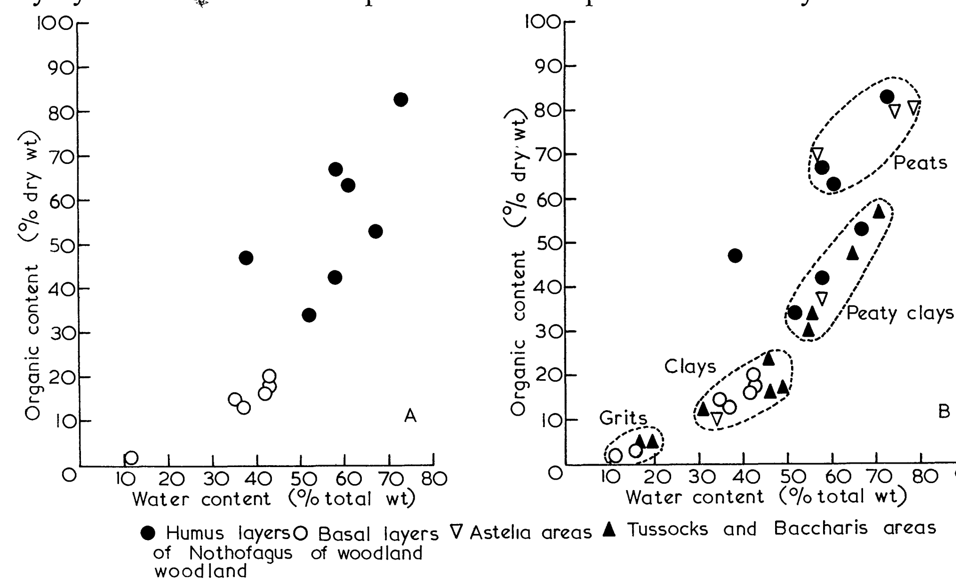

Fig. 7. Water content and organic content of soil samples from the Cordillera de San Pedro. A — *Nothofagus* woodland *mors* and basal sands. B — all vegetation types.

field is confirmed. In Fig. 7B all determinations from the three main vegetation types are compared.

The apparent similarity between *Astelia* peats and forest *mors* in this diagram fails to allow for the comparatively shallow depth of the latter. The low organic content of *Baccharis* scrub soils may possibly indicate not only a preference for drier or better draining sites, but the low annual deposition of organic matter from the small evergreen leaves of this shrub, and the grasses among which it grows.

pH determinations

Table 3 gives the results of pH measurements for these main soil types, and also values for a patch of *Nothofagus-Tepualia* woodland. There is an evident general agreement with the Chepu series, especially in the very low pH of the *Tepualia* forest *mor* and the fairly low value (4·2) for *Nothofagus* forest soils.

Table 3. *The pH of soil samples from the different vegetation types at San Pedro*

Vegetation	pH				Mean	Mean organic content %
Tepualia-Nothofagus woodland	3·7	3·8	3·9	3·9	3·8	(83)*
	3·8	3·8				
Nothofagus woodland	4·3	4·4	4·0	4·0	4·2	54
	4·2	4·0	4·0	4·0		
	4·4	4·6	4·3	4·4		
	4·1	4·1				
Astelia bogs	4·5	4·3	4·3	4·5	4·4	64
	4·3	4·5				
Baccharis scrub	4·5	4·6	4·3	4·3	4·4	34
	4·4	4·5	4·4	4·3		
	4·5	4·3				
Basal grits etc.	4·7	4·7	5·0	5·1	4·9	15

* Only one determination of organic content from the same site as these pH samples.

Discussion of the soils of the Cordillera de San Pedro

The high rainfall of the Cordillera de San Pedro, and the gently inclined terrain, over an impervious schist which is not buried under accumulated glacial debris, combine to make the ground much wetter than that around Chepu. Consequently the predominance of gley or peaty gley soils is not surprising: the most remarkable feature is perhaps the absence of deeper peat in a region whose relief and climate would seem wholly suited to its development. Only one *Sphagnum* bog, with depths little exceeding 2 m, was found, while most of the *Astelia-Donatia* bogs overlie less than 1 m of peat. There is no doubt that the *Astelia* bogs are the chief peat-formers of the plateau, and it is possible that their concentration, and that of organic accumulation, to hollows and soakways reflects a liability to summer drought which was not apparent at the early date of the expedition's visit. The shallowness of the forest *mor* layers (which contrasts with the deep peats of the 'tepual' around Chepu) may similarly reflect some such factor, and the position of most forest sites examined on knolls or moderate slopes with easy surface run-off may also be relevant.

It is hard to assess how much the burning of the ground for sheep pasture may have destroyed superficial humus layers from the grassland, *Baccharis* and wood margin areas. Charcoal fragments and dead trees are conspicuous in some of these places, and a stepped micro-topography with evident erosion and downwash was noted in others.

Baccharis scrub is present in many places — knolls and ridge flanks — which are similar to the sites at present occupied by woodland and it may well be, as Dr E. J. Godley has suggested, that it may mark in many places the site of former forest whose upper humus layers have been destroyed.

It must be emphasized that the open nature of these uplands cannot be interpreted simply as an effect of altitude. Trees grow on the highest ridges of the plateau and on the narrow crest of the Cerros de Metalqui which seem to overtop San Pedro to the westward. The forest forms a continuous blanket over the steep slopes rising to the western lip of the plateau, only to stop there except for small patches, themselves concentrated on knolls, ridge flanks and gully sides. This pattern suggests most strongly that impeded drainage rather than altitude is the determining factor. Vegetationally speaking, the Cordillera de San Pedro can be regarded as an outlying tract of Magellanic moorland, and this formation is normally associated with high rainfall, low temperatures, poor drainage and intractable igneous rock. It is noteworthy that just as at Chepu the transition from Valdivian to *Nothofagus* woodland could be correlated with edaphic factors in turn dependent on drainage, so at San Pedro the change from a species-poor *Nothofagus* forest to open country closely resembling Magellanic moorland seems to accompany a further increase in soil wetness. The results from Chiloé thus underline the importance of increasing rainfall and deteriorating drainage as well as temperature decline, in determining the vegetation patterns of the western island zone.

OBSERVATIONS AT PUERTO EDEN, WELLINGTON ISLAND

Topography and vegetation

Wellington Island is one of the largest of the series of rugged islands lying between the Gulf of Penas and the Magellan Straits (Fig. 1). It is made up of mountain ranges rising to 1000-1300 m, separated by deep, formerly glaciated, valleys. The permanent snowline is at about 1100 m and small glaciers occur on the highest peaks. The rainfall at Puerto Edén approaches 5000 mm, and the mean temperature is around 7·5° C.

The country around Puerto Edén at the northern extremity of the Magellanic moorland zone is fairly typical of the region as a whole, but has a little more woodland than regions farther south. Woodlands, dominated by *Nothofagus betuloides*, occur along the coasts, on low-lying islands in the bay, and in gullies and on some of the slopes of the mountains. Forest coverage is nowhere complete, and the intervening ground supports a variety of bog associations. In these the 'carpet' plants *Astelia pumila*, *Donatia fascicularis*, *Gaimardia australis* and *Oreobolus obtusangulus* are prominent. Tussocks of grasses and of *Schoenus laxus* and other Cyperaceae are elsewhere the most notable components. Occasional trees of *Pilgerodendron uviferum* grow on the slopes, the species, as at San Pedro, being a plant of forest edges. Higher up the evergreen woodland becomes dwarfed and gives way to a deciduous dwarf scrub of *Nothofagus antarctica* which ascends to 600 m but nowhere forms large thickets. The *Astelia* carpet-bogs also ascend to about 600 m, but are here restricted to wet hollows, the rocky ground being covered by a mixed association of bryophytes, Cyperaceae, and other small vascular plants.

Soils of lowland areas around Puerto Edén

The soils of three selected lowland regions were examined, and the stratigraphy in these series is shown in Figs. 8a, 8b, and 8c. It is immediately evident that peat is of universal occurrence in the whole of this area. In series 8a the two forest sites had 60 cm and 75 cm of dark wet peat resting on coarse sand and showing no gradation into it: the bog areas on the same coastal terrace differed only in having 130 cm to 150 cm of rather

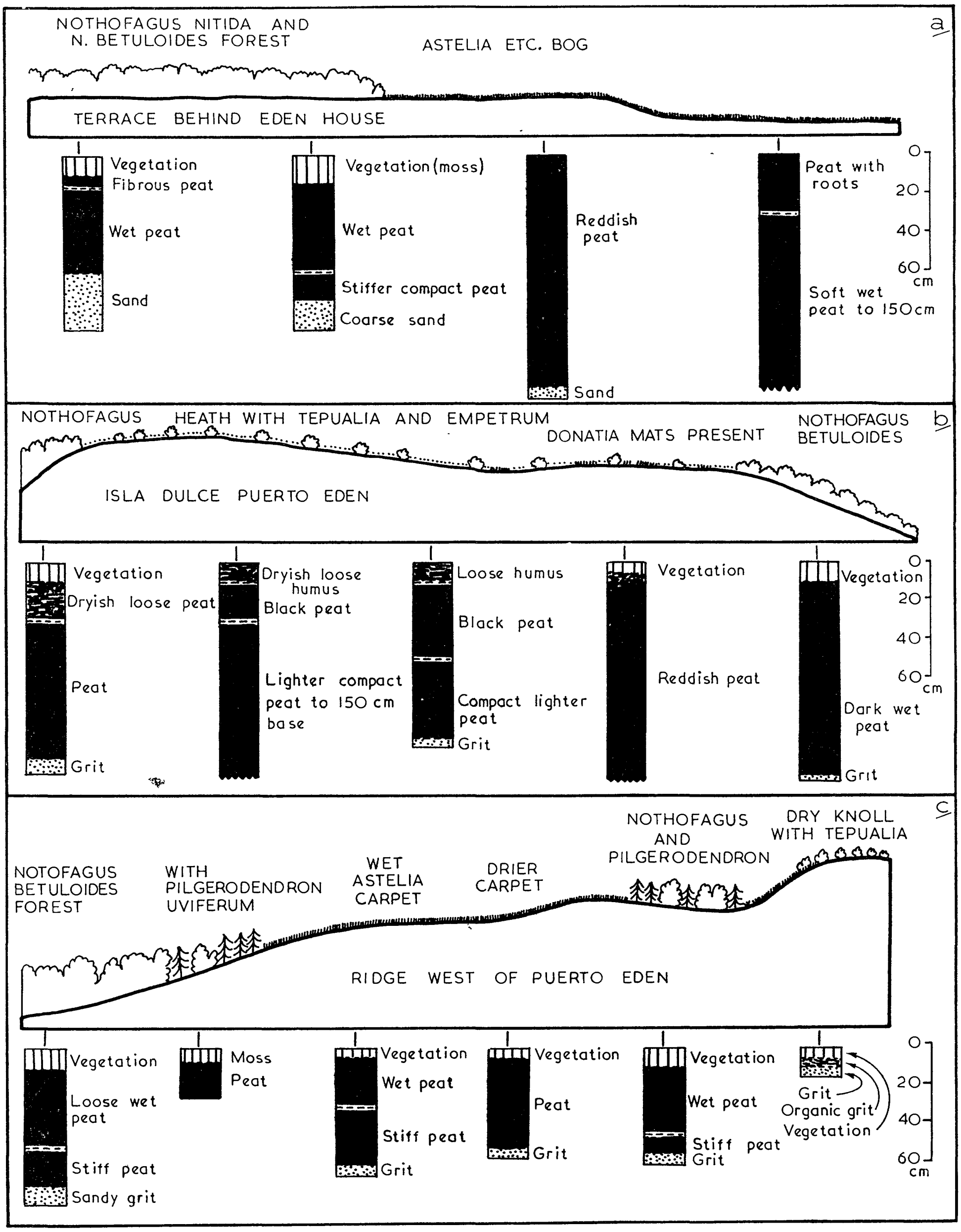

Fig. 8 Vegetation types and soil profiles around Puerto Eden.

wetter reddish-coloured material. Even on the steep ridge examined in series 8c the peat depth varied with topography rather than vegetation type. The chief regional difference in this series was that in the forested gully the peat rested on about 10 cm of coarse sand (possibly downwash) whereas on the ridge crest it lay directly on the rock. As might be expected, in the damp woodlands litter is almost absent, the ground being covered by a bryophyte carpet and dense growths of ferns and young trees, and the soil fauna is strikingly poor.

Determinations of water content, organic content, and pH

The results of a series of measurements made on soil samples collected from the core series discussed above are set out in Table 4. Bearing in mind the inaccuracies in the method used, and the small quantity of residual ash, it can only be concluded that there

Table 4. *Water content, organic content and pH of lowland soils at Puerto Edén*

Vegetation	Water content % total weight	Organic content % dry weight	pH
Nothofagus forest: peats	85	96	4·4
	83	76	4·0
	80	100	3·6
	83	91	–
	90	100	3·6
	85	100	3·7
	71	100	3·6
	84	100	4·1
Mean	83	95	3·9
Tepualia patches and heath: peats	86	100	3·6
	79	100	3·4
	87	100	3·7
	68	64	3·7
	72	82	3·9
Mean	78	89	3·7
Astelia carpets: peats	81	100	3·9
	87	100	3·8
	80	87	3·8
	80	97	3·6
Mean	82	96	3·8
Nothofagus forest: basal sands	19	6	5·0
	15	2	–
	27	8	4·0
	22	7	4·3
	12	3	5·0
Tepualia: basal sand	22	6	4·5
Astelia carpets: basal sand	25	11	4·6
	17	8	4·3
Mean	20	6	4·5

is no detectable difference between the peats of the forest, open 'heath' with *Tepualia* and *Empetrum*, and 'carpet bogs' sampled. Nor does there seem to be any significant pH difference though it is interesting that the sites with *Tepualia* have the most acid values (3·7) while the *Nothofagus* samples average 3·9. Both these figures agree within 0·1 of a unit with the peats beneath these trees at Chepu.

Similarly the basal mineral layers in these lowland sites show no evident variation from place to place. All are drier than the upper peats (though this is probably largely exaggerated by the expression of the results in terms of percentage composition by weight) and all contain negligible amounts of organic matter. As at Chepu and San Pedro they are less acid than the peaty layers above them. Evidently there is negligible downwashing of organic material from the overlying peats into these basal sands.

Soils of an upland area above Puerto Edén

A rather cursory examination was made of the soils in one upland area at 550-600 m on the crest of the ridge running westwards from just above the house at Puerto Edén. In this area the *Astelia* carpets which filled soakways and wet hollows overlay 10-30 cm of reddish peat. Elsewhere, on steep slopes, terraces among rocks and over rock slabs, a mixed carpet of mosses, lichens, liverworts and a few vascular plants covered a few centimetres of brownish or reddish mineral soil which rested on the rock.

Table 5. *Water content and organic content of some upland soils from Puerto Edén*

Vegetation		Water content % by weight	Organic content % of dry weight
Astelia carpets		55	47
		68	54
		76	85
		77	84
	Mean	69	67
Mixed carpets		51	18
		53	33
		39	13
		29	7
	Mean	43	18

Table 5 gives the results of a few analyses of water and organic contents which make this distinction plain. In Fig. 9 the water and organic contents of all Puerto Edén soils are

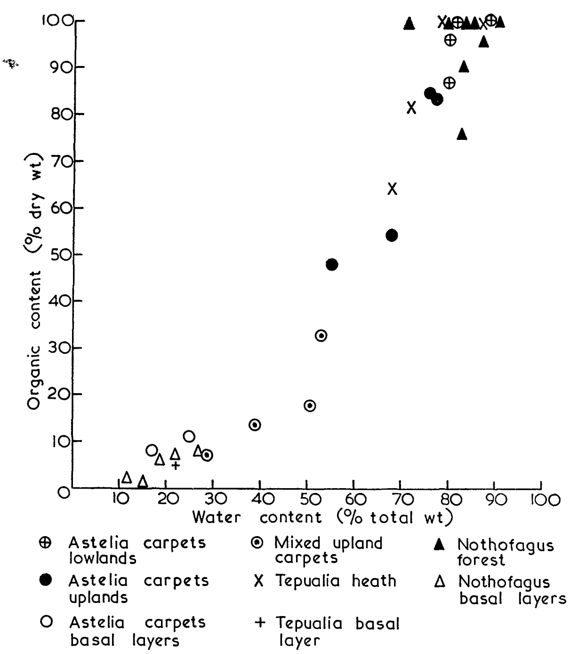

Fig. 9. Organic content and water content of soils from Puerto Eden.

set out together, again illustrating this difference and showing how the organic content of *Astelia* peats seems to be lower at these high altitudes. Probably wind-blown debris is directly incorporated in these deposits. Unfortunately the sudden curtailment of the field programme at Puerto Edén made the further exploration of these upland soils impossible.

Discussion of soils around Puerto Edén

It is generally agreed that one of the most characteristic features of the Magellanic moorland zone is the prevalence of blanket peat. Around Puerto Edén this formation extends everywhere except on the steepest and rockiest slopes, from sea level upwards to about 400 m. At higher levels there is a definite reduction in the depth and extent of these bog deposits and by 600 m they are shallow and rare. This restriction certainly does not reflect any diminution in the wetness of the ground or acceleration in water run-off: many areas at the 600 m level appear topographically ideal for peat formation. Presumably the limitation of peat to the lower slopes reflects some influence of temperature, perhaps acting directly in forcing a short growing season on the dominant plants. It is tempting to correlate the transition from peat-forming to non peat-forming vegetation with the parallel change from dominant evergreen to deciduous trees and see both as reflexions of the cold mountain environment.

Puerto Edén clearly resembles the Cordillera de San Pedro in many of its features, but goes one stage further in the extent of peat formation. Broadly similar vegetation prevails throughout the southern islands southwards to Navarino and Cape Horn (Godley 1960). In all these areas the woodlands are discontinuous, occurring chiefly on coastal flats, gullies and patches on the hillsides. In some cases woodland seems to be excluded by the impeded drainage of flats and hollows, as it was on San Pedro. In others a mere absence of soil from exposed, barren, and recently glaciated rocky hills seems to be responsible.

OBSERVATIONS IN THE NORTH OF NAVARINO ISLAND

Topography and vegetation

Navarino Island (Fig. 1) stands somewhat apart from the other regions discussed in this paper, because its northern shores have a much drier climate. At Puerto Williams, and other places on the coastal strip along the Beagle Channel, the annual rainfall is below 20 in. (510 mm) and the mean annual temperature is also low (5·5° C). Beside the Beagle Channel there is a strip of land made up of elongate morainic or fluvio-glacial ridges running parallel to the coast, and inland from this steep slopes mount to a range of hills whose summits slightly exceed 1000 m.

The region lies within the zone of deciduous forest, and the lowland strip has *Nothofagus pumilio* and *N. antarctica* woods on the ridges. *N. pumilio* dominates the main hill slopes, passing upwards into dwarf scrub and terminating rather abruptly at about 500 m. Hollows in the lowland region contain *Sphagnum* bogs, while on the uplands flushes and streamsides are dominated by *Marsippospermum grandiflorum*. The open uplands are, however, for the most part dry and stony, and support 'heaths' of *Empetrum rubrum* and communities of 'cushion plants' like *Bolax gummifera* and *Azorella* spp.

Lowland soils of northern Navarino

A series of profiles was examined across a ridge and hollow system near Puerto Williams (Fig. 10). In this area peat is strictly limited to hollows, and organic accumulation on the ridge crests is slight. All the soils of the ridge crests are brown earths with a capping of dry litter above a shallow horizon of finely broken-down humus. There is an abundant soil microfauna, especially of mites and collembola in these layers. Lower down, the organic layers grade rapidly into a hard, compact, sandy or gritty mineral soil. The dryness of this soil may at the time of study have been accentuated by a two-week drought, but a later re-examination after heavy rains revealed no marked change and

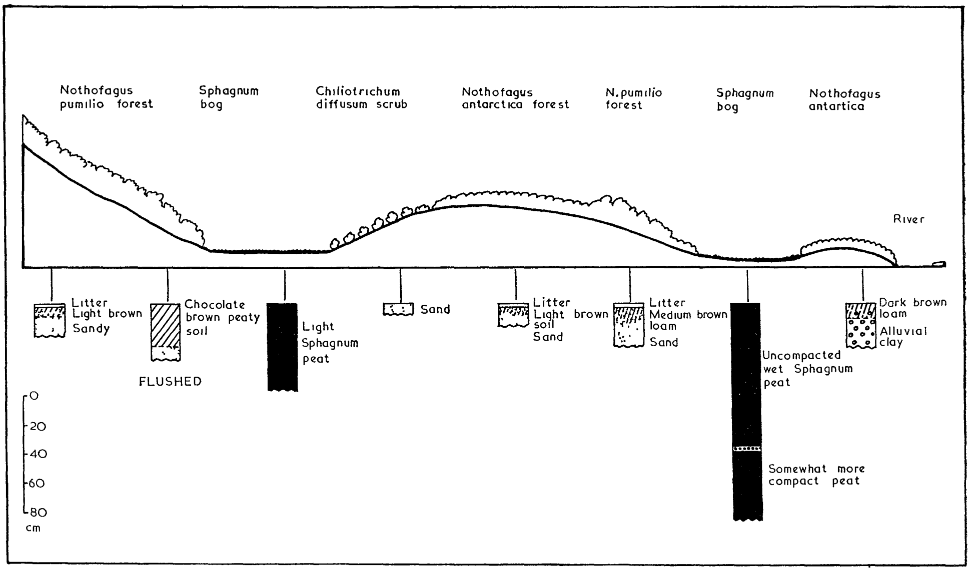

Fig. 10. Vegetation types and soil profiles on northern Navarino.

there is no doubt that these ridge-crest soils are quick draining, with little water-holding capacity. The deeper layers were not observed in these cores, but sections exposed in roadside pits showed that the upper mineral layers graded evenly into unaltered glacial material, with little or no marked colour change.

The *Nothofagus pumilio* forests of the hills slopes south of Puerto Williams also have dry mineral soils with shallow organic surface layers. There are, however, local flushed areas where up to 30 cm of black structureless peat has formed.

Water content, organic content and pH of lowland soils

The results of such measurements are set out in Table 6. At first glance they are difficult to interpret, especially because of the wide variation in water content. This may perhaps be attributable to seepage, or to local variations caused by the dryness of the season. Local flushing was certainly responsible for some of the wettest, most organic and least acid patches of forest soil encountered. The drainage waters in the streams around Puerto Williams have a circumneutral or even alkaline reaction, pH values of 7·0 and 7·2 being recorded for the main stream by the hydro-electric plant which supplies the Naval Base.

Upland soils of northern Navarino

On these uplands organic material is found only below the vegetation patches. Large cushions of *Bolax* and *Azorella* overly 10-20 cm of peaty material: under *Empetrum*

Table 6. *Water content, organic content and pH of some lowland soils on the north side of Navarino*

Vegetation	Water content %	Organic content %	pH
Sphagnum bog	86	100	4·5
	92	90	4·4
Dry scrub with *Chiliotrichum*	26	11	4·6
	18	5	4·4
Nothofagus antarctica	14	15	–
	40	9	5·2
	54	8	4·7
Nothofagus pumilio	33	54	6·3*
	24	25	4·5
	19	7	4·4
	77	92	6·9*
N. antarctica and *N. pumilio*, deeper layers	16	5	–
	14	4	5·4
	23	0	4·9
	16	16	6·3*

Asterisks indicate samples from places noted in the field as being flushed.

organic accumulations are less evident and confined to the uppermost few centimetres. The peats beneath the plant mats rest abruptly on a mineral substratum, and this is exposed in some places between the adjacent cushions. These cushions and especially the *Empetrum* mats seem to be subject to cyclical processes of growth and erosion and it is likely that the deposits associated with them are similarly transient.

Table 7 summarizes the results of a series of water content, organic content and pH

Table 7. *Water content, organic content and pH of upland soils on Navarino*

Vegetation	Water content %	Organic content %	pH
Bare downwash soil	26	14	4·6
	19	7	4·4
Empetrum mat	58	62	5·0
	45	47	4·1
Below *Bolax* and *Azorealla*	67	95	4·4
	60	89	4·5
Mineral layer below cushion	15	17	4·0
Grassland, over downwash soil in hollow	50	21	4·6

measurements made on these upland soils. It is evident that the mineral content varies widely and that the incorporation of wind-blown material into the peats is significant, especially beneath the less densely-growing cover of *Empetrum*. No observations were made on the peats of *Marsippospermum* communities.

Discussion of soils on northern Navarino

Just as the peaty soils of Puerto Edén are typical of Magellanic moorland, so it is likely that the dry, well-drained, shallow brown earth soils of northern Navarino are typical of the deciduous forest belt in much of its range east of the Andes. As Butland (1957) and Habit (1954) have pointed out, along this side of the Cordillera fluvio-glacial and morainic substrata predominate as parent material. On Navarino these substrata support deciduous forest growing near to the high-rainfall extremity of its range, and it is therefore most likely that even drier regions over the same parent type will have soils with even more slight and superficial organic contents. Similarly, on the uplands of this zone, it is likely that organic accumulation will be restricted, as on Navarino, to flushed areas and the interior of certain types of plant mat.

CONCLUSIONS

At the present stage it is not possible to comment usefully on the schemes of subdivision of southern Chile into soil provinces. It is clear that Butland's (1957) broad statement that the western island zone is characterized by tendencies towards peat formation and podsolization, while the eastern deciduous forest and steppe belts have drier, more freely-draining soils, is applicable. Podsol profiles have not, however, been observed at all frequently in the areas described in these pages, and where they do occur they seem most characteristic of cleared and grazed regions. This may, however, be a reflection on the selection of sample areas and the methods used rather than a valid generalization. It is also clear that certain characteristic vegetation types are generally associated with definite types of soil: that for example, the typical 'Valdivian forest' is associated with fairly free-draining brown-earths while the southern evergreen beech species *Nothofagus nitida* and *N. betuloides* can flourish in wetter, more acid, and more peaty situations.

The present observations also confirm the importance of the parent material to soil type and vegetation. The differences between the vegetation around Chepu, over considerable depths of glacial and fluvial deposits, and that on the Cordillera de San Pedro where a hard, impervious rock lies close below the surface are evident. Since drainage is a factor of extreme importance in these areas, these geological differences are likely to be of real significance and their utilization by Vogel (1957) in his classification of Chiloé soils is justified. Similarly Habit's (1954) separation of Magellanes into the zone of the Cordillera and the zone of deposited sediments is evidently reasonable if one compares the observations on northern Navarino with those from typical western Magellanic moorland around Puerto Edén. Godley (1960) has observed that the distribution of the Magellanic moorland formation accords closely with that of the intractable Andean diorite, which is a further indication of the real significance of rock type in determining the vegetation of this recently-glaciated country with its relatively young soils.

In all their main features the soils of this part of southern Chile seem comparable with those of the northern temperate zone, despite the totally different nature of the vegetation. The prevalence of peat in the westernmost Magellanic moorland invites comparison with the islands of the subantarctic and south temperate zone where peat formation is equally prominent. The factor common to all these regions and doubtless the main agent controlling peat formation is the oceanic climate; but within these regions two general types of bog vegetation may be distinguished. Godley (1960) has stressed the importance of carpet bogs in the sub-antarctic region and the unimportance of *Sphagnum*. He considers on these and other grounds that only the Magellanic moorland among the south Chilean vegetation regions can be called subantarctic. The cushion plants of the bogs here are similar to those on the New Zealand subantarctic islands (Aston 1909, Oliver & Sorensen 1951). On the species-poor Macquarie Island mosses are of importance in the bogs, and the cushion plants are two species of *Colobanthus*. *Sphagnum* is again unimportant (Taylor 1955). On the other hand, in islands at lower latitudes the bog vegetation is different. *Sphagnum-Bryales* bogs occur on Tristan da Cunha and Gough Island (Wace & Holdgate 1958, Wace 1960) and *Sphagnum* on New Amsterdam.

SUMMARY

South-western Chile, between 42° S. and 56° S., is a region of mountainous islands with an oceanic climate and evergreen rain-forest or peat-forming herbaceous vegetation. At Chepu on Chiloé Island (42° S.) much of the country is made up of alternating ridges and hollows. The former support a rich broad-leaved evergreen forest (Valdivian forest) dominated by *Eucryphia cordifolia*, *Weinmannia trichosperma*, *Laurelia serrata* and *Amomyrtus* spp. These areas have a brown-earth soil whose upper layers contain about 36% organic matter (expressed as a percentage of dry weight) and have a mean pH of 4·9. The hollows contain woodland dominated by *Nothofagus nitida* and *Tepualia stipularis*: they have waterlogged peaty soils of about 60% organic content and pH 3·8 to 4·0. This separation of the two vegetation types is of interest because the *Eucryphia* forest is characteristic of warmer and drier regions ranging northwards from the study area while *Nothofagus* woodlands characterize the colder and rainier southern regions.

On the central uplands of Chiloé Island peat formation still occurs chiefly in hollows, and *Astelia pumila* dominates the bog vegetation. Gleys and peaty gleys are widespread, and the forest patches (of *Nothofagus*) have only shallow superficial acid (*mor*) humus layers. Farther south, at Puerto Edén on Wellington Island (49° S.), while the vegetation has much in common with the Chiloé uplands, blanket peat is developed almost everywhere below 600 m, and this is certainly to be associated with the much higher rainfall. Peats developed in *Nothofagus* forest, *Tepualia* patches and heath, and *Astelia-Donatia* bog have alike between 90 and 96% organic content, and pH from 3·7 to 3·9. Only on the mountains above 600 m is peat formation checked and an appreciable amount of wind-blown mineral matter incorporated in the material below the vegetation mats.

In contrast to these wet western areas, the northern shores of Navarino Island (55° S.) have a rainfall below 20 in. (51 cm) and a vegetation of deciduous woodland developed over very dry, free-draining brown earth soils derived from a parent material of moraine and glacial sands. Peat formation is here restricted to regions of impeded drainage, and even on the uplands organic accumulations only occur in streamside bogs and within cushions of plants such as *Bolax* and *Azorella* species.

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