

SOILS OF THE ARID ZONES OF CHILE

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, ROME



CONTENTS

| | <u>Page</u> |
|---|-------------|
| INTRODUCTION | 1 |
| <u>The Pacific Arid Zone</u> | 1 |
| A. The desert environment of Northern Chile ("Absolute Desert") | 1 |
| B. The semi-desert environment of north-central Chile | 4 |
| <u>The Patagonian Arid Zone</u> | 5 |
| ENVIRONMENTAL CHARACTERISTICS OF THE NINE DESERT SOIL ASSEMBLAGES OF THE NORTHERN DESERT DIVISION OF THE PACIFIC ARID ZONE ... | 6 |
| 1. <u>Region of the Saline Desert Soils</u> | 6 |
| (a) Assemblage of soils dominated by dry residual solonchaks | 6 |
| (b) Assemblage of saline Lithosols and Regosols ... | 9 |
| 2. <u>Region of Alkaline Desert Soils</u> | 13 |
| (a) Red Desert soils | 13 |
| (b) Assemblage of Lithosols and Regosols related to Red Desert soils | 17 |
| 3. <u>Region of Soils Transitional between True Desert Soils and Semi-Desert Soils</u> | 20 |
| (a) Coastal Desert soils | 20 |
| (b) Assemblage dominated by weakly saline lithosolic and regosolic desertic soils, rich in calcium and in part with gypsum crusts | 22 |
| (c) Assemblage dominated by greyish and brownish "sierozem-like" soils of the cool desert uplands ... | 24 |
| (d) Assemblage dominated by Lithosols related to Minimal Brown Forest soils | 26 |
| (e) Steppe grassland soils of the Andean altiplano ... | 29 |
| ENVIRONMENTAL CHARACTERISTICS OF THE SEVEN SEMI-ARID SOIL ASSEMBLAGES OF THE SEMI-DESERTIC ENVIRONMENTS OF NORTH-CENTRAL AND CENTRAL CHILE | 32 |
| 1. <u>Region of Calcic Brown Soils of the Transverse Valleys</u> | 32 |
| 2. <u>Region of Semi-Arid Soils with Neutral to Slightly Acid Reaction</u> | 34 |
| (a) Sub-region of "coastal prairie" soils | 34 |
| (b) Sub-region of Reddish-Brown Lateritic soils and Red-Yellow Podsollic soils of the coastal hills ... | 35 |
| (c) Sub-region of Non-Calcic Brown and related transitional soils, and Regosols of the Central Vale | 37 |

| | |
|---|----|
| - Soil assemblages dominated by Non-Calciic Brown soils | 37 |
| - Soil assemblages transitional between Non- Calciic Brown and Red-Brown Lateritic soils ... | 38 |
| - Soil assemblages dominated by Regosols derived from basaltic sands of alluvial origin ... | 39 |
| (d) Sub-region of Lithosols and Minimal Brown Forest steep-land soils, and associated soils of the Andean foothills and ranges | 40 |

| | |
|---|----|
| ENVIRONMENTAL CHARACTERISTICS OF THE TWO SEMI-ARID SOIL ASSEMBLAGES OF THE PATAGONIAN ARID ZONE | 43 |
|---|----|

| | |
|--|----|
| 1. <u>Region of Soils Rich in Calcium</u> | 43 |
|--|----|

| | |
|---|----|
| 2. <u>Region of Semi-Arid to Sub-Humid Soils of Neutral Reaction at the Patagonian Desert Margin</u> | 44 |
|---|----|

| | |
|-------------------|----|
| REFERENCES | 45 |
|-------------------|----|

| | |
|--|----|
| TABLE 1. Summary of broad soil characteristics of the eight arid zone regions of Northern Chile: Soil data selected from the more developed soil profiles on the most stable land surfaces | 46 |
|--|----|

| | |
|---|--|
| APPENDIX: DESCRIPTIONS OF SOIL PROFILES REFERRED TO IN THE TEXT | |
|---|--|

INTRODUCTION

Arid and semi-arid soils cover more than half the total landscape of Chile. They occur in two distinct sectors of the country: they occupy all the northern half, from latitude 18°S to nearly 37°S, and extend from the coast to the summit of the Andean cordillera; and they reappear again in the far south, between latitude 43°S and about 55°S, where they occur on the eastern or Patagonian side of the Andes. These two distinct sectors with arid or semi-arid soils can be conveniently referred to as:-

I. The Pacific Arid Zone

II. The Patagonian Arid Zone.

I. The Pacific Arid Zone

Within the Pacific Arid Zone there are two major environmental divisions:-

A. The true desert environment of the coastal ranges and inland "pampas" of the Pacific piedmont of the Andes of Northern Chile. This type of environment extends as far south as latitude 30°S, but within this division there are well-defined environmental regions ranging from absolute desert near the coast, to regions that are marginal between desert and semi-desert occurring at elevations ranging from 2,500 metres to almost 6,000 metres on the Andean altiplano.

B. The semi-desert environment of the northern part of Central Chile, between latitude 30°S and about 37°S, covering an altitudinal range from sea-level to about 5,000 metres.

A. The desert environment of Northern Chile ("Absolute Desert")

The northern half of Chile has the climate equivalent to that of an extremely dry intermontane valley, bounded on the east by the Andean cordillera and the whole breadth of the South American continent, and bounded on the west by the cold Humbolt Pacific current which effectively dehydrates the moist generated in the Southern Pacific ocean (Wright and Espinoza, 1962).

This part of Chile, extending from latitude 18°S to latitude 30°S is occupied by soils which fall within the category of arid zone soils, and some of these are amongst the most arid soils in the world. There is reason to believe that in some parts extreme desert conditions have been in force for at least 30 million years (Wright, Melendez, in press).

The landscape of this part of Chile consists of the Andean altiplano with its associated high mountain peaks; the Andean slopes and associated outlying foothills, and the plains as pampas which are of subdued relief but extend from sea-level to about 2,300 m. A minor range, consisting of a chain of relatively low hills borders the seaward margin of the pampa.

Within this simple landscape arrangement there are three readily distinguishable soil regions, corresponding to three distinctive environmental regions. Moreover, within the three regions, various areas possessing different soil assemblages can be broadly identified. Actually, within the whole of this northern desert zone, nine separate soil assemblages can be distinguished.

In region 1, which comprises much of the northern part of the coastal range and the adjacent plains to the east, saline soils predominate. Dry residual solonchaks dominate the soil assemblage of the plains and shallow depressions, while Lithosols and Regosols predominate on the coastal range. In region 2, which occupies a low position on the broad Andean piedmont (with elevations ranging from about 500 m to about 2,300 m), the characteristic soils are alkaline rather than saline. Part of this area is occupied by typical Red Desert soils, but a far larger part is occupied by Lithosols and Regosols related to Red Desert soils. In region 3 (which extends from the upper Andean piedmont, over the foothills and the main cordillera ranges, eventually on to the Andean Altiplano), the soils have more varied chemical characteristics and five distinct soil assemblages can be recognised. The soils of region 3 range from true desert soils through various transitional stages towards semi-desert soils.

The nine soil assemblages of the Northern Desert division of the Pacific Arid Zone are listed below:-

1. Region of Saline Desert Soils

- a) True desert soils that are mainly dry residual solonchaks, in part salitrous (impregnated with sodium nitrate); with associated salares (plains of salt accumulation), recent alluvial soils, solonchaks, and dry lacustrine soils. This region extends from about 25°S, northward to about 20°S, and lies mainly to the west of the centre of the lowlands; of an average width of twenty miles. (Map Unit 1.)
- b) True desert soils that are strongly impregnated with salts (sodium chloride predominating) and in part have cemented gypsum crusts at or near the surface. Associated with these soils are dry residual solonchaks, salares, recent alluvial and colluvial soils which are usually somewhat saline, and pale reddish brown soils that are transitional to coastal desert soils. This region extends from about latitude 25°S all the way to the Peruvian border, along the western flank of the lowlands and of a width that varies between 10 and 35 miles. (Map Unit 2.)

2. Region of Alkaline Desert Soils

- a) Red Desert soils. True desert soils with distinct profile development, commencing on the lowlands in about latitude 30°S and extending north of latitude 28°S. (Map Unit 3.)

ZONAS ARIDAS DE CHILE ARID ZONES OF CHILE

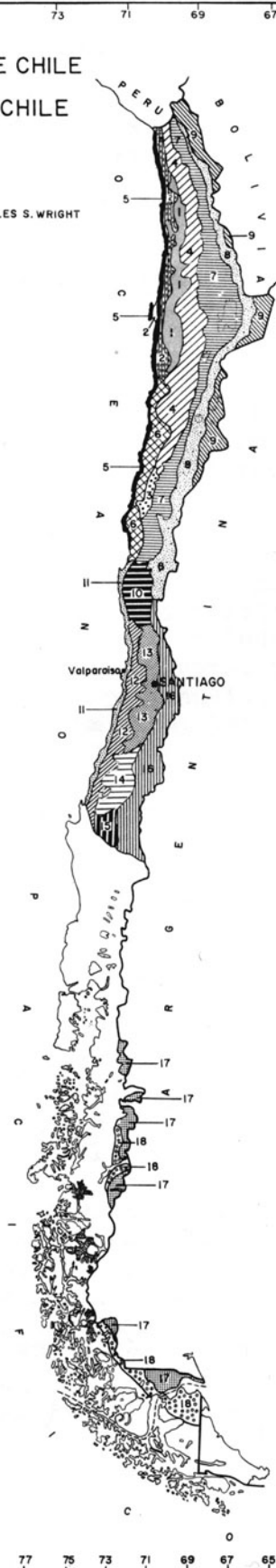
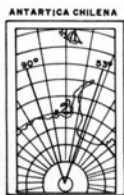
1963

POR: CARLOS DIAZ VIAL Y CHARLES S. WRIGHT

80°
S. Faja
O. S. Ambr.
Suelos y G.

109°
L. de
Pasco

15. J. FERNANDEZ



I - ZONA ARIDA DEL PACIFICO

I - ARID ZONE OF THE PACIFIC

A. DESIERTO ABSOLUTO

A. ABSOLUTE DESERT

1) Region of saline soils

1) Region of saline soils
Predominan Solonchaks fósiles
Mainly dry residual Solonchaks

2) Predominan Litosoles y Regosoles salinos en parte con una costra de yeso
Mainly saline Lithosols and Regosols, in part with gypsum crusts

2) Region of alkaline soils

Suelos Rojos de Desierto
Red Desert soils

4) Predominan Regosoles y Litosoles con algunas características de los Suelos Rojos de Desierto
Mainly Regosols and Lithosols related to Red Desert soils

3) Areas marginales: suelos con características químicas variados

3) Marginal region: soils of variable chemical characteristics

a) Areas costaneras

a) Coastal
Suelos Desérticos de la costa
Coastal Desert soils

6) Suelos Litosólicos con calcio
Lithosolic soils with calcium
b) De mediana altitud
Moderate elevations

7) Predominan Litosoles y Sierozem Mínimos
Mainly Lithosols, with 'Minimal Sierozems'

8) Predominan Litosoles y Suelos Pardos Forestales Mínimos
Mainly Lithosolic soils with 'Minimal Brown Forest soils'
c) Altiplano
c) Altiplano

9) Suelos de Estepa del Altiplano
Altiplano steppe soils

B. SEMI - DESIERTO

B. SEMI - DESERT

1) Región con suelos calcáreos

1) Region of calcareous soils

10) Suelos Pardos y Pardos Cálcicos
Brown soils and Calcic Brown soils

2) Región de suelos neutros a suelos con tendencia a acidificarse

2) Region of neutral to slightly acidified soils

a) Areas costaneras

a) Coastal
11) Praderas Costaneras sobre terrazas marinas
Coastal Prairie soils of the marine terraces
b) Cordillera de la Costa
Cordillera of the Coast
b) Coastal ranges

12) Tránsitos de Pardos No Cálcicos a Suelos Pardo Rojizo Lateríticos incluyendo Tránsitos a Suelos Rojo Amarillo Podzólicos.
Intergrades between Non-Calcic Brown and Red-Brown Lateritic or Red-yellow Podzolic soils
c) Suelos del Llano Central
Central vale

13) Suelos Pardos No Cálcicos y Aluviales recientes
Non-Calcic Brown soils and Recent Alluvial soils

14) Tránsitos a Suelos Pardo Rojizo Lateríticos; Aluviales recientes y Trumao
Intergrades with Red-brown Lateritic soils, with associated Recent Alluvial soils, Trumao soils etc.

15) Regosoles
Regosols
d) Valles Andinos y alta montaña
Andean valleys and cordillera

Predominan Litosoles y suelos asociados a: Trumao; de cenizas volcánicas recientes; Pardos Forestales Mínimos; Praderas Mínimas; etc.
Mainly lithosols related to Minimal Brown Forest soils and to Minimal Prairie soils, with associated Trumao soils, Recent Volcanic Ash soils, etc.

II - ZONA ARIDA DE LA PATAGONIA

II - ARID ZONE OF PATAGONIA

1) Región con suelos ricos en calcio

1) Region of calcareous soils

7) Suelos Castaños Medios y Mínimos
Chestnut and Minimal Chestnut soils

2) Región marginal con suelos neutros

2) Region marginal to Andean ranges, with soils less rich in carbonates

16) Suelos de Praderas Mínimas (o Praderas Magallánicas) y Praderas - Planosoles.
Minimal Prairie soils (or Magellan Prairie soils) with associated Prairie-Planosols

Dib. H. Orozco Patiño

- b) Lithosols and Regosols related to Red Desert soils. True desert soils with extremely weak profile development, strongly regosolic in nature; with minor areas of dry residual solonchaks, and recent alluvial and recent colluvial soils which are in part saline. This region extends from about latitude 28°S , northwards to the Peruvian border, through the central part of the lowlands. (Map Unit 4.)

3. Region of Transitional Soils between True Desert Soils and Semi-Desert Soils

- a) Coastal desert soils. Pale reddish-brown coloured coastal desert soils, in part lithosolic, that are developed along a very narrow strip extending from 30°S to near the Peruvian border. Associated with these soils are regosols, recent dune sands, recent soil of marine terraces, and recent alluvial and colluvial soils. (Map Unit 5.)
- b) Desert soils that are mainly weakly impregnated with salts but are rather calcareous and in part have gypsum crusts at or near the surface. Lithosolic and regosolic soils predominate, but associated soils include dry residual solonchaks, salares, recent alluvial and colluvial soils, and pale reddish brown desertic soils that are transitional to coastal desert soils. This region extends from about latitude 25°S to 30°S , with a width varying from 5 to 20 miles. (Map Unit 6.)
- c) Greyish and brownish sierozem-like soils of the cool desert of the Andean foothills and adjacent plains. These soils extend from about latitude 30°S to the Peruvian border along the western flank of the Andes, and include local areas of solonchaks and salares. (Map Unit 7.)
- d) Lithosols related to minimal Brown Forest soils and Sierozems; with considerable development of recent colluvial and alluvial soils, in part extensively terraced by former civilisations; and some small areas of Páramo-like soils, Non-Calcic Brown soils and Calcic Brown soils. This region extends from about 32°S , northward to the Peruvian border; occupying the higher slopes of the Andes between 10,000 and 12,000 ft. (Map Unit 8.)
- e) Steppe-grassland soils of the Andean altiplano, with associated lithosols, regosols, sierozems, recent alluvial soils, bog soils, solonchaks and salares; with some development of red desert soils on the southern extension of the altiplano. The altiplano soil region extends into Chile in three places: between latitude 28°S and 25°S ; between 24°S and 23°S , and between 20°S and $17\frac{1}{2}^{\circ}\text{S}$, although it is in reality a continuous system passing mainly through Argentinian and Bolivian territory. (Map Unit 9.)

B. The semi-desert environment of north-central Chile

South of latitude 31°S a gradual increase in the amount of rain, falling mainly in the winter months, brings a gradual transition from true desert to semi-arid conditions. The summer months are almost invariably extremely dry and since potential evaporation far exceeds the precipitation the soils suffer a water deficiency which ranges from eight to ten months in the north of this zone, to about two months near the southern limit of this zone, in about latitude 37°S .

Drought conditions are most severe in the Central Vale, between the coastal ranges and the foothills of the Andes. On the western flank of the Central Vale, sea mist and occasional sea fogs bring some small amount of additional moisture to the vegetation and to the soil surface; on the eastern flank, the steeply ascending slopes of the Andes receive additional orographic rainfall and considerable snowfall in winter.

The landscape of this zone consists of a narrow coastal lowland strip, backed by the relatively low coastal ranges; followed by the lowland plains of the Central Vale, and then the gradually or steeply rising slopes of the Andean ranges. In this part of Chile there is no well-defined altiplano.

Within this arrangement of landscape there are two major soil regions. In the first of these the soils are all predominantly calcareous while in the second major soil region the main soils range from weakly calcareous to neutral in reaction, and in some cases show a tendency to become distinctly acid. In this second soil region there are six well-defined kinds of soil assemblages.

The main soil assemblages of the semi-arid division of the Pacific Arid Zone in north-central Chile are described briefly below:-

1. Region of Calcareous Soils

Brown and Calcic Brown soils of the transverse valleys, with associated Grumosols, Rendzinas and Non-Calcic Brown soils, and with related stepland soils, Lithosols, Regosols, and Recent Alluvial and Colluvial soils. This region extends from 30°S to $31^{\circ}30'\text{S}$. (Map Unit 10.)

2. Region of Soils with Neutral Reaction Grading to Soils with a Tendency for some Acidification

- a) Soils of the coastal lowlands. Predominantly "Coastal Prairie" soils developed on marine terraces, associated with Red-Brown Lateritic soils and Red-Yellow Podsollic soils and with derived Recent Alluvial and Colluvial soils; local development of young dune soils, Gley soils, etc. This assemblage occurs from about 30°S to $36^{\circ}30'\text{S}$. (Map Unit 11.)

- b) Soils of the coastal ranges. Predominantly Red-Brown Lateritic soils and Red-Yellow Podzolic soils and their related steep-land soils; but including areas of Recent Alluvial and Colluvial soils and Grumosols. This assemblage occurs mainly between 30°S and 36°30'S. (Map Unit 12.)
- c) Soils of the Central Vale.
(i) Predominantly Non-Calcic Brown soils and soils transitional between Non-Calcic Brown soils and Red-Brown Lateritic soils, together with related steep-land soils, Recent Alluvial and Colluvial soils, and with local development of Grumosols. This assemblage occurs from 32°30' to 36°30'S. (Map Unit 13.)
(ii) Predominantly Non-Calcic Brown soils and related steep-land soils, Lithosols, Recent Alluvial and Colluvial soils, with associated Grumosols, Rendzinas, and soils transitional to Red-Brown Lateritic soils and their related steep-land soils. This assemblage occurs mainly between latitude 33°20'S and 37°30'S. (Map Unit 14.)
(iii) Predominantly Regosols derived from recent basaltic sands of alluvial origin, together with Trumao terrace soils and Red-Brown Lateritic soils, etc. This assemblage occurs only between 37°S and 37°30'S. (Map Unit 15.)
- d) Soils of the Andean ranges. Predominantly Lithosols and steep-land soils related to Minimal Brown Forest soils, together with related Recent Alluvial and Colluvial soils; and with associated Trumao soils and Red-Brown Lateritic soils of the lower piedmont slopes. This assemblage occurs from about 30°S to 37°30'S, but the associated Trumao and Red-Brown Lateritic soils are restricted to the southern third of this area. (Map Unit 16.)

II. The Patagonian Arid Zone

Within the Patagonian Arid Zone two main soil regions have so far been recognised, one with distinctly calcareous soils, and a marginal region in which the soils range from weakly calcareous to non-calcareous and of neutral reaction.

1. Region with Soils Rich in Calcium

Mainly Medial and Minimal Chestnut soils, associated with Calcisols, Brown Calcic Soils, Solonchaks, etc. This region occurs to the north of the eastern mouth of Magellan Straits, reaching from Laguna Blanca and Oazy Harbour, to Cape Dungeness. A similar assemblage of soils is also found in the vicinity of Chile Chico, in Aisen Province. (Map Unit 17.)

2. Marginal Region with Neutral Soils

Mainly Minimal Prairie soils (Magellan Prairie soils) and Prairie-Planosols, locally associated with Half-Bog and Bog soils. This region occurs immediately to the west of the last-described region, and is represented in Aisen Province as well as Magallanes Province. In the former area there is considerable development of soils derived from volcanic ash which are recognised as Trumao soils, although they are but weakly weathered. (Map Unit 18.)

ENVIRONMENTAL CHARACTERISTICS OF THE NINE DESERT SOIL
ASSEMBLAGES OF THE NORTHERN DESERT DIVISION
OF THE PACIFIC ARID ZONE

1. Region of the Saline Desert Soils

a) Assemblage of soils dominated by dry residual solonchaks, in part salitrous. (Map Unit 1.)

(i) Landscape

These soils are associated with a landscape that is made up essentially of a series of inter-connecting basins and adjacent gently sloping plains. The older alluvial and colluvial gravels of certain areas were once impregnated and cemented by sodium nitrate and allied salts. These salitrous gravels are largely buried under much younger alluvial and colluvial materials, but where they are not too far beneath the surface, they have been extensively mined for the nitrate fertilizer industry. The central part of many of the shallow basins in the landscape are now slowly filling with alluvial silt and very fine sand (fig. 1), all to a considerable degree impregnated with sodium chloride. The central parts of the depressions are commonly occupied by salares in which the salt content is continually augmenting through the rise of capillary water from the saline watertable which commonly lies at two to five feet below the surface. Small island hills of granitic rocks or indurated sedimentary rocks rise, in places from the floor of the basins.

(ii) Climate

There is a general scarcity of climatic data in this region but, in general, it is expected to resemble that of the following region, with no measurable annual rainfall, with exceedingly infrequent heavy rainstorms of very brief duration, with wide daily temperature extremes, and with very high evaporation rates.

(iii) Vegetation

Over much of the area there is neither permanent or ephemeral vegetation. As in the case of the preceding region, permanent tree growth occurs in situations where the groundwater lies not too far beneath the surface. In former times (before the trees were cut to provide wood for the fertilizer industry and its attendant population), some of these desert basins were partially covered with flourishing tamarugo forests (fig. 2). Afforestation schemes, employing tamarugo, are having considerable success in these areas. Despite the surface salt crusts, tamarugo trees survive (fig. 3) and also salt grass likewise grows freely where the groundwater is close below the surface. Some of the salars show the surprising sight of mats of this grass growing between the salt pillars (fig. 4), taking some advantage from the moisture condensed at night on the surface of the salt.

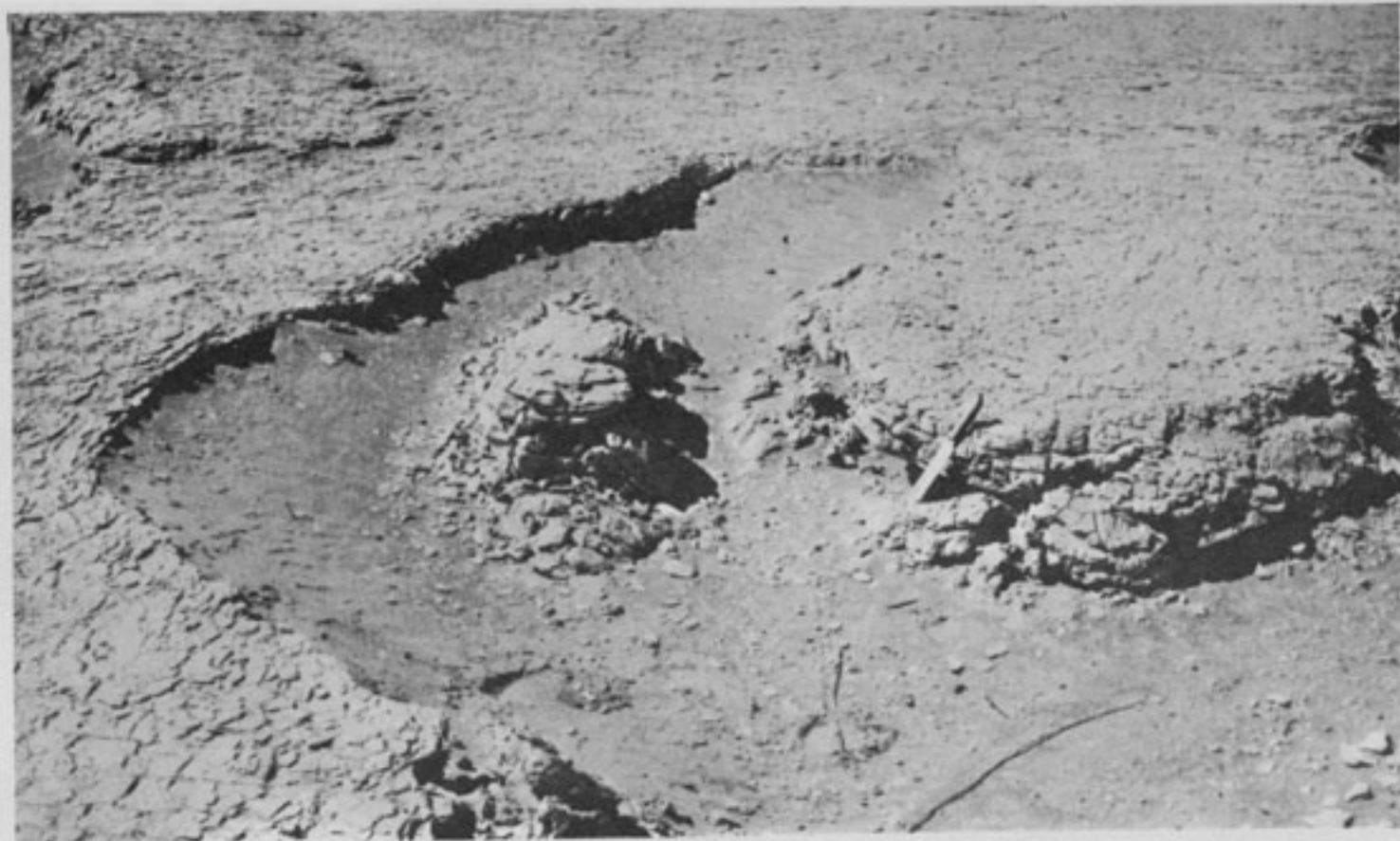


Fig. 1 - Silt accumulation near central part of salitrous desert basin,
Pozo Almonte, Tarapacá Province.

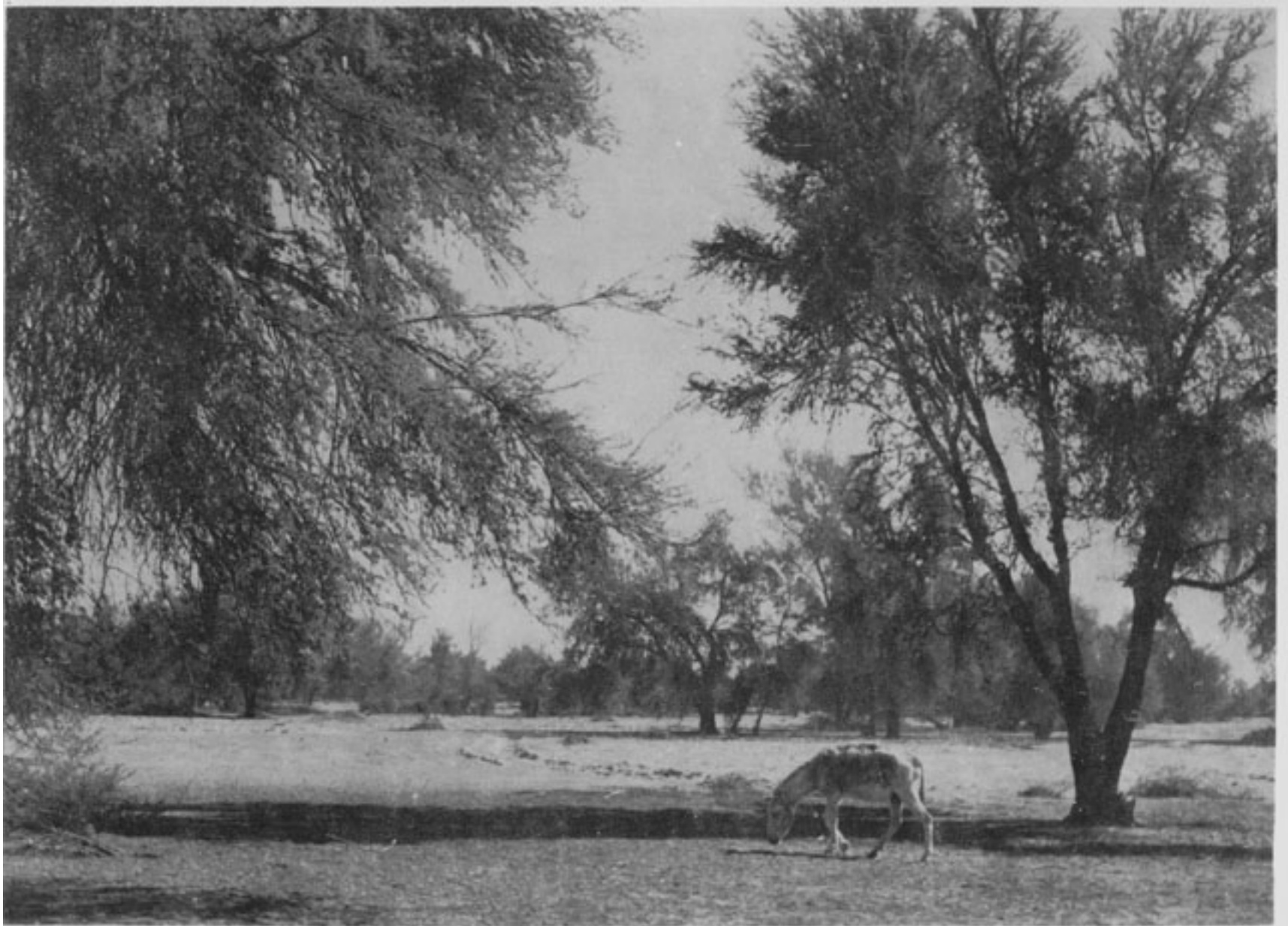


Fig. 2 – Natural tamarugo forest growing at margin of salitrous desert region. La Guiaca, Tarapacá Province.

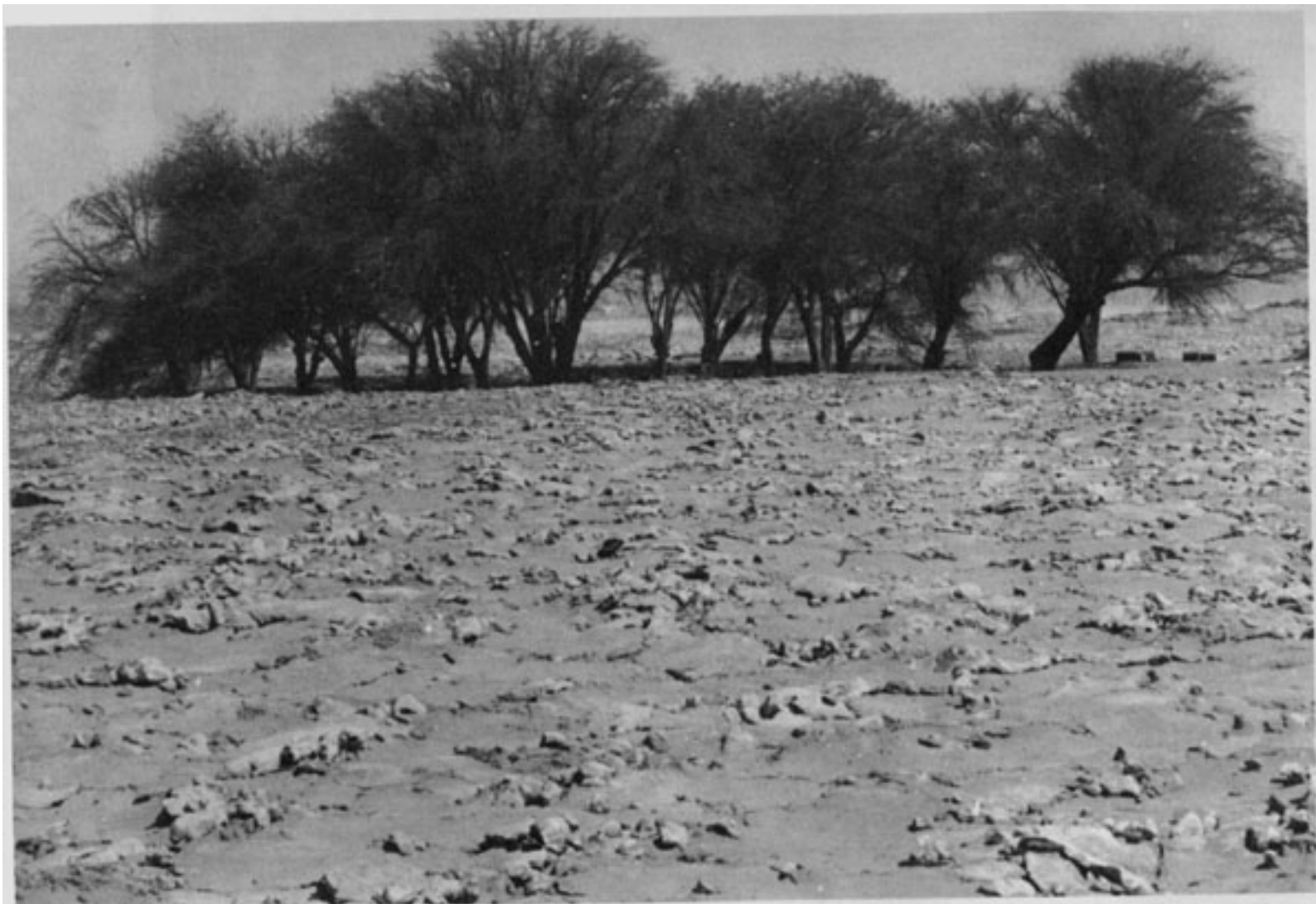


Fig. 3 - Clump of tamarugo trees growing in salar, near Huará, Tarapacá Province.



Fig. 4 – Salt grass growing in Pintados salar, Tarapacá Province.

(iv) Soils

There is a considerable variety of soils found within this region. The oldest soils are those found where the salitrous gravels occur at the surface. Profiles are very shallow, the top-soils being seldom more than 2.5 cm in thickness, and pinkish-grey in colour. Below this is a whitish horizon very rich in sodium chloride crystals, grading into gravel cemented with rock-salt containing micro-crystals of sodium nitrate, (see appendix, profile No. 1).

More commonly, younger soils derived from recent colluvial or alluvial materials occupy the landscape. The profiles are all somewhat laminated, with coarse sand, very fine gravel, fine sand or silt layers of no great individual thickness. The uppermost layer is often lightly held in place by sodium chloride crystals that have deliquesced in the night dew or by condensation of moisture from coastal fogs, and subsequently recrystallised between the sand grains. Beneath this is usually a very thin loose layer with only a very few sodium chloride crystals but a considerable amount of powdery white sulphate crystals. Most of these appear to be sodium sulphate, in the form of "mirabilite". Cementation by "rock-salt" increases with depth in the older alluvial or colluvial soils, and certain strata may be very strongly cemented.

A very conspicuous soil is formed where very fine sand and silt accumulate near the centre of many of the shallow depressions. These are usually very highly laminated, and include layers of coarse sand. The whole profile may be rich in carbonates, and the lowermost layers actually cemented with calcium carbonate. Typical profiles are given in the appendix (Nos. 2 and 3).

A feature of this soil assemblage is the presence of extensive salares where the water-table lies just below the salar surface; the surface is usually smooth and soft, consisting of damp salt crystals. The nature of the crust on the salares is greatly modified in areas where blowing fine sand and silt are able to accumulate, and many salares show a distinctive pattern of low dunes interspersed in a sea of salt pillars or waves (fig. 5). A profile of a typical salt crusted salar (fig. 6) is given in the appendix (No. 4).

(v) Soil processes

Leaching and weathering are minimal and operate intermittently only at very long intervals. The most regular accession of moisture for soil processes comes with the condensation of dew at night, and from the occasional influx of coastal fog. This permits the operation of only superficial weathering processes which have little influence on soil profile development in areas where the soils are intermittently accumulating, or eroding through the action of wind.

The dominant soil process is one of upward movement of salt from the subterranean saline watertable, but even this has little enough influence in areas with intermittent soil accumulation.

The activities of the drift regime commonly nullify all the other soil processes. The organic regime has little influence: usually it also is minimal in operation, and even where remnants of the original tamarugo forests still exist, the accumulation of leaf litter takes place (fig. 7). Despite suitable temperatures, the arid nature of the soil surface and the salinity of the environment is such that removal by wind is the only factor that prevents the accumulation of great mounds of litter.

(vi) Soil classification

Roberts and Díaz (1959) provisionally included the soils of this region with the "Lithosols and Regosols related to Red Desert soils". Basically, it is an area of solonchaks, but since area within the influences of subterranean groundwater has steadily contracted over the centuries, the present soils may be better regarded as "Dry, Residual Solonchaks", as suggested by Kovda (pers. Comm. 1962). The associate soils are mainly solonchaks, recent alluvial and colluvial soils, and Regosolic or Lithosolic Red Desert soils.

(vii) Agriculture

Primitive agriculture in this region concentrated upon the use of parts of the solonchak areas, employing wide pits (called "canchiones") dug down to within about 50 cm of the level of the watertable. These pits were dug in areas where the soils were predominantly fine sands and silts, and the capillary rise of the water in the soil permitted the growth of maize and other moderately salt-tolerant crops. The inevitable surface accumulation of salts that formed on the soil in these pits was repeatedly removed to permit a longer agricultural life for the pits, but eventually, when salt-accumulation reached impossible proportions, a new series of pits was excavated alongside the old ones and so subsistence crop production was maintained.

Modern agricultural practices are restricted to a few valley bottoms where the river water is not too intensely alkaline to completely prohibit its use for irrigation. Here, mainly in restricted areas where the deeper, less-saline groundwater supplies are tapped by means of bore-holes and pumps, modest vegetable production is possible. The very high evaporation rates prevailing in the region inevitably promote accumulation of salts at the soil surface, and in some parts where the soils have restricted drainage, the land has become saline and even strongly alkaline as a result of irrigation. The high cost of sprinkler equipment, as much as the poor quality of most of the water available, has prevented the development of spray irrigation in the region. The range of crops that can be grown under irrigation is similar to that of the region first described but there is a higher frost risk, and also species sensitive to a steadily building salt concentration in the soil do not thrive well.



Fig. 5 - Accumulation of fine sand and silt may suppress the upgrowth of salt pillars.
Pintados salar, Tarapacá Province.



Fig. 6 - Profile of crusted salitrous desert soil (Pintados series).
Pintados salar, Tarapacá Province.



Fig. 7 - Accumulation of litter under tamarugo plantation forest and soil profile. Pintados salar, Tarapacá Province.

b) Assemblage of saline Lithosols and Regosols, in part with gypsum pans. (Map Unit 2.)

(i) Landscape

The landscape of this area consists typically of coastal hills and old piedmont plains; the latter are, in many places, deeply dissected, with their remnants left as broad but separate, gently undulating plateaus known locally as "pampas". These plateaus are best developed in the far north, in the Department of Arica. Further south, the old peneplain surface is partly buried beneath younger alluvial and colluvial materials, derived mainly from the hills of the coastal ranges.

Included flattish areas, and broad, shallow basins, are usually occupied by salars (fig. 8).

(ii) Climate

With regard to rainfall, this area is as dry as the preceding one, but there is a considerable accession of surface moisture derived from condensation of coastal fog. Regular coastal fog and mist (known locally as "camanchacas") are a special feature of this region and their presence is due to the interposition of the stream of cold air accompanying the northward course of the Humboldt current between the warm, moist air of the South Pacific and the arid landscapes of Northern Chile.

The annual precipitation in the form of rain over the area probably is less than 2 mm, and many decades pass without measurable rainfall; yet the surface soils are moistened regularly by heavy night dews, and, on days with the coastal fog that is slow to disperse, the surface of the soils may remain moist until nearly midday. The depth to which the soil is visibly wetted ranges from a few millimeters to about 2.5 cm. Tests with cobalt chloride made on apparently dry soil showed that the film of moisture on the sand grains penetrates even more deeply - to about 8.5 cm; and it is suspected that there must be a kind of internal dew condensation aided by the actual presence of deliquescent salts in the soil profile. The mean relative humidity of the air is about 60%, but the humidity frequently rises to 100% during the periods of coastal fog.

The mean annual temperature of the area is about 19°C, with mean summer temperatures of slightly over 25°C and mean winter temperatures in the vicinity of 16°C.

(iii) Vegetation

Most of the area is without any plant cover, and permanent vegetation is only to be found on the younger alluvial soils at the bottom of the deeply incised river valleys. On the desert pampa, the only plant to be found is a root-less, semi-succulent, grass-like plant, *Tillandsia* (fig. 9), which grows only where dune sands are actively accumulating and derives its moisture

directly from the "camanchacas". In this region there is no development of ephemeral plants and the soils are apparently devoid of viable plant seeds. Insect burrows are only occasionally seen below stones and salt crusts, and the only animals common in the region are small lizards.

(iv) Soils

The oldest and most stable soils in the region show several unusual profile features. The soil surface often has a poorly developed desert pavement and the surface stones have only a weak development of desert varnish. The larger stones on the soil surface are often hollowed out by weathering (fig. 10). The process starts at the surface in contact with the soil, and ultimately eats its way right through to the upper surface to produce a hollow stone ring. The process must be a very slow one but continuity of the process is made possible by the continual growth of a column of salt crystals into the hollow weathering cavity. This probably ensures that the inner surface of the stone is in contact with a moist surface for the greater part of the time. The salt-filled cavities sometimes remain moist until well into the afternoon, and further condensation of moisture usually occurs on the following night, so that the weathering process on the undersurface of the stones may well be almost a continuous one (Wright and Melendez, in press).

The soils themselves have a surface layer of 1 to 4 mm thickness, composed of sand and loose salt crystals. The latter deliquesce during periods of high atmospheric humidity and recrystallise on drying, to form a thin weak crust which usually splits apart and the individual plates curl up at the edges like pot-sherds. Below this layer, there is a layer of white powdery mirabilite (sodium sulphate) crystals, grading downwards somewhat coarser crystals of tenardite (the less-hydrated form of sodium sulphate), both somewhat mixed with sand grains and sodium chloride crystals. This sodium-sulphate-rich horizon is from 2 to 4 cm in thickness; with increasing depth in the profile, appear magnesium and calcium sulphate crystals, always with an increasing proportion of sodium chloride crystals. At about 10 cm the whole soil material is usually strongly cemented with sodium chloride (see appendix profile 5). In some soils a white "caliche" (calcium sulphate) hard pan is formed (fig. 11). In many soils the sands associated with the upper part of the hard pan are reddish-brown in colour and contain a little clay.

Salares are small but abundant in the area and take many forms. Where the saline groundwater lies far below the surface the salt crust is usually smooth with a weakly developed fissure pattern (fig. 12). Where the return of salt to the surface is stronger, the fissure patterns are closer and more regular (fig. 13), giving a "crab-shell" sculpturing to the salar surface. In salares with more intense salt accumulation, the surface develops



Fig. 8 - Landscape of saline desert region showing development of salars on flattish terrain. Salt crust in foreground is about 1 metre in thickness. 18 miles south of Arica, Province of Tarapacá.



Fig. 9 - *Tillandsia* growing on actively accumulating dune sands of Pampa Chaco, about 50 miles south of Arico, Tarapacá Province.



Fig. 10 - Surface stones of the saline desert region hollowed out by weathering. Pampa Chaca, about 28 miles south of Arica, Tarapacá Province.



Fig. 11 – Soil profile showing gypsum hardpan. Eroded desert surface near Tana, about 106 miles south of Arica, Tarapacá Province.



Fig. 12 - Surface of salar where salt accumulation is weak. Fissure pattern weakly developed and very slight salt accumulation as fresh crystals at lip of fissures. Knife used as scale is 10 inches long. Pampa Chaca, Department of Arica, Province of Tarapacá.

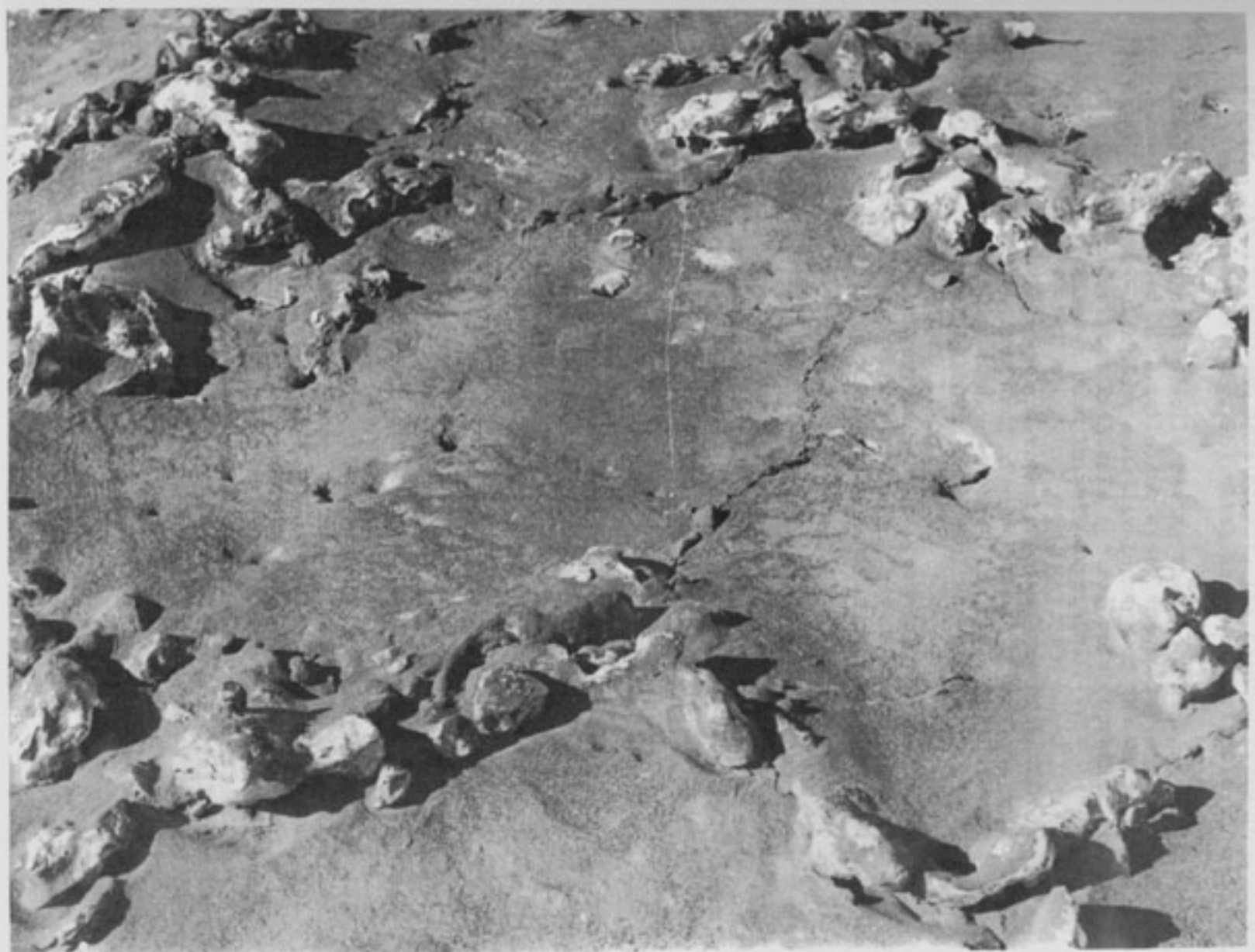


Fig. 13 - Surface of salar where the return of salt to the surface is stronger. Fissure pattern closer and more regular, with strong salt crystal growth along lip of fissure. Pampa Chaca, Department of Arica, Tarapacá Province.

successively an appearance of foaming waves (fig. 14), then a very choppy sea (fig. 15) and finally upgrowths resembling coral appear. At its maximum development, the solar surface is a mass of jagged upgrowths (fig. 16) which are very difficult to traverse.

Associated with stable soils having the above general profile, there are related hill soils and stepland soils (appendix profile No. 6 - all of which show some development of the white mirabilite layer); and associated lithosols and regosols (appendix profiles Nos. 7 and 8) which abound in salt crystals.

In the latter the sand and rock fragments are often firmly cemented by salts, yet they are too young to show the typical segregation of sulphates. Amongst the regosols there are soils of colluvial, alluvial and aeolian origin.

In many places the very resistant gypsum crusts are brought to the surface through wind erosion. They may form a continuous sheet, or may lie on the surface as individual plaques (fig. 17).

(v) Soil processes

Little is known for certain about the soil processes in these unusual soils. It seems certain that the leaching process is inoperative or completely cancelled out by the very strong capillary return of salts to the surface. The only indications of weathering to be found in these soils lies in the reddish-brown discolouration caused by iron-oxide staining on the surface of the sand grains.

The salt impregnation of the soil parent materials appears to be a residual feature associated with the original formation of the piedmont. The uppermost part of this pan is full of crescent-shaped cavities from which the salt has disappeared, possibly by movement upwards.

It seems possible that under the influence of the moisture condensed from the "camanchacas" a film of moisture is periodically formed connecting the salt-impregnated and cemented subsoil materials with the soil surface, and that capillary movement repeatedly "siphons" salt from the underlying materials leaving the cavities aforementioned. The relative mobility of the compounds is reflected in their position of re-accumulation in the soil profile:- the sodium chloride crystals regularly arrive right to the soil surface, where they are mainly blown away like sand after recrystallisation during the heat of the day; whereas the sodium sulphate crystals usually fail to reach the surface and accumulate just below the uppermost soil horizon; and the much less soluble calcium sulphate crystals are left behind, gradually thickening and cementing to form a dense hard pan.

The sodium chloride crystals blown away tend to accumulate in depressions in the landscape, and gradually, with repeated solution and recrystallisation during the "camanchacas", strong sodium chloride crusts are formed in these areas. Thus, blowing salt crystals and not saline groundwater become the main agency in the formation of salars in this region. There is no groundwater within 50-100 cm in these basins, and the thickening of the salt-crusts can only be due to aeolian accumulation. The process of salar formation is an active one. As the crusts thicken, they become cracked and fissured under the diurnal temperature fluctuations and fresh aeolian salt accumulating in these fissures, dissolves and then re-crystallises slowly under the less extreme conditions below the surface to form long needle-like crystals which build up a crenellate edge to the fissures. These upgrowths of salt have a wet deliquescent surface during the "camanchacas" and when the fog passes and sodium chloride crystals again begin to blow across the desert, fresh salt crystals stick on the irregular upgrowths of the upturned edges of the fissures until, with time, a mass of salt pillars (some individual pillars are 30-40 cm high) is formed. In the final stages of the process, even mushroom-shaped and hammerhead-shaped pillars may be found. The rate of growth of the salt pillars seems to be controlled by the local supply of aeolian salt crystals; by the frequency and duration of "camanchacas"; by the direction and force of the prevailing winds; by the amount of loose sand accompanying the salt crystals, and similar factors. In a season when "camanchacas" have been infrequent, the surface of a "salar" may appear dead and lifeless; - a few months later, after several periods of coastal fog, all the pillars may be showing new crystalline growth on one side; or later in the year, may be showing vigorous new crystalline growth in all directions.

Biological soil processes are at a minimum in this region, although the soils are not completely devoid of microbiological life (Dimenna, pers. comm. 1962). The whole soil profile shows no reaction with hydrogen peroxide; nor to hydrochloric acid (except in the case of some surface soils where the weak accumulation of calcareous dust blown from the adjacent sierozem soil region is suspected).

The soil processes associated with the drift regime are not particularly active in this region because the surface soils are continually reforming their thin salty crust. Both fine sand and salt crystals are continually moving over the landscape, but actual erosion by wind is minimal in comparison with the other desert soils in Chile. It is common to find very steep slopes thickly mantled by rock debris and sand, perfectly stabilised by the presence of recrystallised salt; - the wind can apparently only detach the few loose sand grains from the surface layer, and cannot attack the main mass.



Fig. 14 - Micro-relief resembling foaming waves developing on surface of salar with strong salt accumulation. Pampa Chaca, Department of Arica, Province of Tarapacá.



Fig. 15 - Micro-relief resembling a choppy sea developing on surface of salar with very strong salt accumulation.
Pampa Chaca, Department of Arica, Province of Tarapacá.



Fig. 16 - Maximum development of salt pillars near Huará, Tarapacá Province.

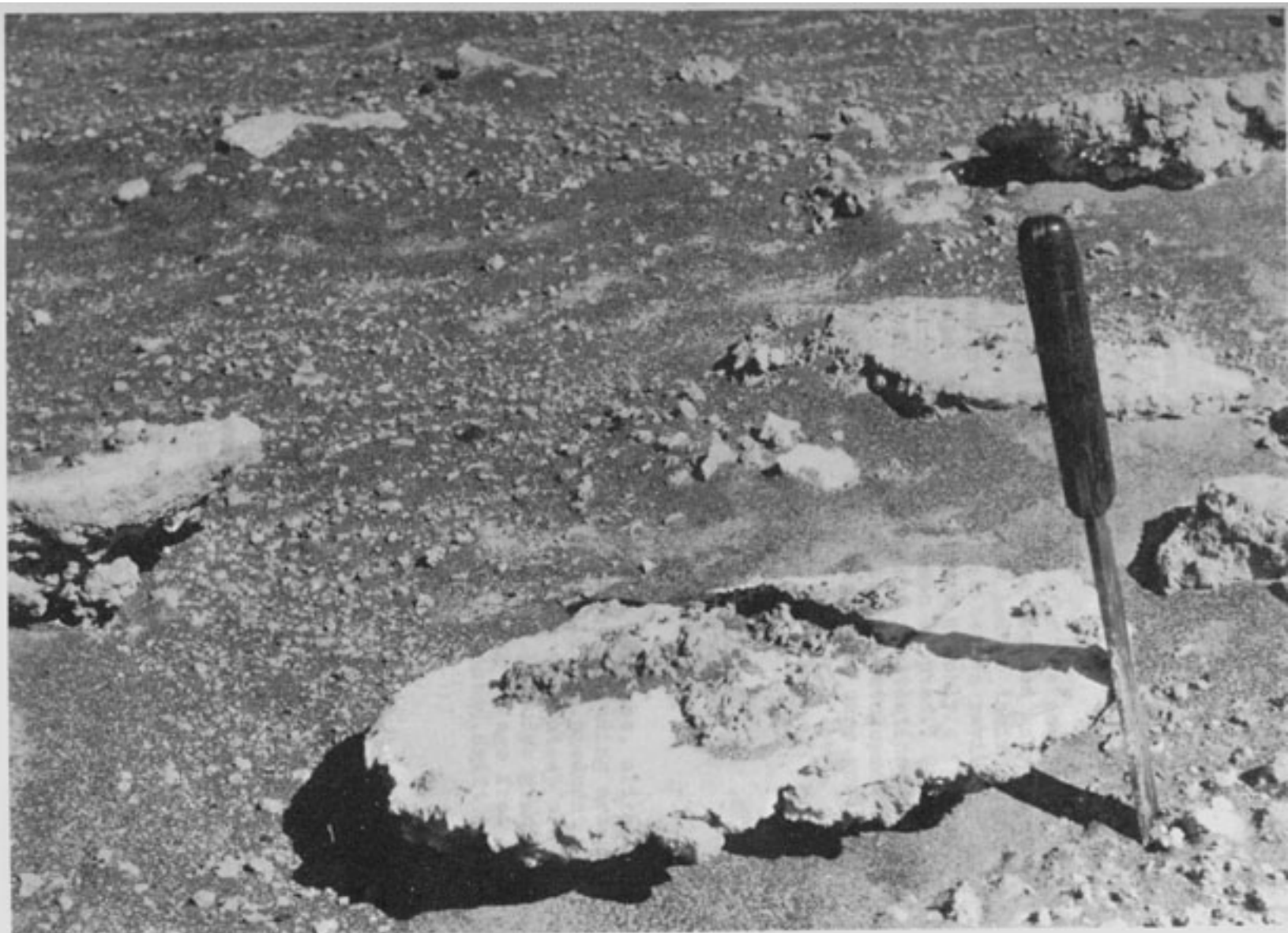


Fig. 17 - Circular plaques of gypsum on eroded desert surface, near Tana, about 106 miles south of Arica, Tarapacá Province.

(vi) Soil classification

The soils of this region have been classified by Roberts and Diaz (ibid) as "Red Desert Soils with Salt Hardpan". Kovda (pers. comm, 1962) considers that they have many features in common with "Dry Residual Solonchak" soils recognised in Russia.

(vii) Agriculture

Primitive and modern agriculture in this region has succeeded only on the better-drained recent alluvial soils of the narrow valley bottoms, which are mainly located in the Department of Arica.

The only permanent indigenous settlements of the part were also located in these valleys, and the Indians devised many ingenious and intricate systems by which water was led to their crops (Diaz, 1959). In recent time, there has been a revival of agriculture in some of these valleys, although in only a few cases have modern border irrigation methods been adopted. In some cases, careless irrigation of the land and inattention to provision of adequate drainage has led to the development of saline and alkali conditions in soils that were once good agricultural land.

2. Region of Alkaline Desert Soils

a) Red desert soils.(Map Unit 3.)

(i) Landscape

The landscape is varied, with flattish terraces, old alluvial fans, and alluvial plains predominating, but including areas of more steeply sloping alluvial cones and colluvial piedmont accumulations; and also hilly land with some very steep slopes (fig. 18). The hilly part of the landscape includes granitic rocks, and indurated sedimentary rocks ranging in age from Paleozoic to Late Cretaceous. The unconsolidated drift mantle consists mainly of ancient alluvial sediments.

(ii) Climate

The mean annual precipitation ranges from about 40 mm in the driest parts to about 100 mm in the wettest parts, with all the rainfall falling as brief showers in the colder months (April to October). The mean temperature of the region is about 15°C, with a mean summer temperature of about 19°C and a mean winter temperature of about 12°C. Up to 2°C of frost may be experienced in mid-winter, and the maximum summer temperatures seldom exceed 28°C. The daily range of fluctuation in temperature is about 15°C.

The mean relative humidity of the air is about 70% and a cloudless sky occurs on 50% of the days.

(iii) Vegetation

A sparse vegetation of low xerophytic shrubs is characteristic of this region. After an unusually showery winter the wide expanse of bare soil between the individual shrubs may be covered by a low carpet of ephemeral herbs, but normally 80-95% of the ground is without vegetative cover (fig. 19). Common shrub species include *Ephedra americana*, *Heliotropium stenophyllum*, *Oxalis gigantea*, *Skytanthus acutus*, *Salbisia peduncularis*, etc., with several species of Cacti.

(iv) Soils

Within this region the oldest, most stable soils with the most distinctive profile development are found on the higher terraces and on some of the older high alluvial plains (see appendix, profile No. 9). Here the desert surface is usually stony, with a patterned desert pavement; in which the exposed upper surface of the stones is brown and polished (but not manganese-coated), and the lower surface often rough and reddish, resting on soil that is pitted and perforated by nesting insects. Topsoils are shallow (5-15 cms), and clearly differentiated from the subsoils, which range from 30-50 cms in thickness and which often merge indistinctly with the underlying parent gravelly alluvium. Topsoils are light brown (with a somewhat reddish hue); subsoils are conspicuously reddish-brown. Calcium carbonate is usually present in small amounts in the topsoil, upper part of subsoil, but becomes very prominent in the lower subsoil, often visible as white filaments. When dry, the topsoils are quite firm and usually have abundant roundish cavities or vesicles which are especially well-developed in the areas of lower rainfall. Topsoil textures range from slightly sticky gravelly sand, to loam; whereas subsoils are much heavier ranging from slightly plastic loam to strongly plastic clay, with often a well-developed blocky or prismatic structure. Weak platy structures are sometimes visible in the topsoils, which are usually slightly hard when dry.

Within this soils assemblage there also occur related hill soils and related steepland soils which have essentially the same profile characteristics, although each horizon is reduced in thickness so that the overall depth of the soil profile may be only 8 to 10 cms (see appendix, profile No. 10), and may, furthermore, be partially buried under loose rock scree. Also included within this region are associated regosolic soils of alluvial, colluvial, or aeolian origin. These have much less developed profiles but which occasionally show some of the regional soil characteristics.

Salt accumulation is not markedly developed in this area, being restricted to local patches of loose, fluffy and slightly puffed soil, usually of a light reddish-brown colour, crumb-structured with clusters of salts-grains between the soil particles and noticeably sticky and plastic when moist. Salt crusts are extremely rare in this zone.

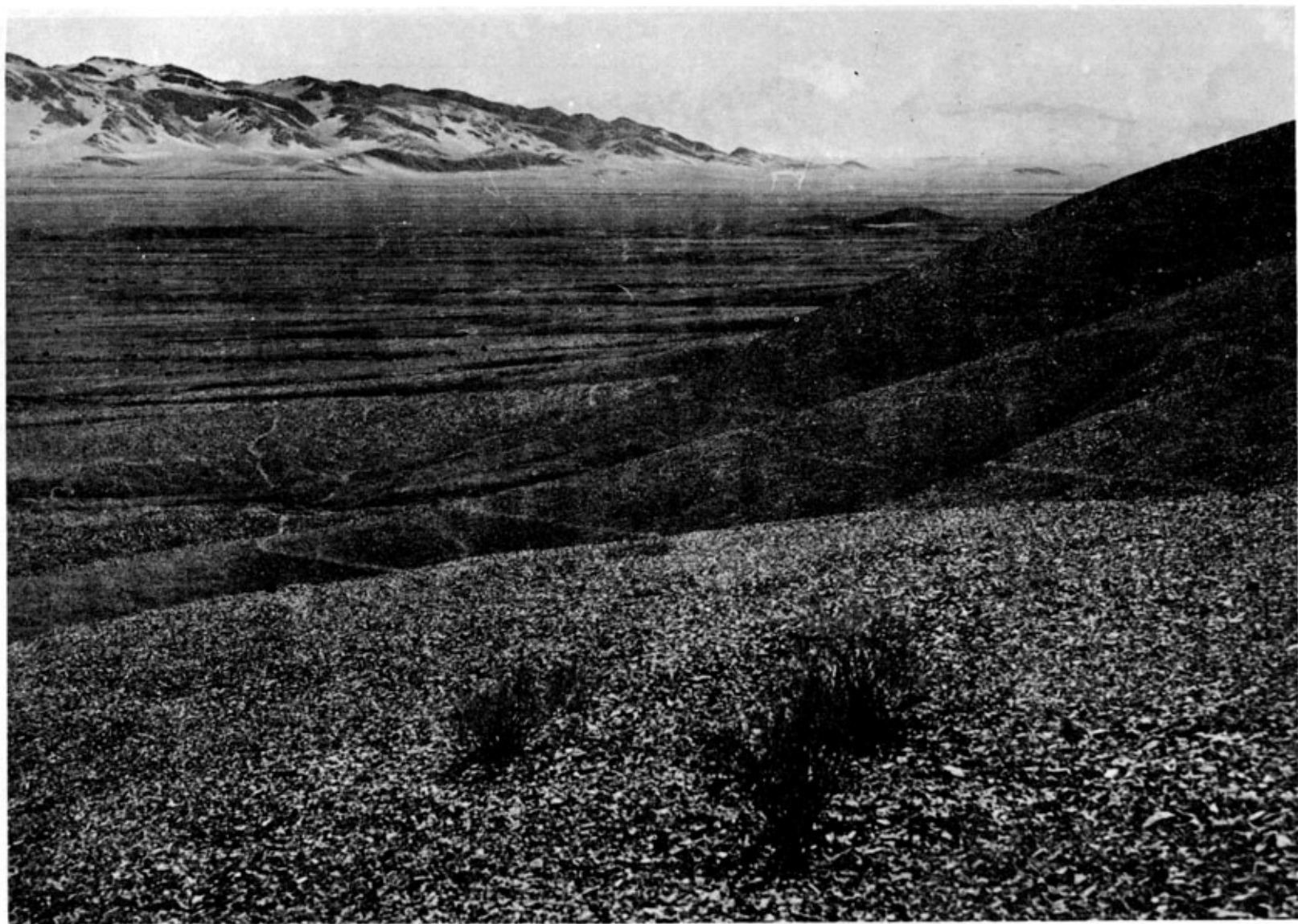


Fig. 18 - Landscape of red desert soil region near Copiapo, Atacama Province.



Fig. 19 - Ephemeral plants that appear after rain. Near Copiapo, Atacama Province.

(v) Soil processes

The desert soils of this part of northern Chile possess a distinctive degree of soil profile development in sites where the soils have been relatively stable over a long period of time.

The most striking feature is the development of the reddish-brown clayey subsoil horizon, fairly sticky and markedly plastic when moistened; and usually possessing a distinctive, regular, coarse blocky or prismatic structure. It is not easy to conceive that this has been formed by simple eluviation of clay produced by weathering of minerals in the shallow topsoil layers, for the degree of leaching in these soils is seldom adequate to wash down all the soluble salts (even carbonates) formed in the topsoil -- much less selectively move the larger clay particles. On the other hand, it is entirely feasible that the clay is produced by the relatively faster weathering "in situ" of minerals present in the subsurface layer of the soil. This is the soil horizon that receives some moisture from the seasonal winter rainfall, yet is not subject to regular and rapid drying out as are the more superficial layers. The surface soil, with its vesicular structure, acts as a barrier to the excessive loss of soil moisture from the layer immediately below and it is in this latter layer that maximum clay development is found. It is also noteworthy that the main development of plant roots occurs in the lower part of the topsoil horizon, immediately above the clayey subsoil horizon, showing that the plants also find the best moisture conditions in this layer.

The weathering process, as a whole, is by no means strong throughout the soil, but appears to be locally active in the horizon where the soil moisture persists longest. Even during the season of the weak winter rains, day-time air temperatures often exceed 25°C and the surface soils become hot and dry between showers while the subsurface layers remain warm and moist.

The soil process responsible for the formation of the bubble-like air vesicles in fine-textured topsoil materials is not fully understood. It may possibly be due to the release of carbon-dioxide gas by the action of rainwater or carbonates formed by the normal weathering of rock mineral particles. There is usually a good correlation between the size and number of vesicles in the upper part of a silty topsoil and the amount of calcium carbonate as indicated by the intensity of effervescence when the soil is treated with hydrochloric acid. Very sandy topsoils and topsoils that lack carbonates usually do not show the vesicular structure.

The intensity of the leaching process is generally sufficient to remove from the upper part of the soil profile most of the chlorides and nitrates and some of the sulphates released by the weathering processes, but is not adequate to move the sulphates of calcium or magnesium, nor the less soluble

carbonates and silica compounds. These tend to accumulate in the subsoil horizons and, in the case of certain parent materials, concretionary layers and hard pans begin to appear.

The upward movement of salts by capillary action is not very pronounced. To a large measure the development and interposition of the horizon rich in clay between the salts contained in the deeper subsoil materials, and the seat of maximum evaporation at the soil surface, creates an effective break in the capillary movement. Weak crusting of the soil surface is sometimes observable in these soils, but this is likely to be due to the formation of very short capillary columns traversing the thin layer of soil material above the clay horizon.

Desert pavements are, as a rule, not strongly developed in these soils, and when present they tend to be partially buried by fine sand and silt lifted by frost action, and by wind-drifted loess. The stones on the desert surface show only moderate development of the desert patina (desert varnish) and the amount of iron and manganese compounds present on the polished surface of the stones is scarcely sufficient to give a reaction with hydrogen peroxide.

The vesicular nature of the topsoil tends to impede the penetration of rainwater and for some hours after a brief rainstorm water may lie on the soil surface.

Processes associated with the organic regime (Taylor and Pohlen, 1962) of the soil likewise leave little trace in the soil morphology. There is sufficient organic matter in the topsoil to permit weak digestion when hydrogen peroxide is applied, but no such digestion occurs with subsoil samples. The main rooting horizon of the perennial shrubs lies in the topsoil but several centimeters below the actual soil surface: very few plant roots occur in the top 3 cm. and only a few of the larger tap roots enter the subsoil. It would appear that the zone 5 to 7 cm. below the actual soil surface provides the most uniform moisture and least extreme temperature conditions for root growth.

Processes associated with the drift regime (Taylor and Pohlen, *ibid*) are comparatively active, including wind erosion and accumulation; in some cases there is mass movement of the surface soil on gentle slopes during heavy rain.

(vi) Soil classification

The hot desert soils of Northern Chile have been correlated with the Red Desert Soils of the United States (Roberts and Diaz, 1962). However, the air temperatures of the Red Desert Soil region of the United States are hotter in summer (mean summer range, 28°C to 30°C) and warmer in winter (mean winter range, 5°C to 12°C); and, whereas the rainfall regime is similar, the mean relative humidity of the air is lower (30% during summer;



Fig. 20 - Landscape of lithosolic and regosolic red desert soils, showing development of "salt eyes" on a colluvial slope. About 50 miles east of Taltal, Antofagasta Province.

45% during winter) in the United States. Similar soils have also been recognised in Argentina (Roberts, pers. comm.) and are shown on the maps of that country (I.N.T.A., 1961).

(vii) Agriculture

Both primitive and modern agricultural operations have always been restricted to areas which can be irrigated. These include some carefully planned modern schemes applied to the older, stable desert soils of the nearly level terraces; but most agricultural operations are still confined to younger soils of the valley bottom lands and to the nearby gently sloping alluvial fans, where simple traditional irrigation systems are easy to apply.

The main crops grown are market garden crops (tomatoes, peppers, melons, string-beans, lettuce, etc.); cereals (wheat, barley corn); forage crops (alfalfa, sudan grass); but some fibre crops (flax cotton) and fruits (papaya, citrus, avocado, chirimoya, grapes) can also be grown in areas with good air drainage where there is less likelihood of frost damage.

Irrigation systems range from primitive free-flooding of the land to modern contour canals. An improvement in yields could be obtained by greater attention to field levelling and the general adoption of controlled border irrigation. In some valley areas, unskilled application of irrigation water is resulting in the formation of saline and alkali soils which are an indication that more attention should be paid to subsurface drainage in these areas.

Weed infestation and insect plagues are additional factors contributing to low production on these soils. The chief fertiliser response is to nitrogen; even better yield responses might be obtained if it was permissible to employ sulphate of ammonia in place of the National product salitre as a source of nitrogen. Results with phosphate are somewhat irregular but leguminous crops, at least, generally show an economic response. Various kinds of guano phosphatic mixtures are commonly in use in the region. Few responses to potash have been recorded in the region.

b) Lithosols and Regosols related to Red Desert Soils. (Map Unit 4.)

(i) Landscape

The landscape associated with these soils consists principally of wide basins of accumulation separated by ranges of hills (fig. 20), and dotted with isolated island hills. The central part of most of the basin areas is occupied by flattish areas of fine-textured alluvial and colluvial materials known as "playas", but in some of these areas the groundwater lies far below the surface. Much of the landscape is youthful but, in the far north, in the Department of Arica, older soils are found on high, stable, remnants of an ancient piedmont plain. For the most part, the landscape is said to resemble the Great Basin of the United States (Roberts, pers. comm.).

(ii) Climate

In this region is found the driest climate of South America, and most areas receive no measurable precipitation in a period of 15-20 years. Rainfall is quite haphazard in distribution, and usually takes the form of a very local, intense thundershower which produces severe erosion and causes tumultuous alluvial fan-building, after which no more rainfall may occur in the particular locality for more than 100 years. Since the air is extremely dry (mean relative humidity probably less than 40%), condensation of dew during the night is comparatively rare, and the soils appear to be entirely dry most of the time.

The mean annual air temperature is probably about 17°C, with a mean difference between summer and winter of only 5°C (mean summer temperature about 20°C and mean winter temperature about 15°C); but with marked daily extremes between day and night temperatures. A night temperature of -3°C may be followed by a day temperature in excess of 30°C. During freezing night temperature, a very small quantity of ice crystals may appear on the desert surface, but the surface soil contains so little moisture that it never becomes properly frozen.

(iii) Vegetation

There is no permanent vegetation over most of this area (fig. 21) and even after a chance rainstorm, the growth of ephemerals is very sparse and restricted to only a very few species.

Many of these shrivel up before they achieve the flowering state. Insects resident in the soil are scarce and are rarely found even below surface stones. There is some permanent vegetation in areas where there is groundwater at from 1 to 2 metres below the surface. This groundwater is moderately to strongly saline, but in these places trees such as Tamarugo (*Prosopis tamarugo*), Algarrobo (*Prosopis chilensis*), Bolivian pepper (*Schinus molle*) and Chañor (*Lycium chañar*) can survive. In other areas, a dense growth of salt grass (*Distichilis spicatus*) may form a dense tall-growing sward. Various species of salt-bush (*Atriplex*) are also found in these areas.

(iv) Soils

By far the largest part of this area is occupied by regosols and lithosols which show virtually no profile development (appendix, profiles No. 11 and 12). Many of the lithosol profiles are buried beneath a thick pavement of tightly packed angular rock fragments (fig. 22).

A greater degree of profile development is apparent in some of the older colluvial fan materials (appendix profile No. 13), in which there is some indication of stratification due to the upward movement of soluble salts. The uppermost layer of sand is weakly cemented with sodium chloride crystals, and with

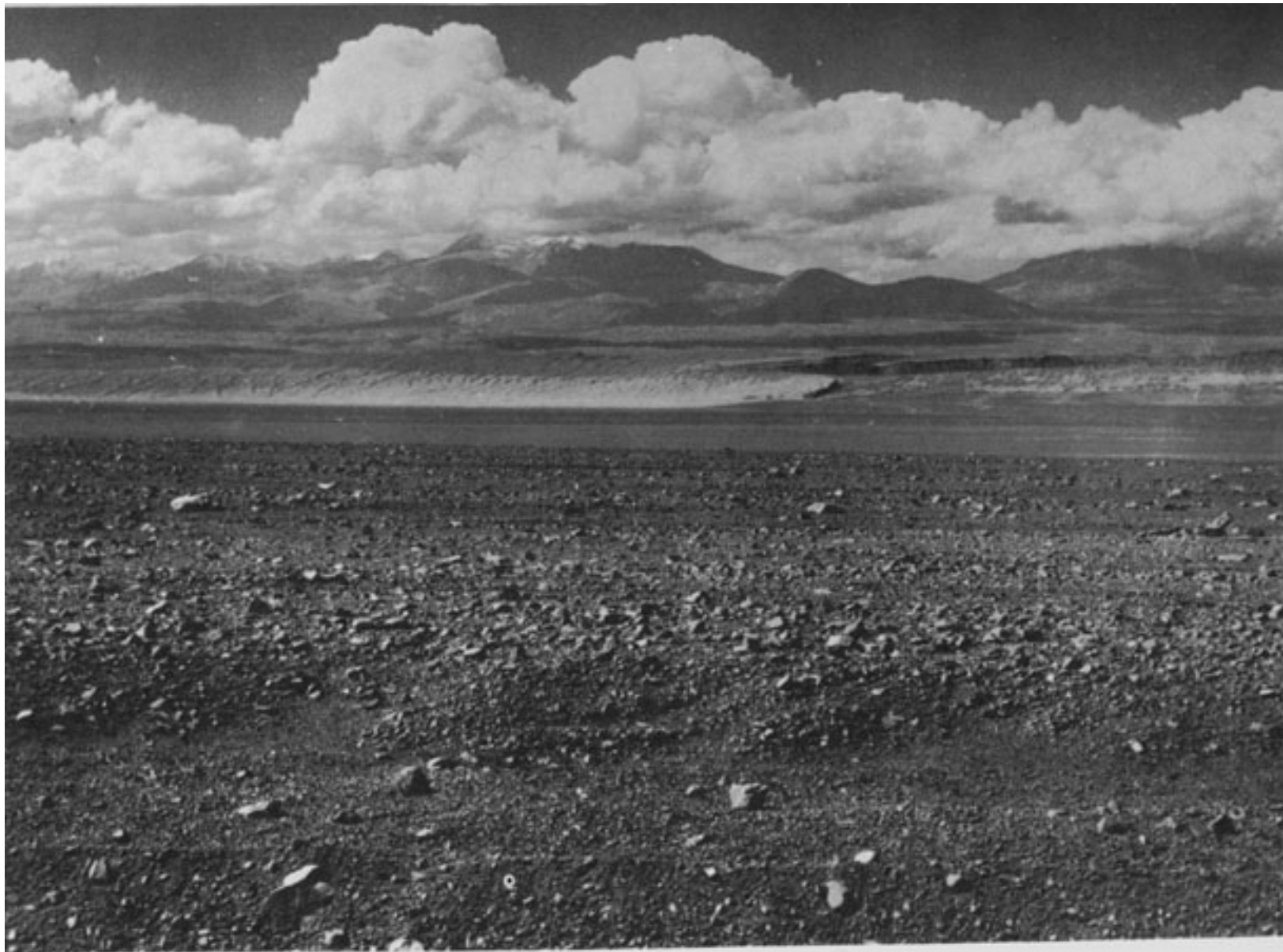


Fig. 21 - Barren desert near Copiapo, Atacama Province, with scattered showers and snow falling on the nearby Andean foothills. Photo taken in July.



Fig. 22 - Mantle of loose rock fragments of the lithosolic red desert soils (see Appendix, soil profile No. 4). Near Llampos, Copiapo, Atacama Province.

increasing depth there is successive appearance of sodium sulphate and magnesium and calcium sulphate crystal accumulations. The deeper substratum is often strongly cemented with a mixture of salts, referred to collectively as "rock-salt".

Two extremes of profiles are known from this area. The oldest and most stable sites in the far north, where any moisture reaching the soil is largely the result of condensation (dew) from the air, show even more strongly the phenomenon of salt stratification (appendix profile No. 14). Many such profiles are transitional to the profiles common in the saline desert region. At the other extreme, in the south of the region, there are profiles that are transitional to the true Red Desert soils of the region first described (appendix profile No. 15; see also fig. 23).

Heavily crusted soils are mainly found in the lowest position on the valley floor or in the vicinity of "playas". These local soils are usually of a very pale grey or yellowish grey colour and may contain more than one salt-impregnated horizon in their profile.

(v) Soil processes

Taking the oldest and most stable of the hot desert soils of this region as a guide to the strength of the soil processes operating, one can only conclude that the extreme lack of soil moisture virtually precludes the operation of consistent weathering or leaching processes, and allows only a minimum of capillary return of salts to the soil surface.

Leaching of soluble salts must occur from time to time when a rare rainstorm passes by, but the soil profiles show no record of this, and it is probable that the brief operation of leaching processes is rapidly cancelled out by the subsequent upward re-distribution of salts during the ensuing capillary movement. Weathering of the finer and more vulnerable rock particles is sufficient only to produce a small release of cations and anions, and the soils are thus not unduly rich in crystalline salts. Carbonates, in particular, are seldom formed in any quantity in these soils.

The regosolic alluvial and colluvial soils of this region however do show more clearly that some leaching and lateral redistribution of soluble salts does occur during the intervals of rain. Usually, at some point towards the toe of an alluvial or colluvial cone there is a zone of salt enrichment, which may give rise to cemented salt crusts within the soil profile. The salt content of the watertable of the low-lying areas likewise derives from this source.

The thin film of iron-oxide that coats the quartz grains and gives a characteristic reddish-brown colour to the 2 to 4 cm. horizon in many of the more stable soils, is a further indication

of the weak operation of weathering processes. Iron and manganese oxides coat thinly the upper surface of the stones forming the desert pavement and give the characteristic desert varnish patina.

The biological pressure in all the soils of this area (except those soils that have a saline watertable) is extremely low, and no digestion occurs when hydrogen peroxide is added. Beneath the tamaruga and pepper forests of the areas with a high watertable, there is often a considerable accumulation of dry leaf and twig litter but there is no indication that this material is being incorporated to any extent into the topsoil, and the rate of litter accumulation is held in check more by the action of wind than by biological agencies.

The drift regime in the majority of the soils of this region is very active; evidence of wind erosion and local sand accumulation (fig.24a) is everywhere to be seen, and erosion by water during a heavy rainstorm can be quite spectacular (fig.24b), cutting deep gulleys in a very brief time.

(vi) Soil classification

Roberts and Díaz (ibid) relate the soil of this region to a group referred to as "Lithosolic and Regosolic Red Desert Soils". The associated soils with groundwater near the surface are generally referred to the Solonchak group. Kovda (pers. comm, 1961) considers that "Dry, residual Solonchaks" are also present.

(vii) Agriculture

Agricultural endeavour is virtually absent throughout this region and attempts at establishing economic forms of farming have never yet been successful in the face of the general scarcity and poor quality of subterranean water supplies, the prevailing high evaporation rates and the degree of activity of the drift regime.

At some future date, if deep bores succeed in tapping subterranean water of good quality, some limited development of agriculture may take place. Until adequate exploration of possible deep subterranean water reserves has been carried out, it would appear that modern man will be no more successful than his primitive forbears in making this part of the Great Chilean desert region habitable.

3. Region of Soils Transitional between True Desert Soils and Semi-Desert Soils

a) Coastal Desert Soils. (Map Unit 5.)

(i) Landscape

The landscape of this area consists mainly of coastal hills, with often sharply cliffed seaward slopes, and a narrow strip of rolling or undulating uplands adjacent to the coastal hills; together with some areas of coastal plain and recently elevated marine terraces. The region is a very long, very narrow strip, seldom more than 3 km. in width.



Fig. 23 - Maximal profile development of region of true desert soils with weak profile development (Region 2).
Near Llampos, Copiapo, Atacama Province.



Fig. 24. a. Drifting loess, forming the landscape of lithosols and regosols, developed on soils. About 60 miles east of Aizu, Fukuoka Province.

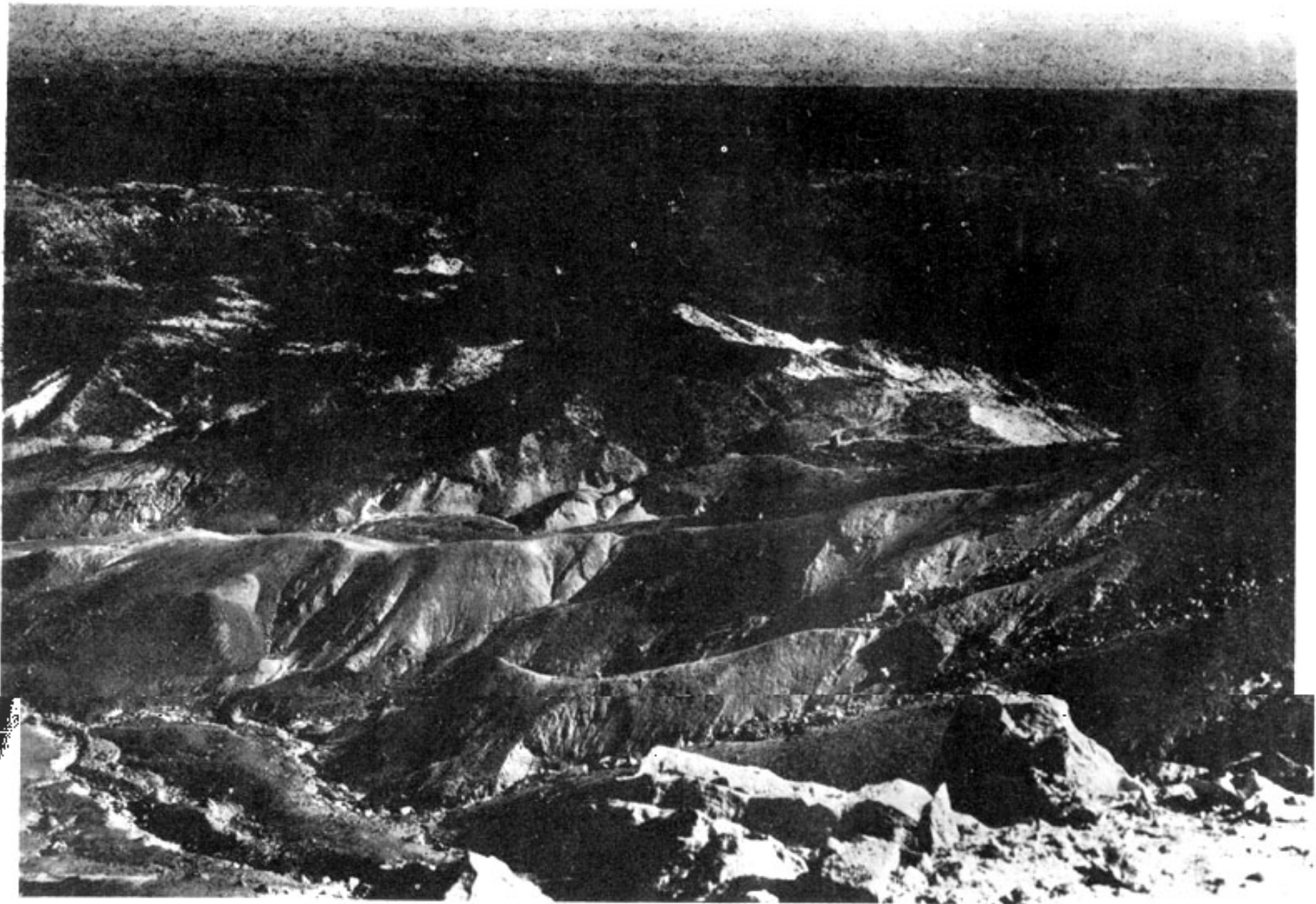


Fig. 24-b - Dissected landscape above the Upper Azapa valley, Tarapacá Province.

(ii) Climate

No precise climatic data is available for this area. In a general way, it probably resembles the climate of the preceding region but with much heavier degree of moisture condensation from the coastal fogs. On many days in the year, much of this coastal strip is shrouded in mist for the whole day, and it is not uncommon to find the soils moist to a depth of 8-10 cm. Additional occasional rainfall also occurs, in the form of a fine, steady drizzle, of several hours duration.

(iii) Vegetation

The plant cover of this area is sparse and consists mainly of cactaceae and xerophytic shrubs of the general Euphorbia, Goldenia, Cristeria, Chenopodium, Tetragonia, Baccharis, Franseria, and Boerhavia. Open ground between the shrubs is commonly covered with lichens. In sheltered niches, small herbaceous perennials and annuals may help to provide an almost complete ground cover.

(iv) Soils

The soil surface is somewhat compacted to a depth of $\frac{1}{2}$ cm. and patterned with a very fine octagonal fissure pattern (fig. 25).

This uppermost horizon is pinkish-grey in colour and notable for the abundance of fine elongated vesicles drawn out between a flaky, laminar structure.

Below this horizon is a reddish-brown vesicular horizon with a fine blocky structure, grading into a light brown powdery and which usually contains a few clusters of gypsum crystals, some sodium chloride.

Below about 15 cm. the soil material is a salt-impregnated cemented, gravelly sand, with some large cavities partially filled with large salt crystals. This grades into greyish cemented sand and gravel at about 25 to 30 cm. (see appendix profile No. 16).

A certain amount of clay is detectable in the uppermost 8 to 10 cm. of most profiles.

An example of a coastal plain soil is given in appendix profile No. 17.

(v) Soil processes

The soils of this area show ample evidence of the active weathering process, but this is restricted to the uppermost part of the soil. There is often sufficient reddish-brown clay present to give textures ranging from sandy loam to sandy loam.

Leaching, on the other hand, is almost inoperative. Abundant fine salt crystals are visible at about 6 cm. below the surface, and the original sodium chloride cementation is usually intact at 15 cm. below the surface.

The upward movement of soluble salts is suspected to be fairly strong in these soils, although nothing like as strong as in the preceding region.

Organic matter is present in the top 4 cm. of these soils but is not abundant. Hydrogen peroxide shows strong digestions in the top 4 cm. and weak digestion between 4 and 6 cm. but below this depth there is no reaction.

Carbonates are present in these soils, especially noticeable in the reddish-brown surface horizon.

The processes of the drift regime are relatively strong. The westerly winds strike along the whole of this coastal region with considerable force and locally the topsoil materials are heaped into small dunes.

(vi) Soil classification

The soils of this region were included with the Red Desert soils with salt hardpan by Roberts and Diaz (ibid).

(vii) Agriculture

No indigenous agriculture has ever been practised on these soils as far as can be ascertained.

At "Areas Verdes" near Antofagasta, opportunity has been taken of a temporary surplus in the city water-supply (which is brought by pipe from springs high in the cordillera, some 150 miles distant) to establish an experimental vegetable-growing station on soils that are in part of recent colluvial origin and partly composed of blown sand from the nearby coast. Here the salt content of the original soils is leached by sprinkler irrigation, and excellent market garden crops are produced in the leached sands when reinforced by organic residues and chemical amendments. A somewhat similar experimental area is proposed for "La Concordia", near Arica city, where the only water available for the project will be obtained from shallow wells and bores.

b) Assemblage dominated by Lithosolic and Regosolic Desertic soils, weakly impregnated with salts and rather highly calcareous; in part with gypsum crusts at or near the surface. (Map Unit 6.)

(i) Landscape

Mainly hilly and steep, with only a thin mantle of weathering rock fragments and with many abrupt rocky slopes. The whole unit comprises the coastal range of this part of Chile and amongst these ranges there are only minor areas of rolling to flattish land and few areas occupied by salares. Alluvial and colluvial debris likewise is somewhat limited in area.



Fig. 25 - Profile of Humboldt fine sandy loam, showing finely-fissured, lichen-encrusted surface. About 2 miles north of Caleta Vitor, Tarapacá Province.

(ii) Climate

In general the climate resembles that experienced by the Red Desert soil area of Region 2, but with some features that are more fully characteristic of the Coastal Desert soil assemblage described above. Sea fogs are more common over the coastal ranges than on the coastal lowlands and on the inland plains; commonly the upper part of the coastal hills are bathed in "camanchaca" humidity from late afternoon to mid-morning, during at least 180 days of the year. When the fog disperses, evaporation rates are likely to be very high. Sea fog moisture rarely condenses visibly in the soils for depths in excess of two centimeters, although it is likely to penetrate much more deeply.

(iii) Vegetation

For the most part the area is without a plant cover, although a very few small lichens do make their appearance on the rocks of some of the higher hills.

(iv) Soils

The soils in this assemblage are predominantly lithosols and are often very shallow. Calcium carbonate rather than soluble salts is the main feature of the soils. The soils give a strong reaction to weak hydrochloric acid from the surface downwards into the fissures of the shattered rock underlying the soil. This reaction is characteristic of all rock types, including the so-called "acid" rocks like rhyolite and granite. Small areas of Regosols (mainly derived from wind-blown very fine sand and silt) occur on the lower slopes and accumulate to considerable depth in the shallow gulleys of the northern drainage patterns. Southern slopes and drainage ways are often swept clean by the wind.

Associated soils in this assemblage include Recent Colluvial soils and a few small areas of Recent Alluvial soils; also a very few patches with salares and dry residual solonchaks. On the tops of some of the higher hills, and along the western flank of this assemblage, there are small areas of soil with characteristics intermediate towards the browner Coastal Desert soils.

(v) Soil processes

The soils of this assemblage show more effective chemical weathering than most of the soils of Regions 1 and 2. Soluble salts appear to be partially leached from the profiles, but the intensity of leaching is not so great that it appreciably affects the distribution of calcium carbonate in the profile. Processes associated with the organic regime are very weak, but those relating to the drift regime are relatively active.

(vi) Soil classification

These soils are regarded as being transitional between the Red Desert soils and the Coastal Desert soils: they are often mapped with the Lithosolic and Regosolic soils related to the Red Desert soils.

(vii) Agriculture

Practically no agricultural endeavour is carried out on these soils (apart from some local gardening around mining centres where water of good quality is available in limited supply), and no large-scale farming operations are ever likely to develop on these soils.

c) Assemblage dominated by Greyish and Brownish "Sierozem-like" Soils of the Cool Upland Desert. (Map Unit 7.)

(i) Landscape

The landscape of this area consists of piedmont plains partly buried under old outwash fans and younger alluvial and colluvial materials; and of ranges of hills along the foot of the Andean cordillera, extending in places up to the very steep slopes of the Andean cordillera itself almost to the very limits of the Andean altiplano. Included within this area are the deeply incised cordilleran valleys, once famous for their terrace garden agriculture, and some very large salares (fig. 26 shows part of the Salar of Atacama).

(ii) Climate

Accurate climatic records are lacking over much of this area. Mean annual rainfall probably lies within the 10-200 mm. range, with rather less than 50% of this falling during the winter months, and the rest received as sporadic summer thunder showers. The relative humidity of the air is probably less than 30% and the potential evaporation is far in excess of the actual precipitation. Soils dampened by rainfall are observed to dry out exceedingly rapidly under the strong drying winds common to the area.

The mean annual temperature of the area is probably in the vicinity of 13°C, with mean summer temperatures above 20°C and mean winter temperature well below 10°C. Frosts may occur at any time of the year and the daily temperature range is commonly in excess of 20°C.

(iii) Vegetation

Throughout this area the plant cover shows a gradual increase from scattered cacti (fig. 27) in the east, ranging westward through open xerophytic scrubland to fairly dense xerophytic shrubland in the higher cordillera foothills (fig. 28). A very common shrub plant is "tola" (*Baccharis tola*). After the rain has fallen over the eastern sector of this region, the ground becomes covered with ephemeral herbs and annual grasses which may endure for as long as two months. In the western (Andean cordillera) sector, the ground beneath the *Baccharis* shrubland has, in most years, a fairly complete cover of grasses and herbs during the months of February and March. In places where groundwater seasonally rises to the surface, shallow peat bogs are developed (fig. 29).



Fig. 26 - The Great Salar of Atacama lies near the boundary between the cool desert soil region and the desertic soils of region 7. View looking west across part of the salar, from the slopes above Toconao (region 7) towards region 6, Antofagasta Province.



Fig. 27 - Typical plant cover of the cool, high plains of the Andean foothill region of desert soils. Scattered cacti and *Baccharis tola* near Mamiña, Tarapacá Province.



Fig. 28 - Fairly dense xerophytic shrubland of the higher cordilleran foothills. About 15 miles east from Ticnamar, Tarapacá Province.

Fig. 29 - Natural vegetation and partial soil profile of shallow peat bog formed where ground-water



Fig. 29 - Natural vegetation and partial soil profile of shallow peat bog formed where groundwater lies near surface. Cool desert region near Aiquina, Antofagasta Province.

(iv) Soils

The soils of the area have some of the characteristics of the desert soils already described; but also some characteristics commonly associated with Sierozem soils and Calcic-Brown soils.

The oldest and most stable soils are those of ancient piedmont remnants; these are most easily seen in the far north, and are usually buried below younger alluvial and colluvial materials further to the south. In these older soils, topsoil colours are pink to pale reddish-brown, and the colour becomes more reddish and yellowish with increasing depth until, at about 30 cm. a very reddish-yellow horizon with calcium carbonate accumulation is reached. A moderate amount of calcium carbonate occurs in the topsoil but strong accumulation is restricted to the lower subsoil. The amount of clay in the whole profile is small but occurs in about equal amounts in both topsoil and subsoil. Topsoils show slightly to moderately developed vesicular structures, but there are no soluble salts in the profile (see appendix, profile 18).

Stable soils showing this kind of profile occupy only a very small percentage of the total area. The commoner soils are the related lithosols (developed on the steeper cordillera slopes, appendix profile No. 19), and hill soils and stepland soils (appendix profile No. 20) that are also obviously related to the stable zonal soil described briefly above. The hill soils and stepland soils are fairly shallow, calcareous, and show the characteristic yellowish to reddish-brown coloured topsoils. There are many alluvial and colluvial fan soils in the area - some almost indistinguishable from the regosolic hot desert soils; others, older and more stable, showing incipient zonal characteristics (fig. 30). Solonchak and "Takyr-like" soils occur in some of the larger basin depressions, often along the margins of the salars.

(v) Soil processes

The weathering processes in this area are operating weakly but more or less equally in both topsoil and subsoil. Soil texture heavier than loams are rare, but even the more sandy soils (apart from the youngest regosols) appear to contain some soil clay. There is, however, no sign of extensive clay eluviation, although leaching is sufficient to remove some of the calcium and carbonates from the topsoil, and to concentrate these substances in the subsoil. There is sufficient leaching to remove the soluble salts from at least the upper 150 cm. of the soil profile, but these salts reappear again towards the toe of many alluvial fans associated with the zonal soils and may form small local salars, or "salt eyes" in the sloping plains.

Processes associated with the organic regime are better developed than in most of the other true desert soils. There is moderate digestion visible in topsoils treated with hydrogen peroxide, and some weak digestion can be obtained even in subsoils.

The drift regime processes are very active. Erosion is locally severe, mainly due to the great intensity of the rainfall during the occasional summer showers. Wind erosion is very active where the natural plant cover is an open one.

(vi) Soil classification

The soils of this area have been referred to the Red Desert soils (Roberts and Diaz, who call them "Minimal Red Desert Soils"); to the Sierozems (V. Kovda, pers. comm., 1962, who refers to them as "Minimal Sierozems"); and to Calcic Brown soils (Roberts, pers. comm. 1959). Many of the associated Regosols are virtually indistinguishable from the Regosolic Red Desert Soils described by Roberts and Diaz (ibid.).

(vii) Agriculture

There are no examples of modern agriculture in the region, but primitive agricultural endeavour is of two kinds:- on the slopes of the Andean mountains pastoral farming is practised; and in the lower foothills slopes of the valleys, irrigated terrace agriculture is carried out (fig. 31).

Pastoral farming involves nomadic flocks of sheep, cattle, llamas and alpacas, ranging freely during the day under the eye of shepherds, but usually being brought back to the vicinity of the village for corralling at night. Terrace agriculture involves the cultivation of alfalfa for fodder, orégano (an aromatic herb used in flavouring soup), potatoes, onions and other vegetables and a certain amount of temperate-climate fruits. The water for irrigation is often brought many tens of kilometers from springs at the head of the valleys, in stone-lined canals constructed by the indigenous populations many centuries ago. (Wright, in press).

d) Assemblage dominated by Lithosols related to Minimal Brown Forest Soils. (Map Unit 8.)

(i) Landscape

These soils are associated with an area that is almost wholly mountainous, with very deeply incised streams and only a very few plateaus, areas of undulating to rolling relief on some of the broader interfluvial ridges. Valley sides are very steep to precipitous and the valley floors are extremely narrow. In a few places, at the heads of some of the larger valleys, terrace garden agriculture is practised at the foot of the mountain slopes (fig. 32).

(ii) Climate

Little exact information is available concerning the climate of this area. The mean annual rainfall is thought to be between 100 mm. and 300 mm., with almost all the rain falling in the months of January, February and March, in the northern part of the region. In this sector a little precipitation falls as snow, usually in June, July or August. In the southern part



Fig. 30 - Soil profile of older alluvial fan soil (Topain Association) with gypsum and carbonate accumulation. About 10 miles east of Lasana, Antofagasta Province.



Fig. 31 - Terrace gardens of Aiquina, Antofagasta Province.

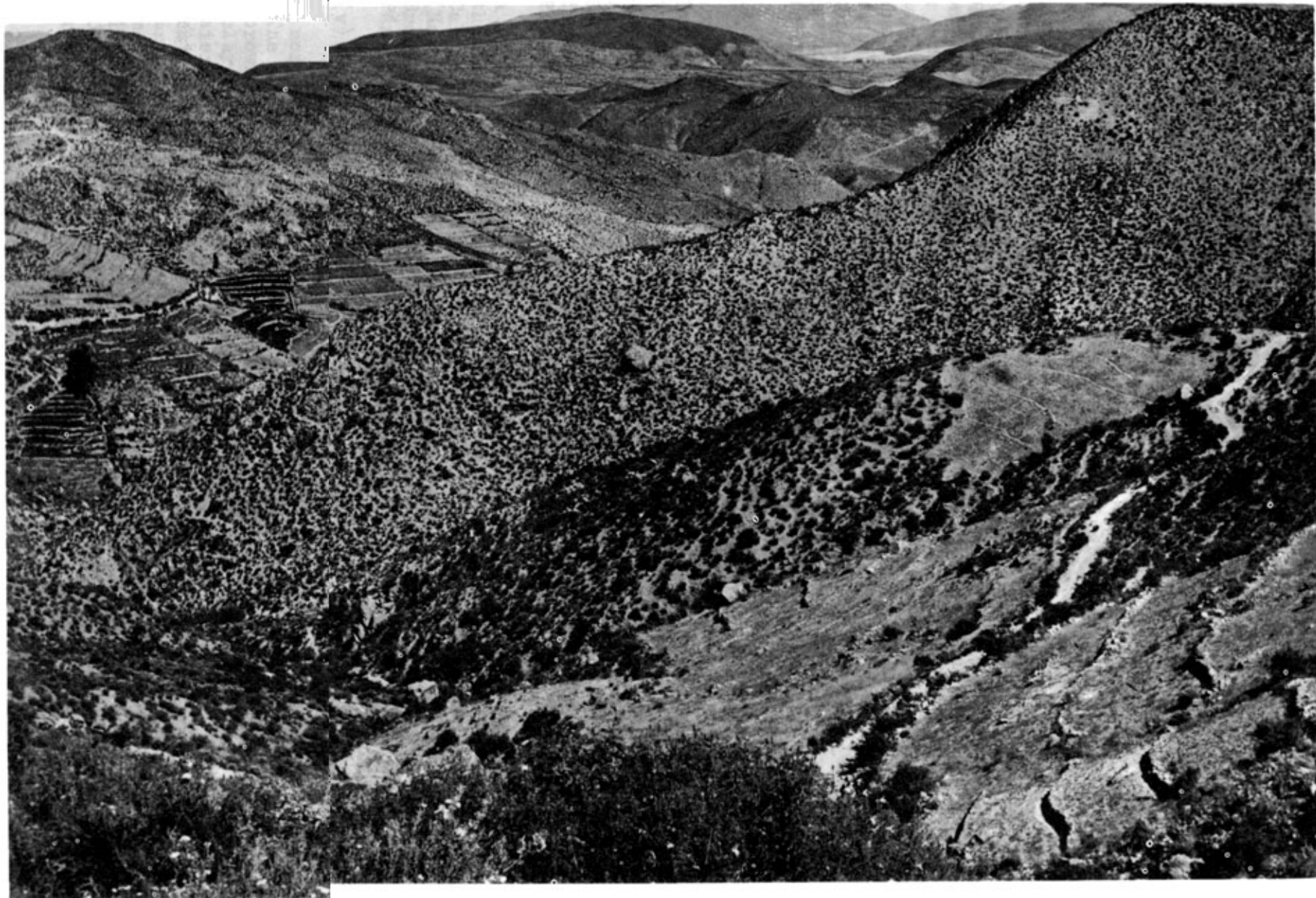


Fig. 32 - Terrace garden agriculture in the high cordillera. The ancient terraces to the right of the photograph have been recently enlarged to permit the easier growing of alfalfa. Near Episcacha (about 10,500 ft.), Tarapacá Province.

of the area, rainfall may be experienced at any time between April and September, often as heavy thunder showers; in addition, over this sector, there is a rather heavier snowfall experienced usually in July and August. The relative humidity during most of the year is expected to be rather low (about 45 to 50%) and evaporation rates are expected to be fairly high. Strong winds are a feature of the region.

(iii) Vegetation

There is considerable diversity of plant cover in this area, probably indicative of a wide range of micro-climates, in addition to the normal changes of climate associated with steeply rising altitude. Over the altitudinal range of this zone (from about 6500 ft. to over 11,000 ft.), the vegetation changes from fairly open scrubland, through closed tall scrubland, to light forest on the shady and less exposed slopes. In the northern sector, a dwarf, wind-shorn forest of quinoa (*Chuquiragua oppositifolia*) may still be found at elevations in excess of 10,000 ft. At these high elevations there is usually some development of tussock grassland (mainly *Stipa ichu*) in the openings between the trees and shrubs, and occasional small plants of *Llaretia* (usually *Laretia compacta*) may be found, although this is more truly a plant of the sub-alpine regions of the altiplano.

(iv) Soils

This area is predominantly one with lithosols and steepland soils (used in the sense as defined by Gibbs, 1962) which, nonetheless, show some relationship to zonal soil groups. The majority of these lithosols and steepland soils show a relationship with minimal Brown Forest soils; although others are more closely related to less developed zonal soils such as Non-Calcic Brown, Calcic Brown soils and Sierozems. The high-elevation Quinoa forest soils of the northern sector have obvious affinities with Páramo soils.

A selection of these profiles is given in the appendix, covering the range from Sierozem-like steepland soils (No. 21); through Calcic Brown steepland soils (No. 22) and related lithosols (No. 23); and Non-Calcic Brown lithosols (No. 24); to Minimal Brown Forest steepland soils (No. 25) and the rather rare Páramo-like hill soils (No. 26).

(v) Soil processes

Throughout the range of soils in this area there is a steady increase in the intensity and depth of soil weathering and leaching. The soils collectively cover the whole range from pale reddish-brown loamy sands to yellowish-brown slightly plastic and sticky clays. The degree of leaching increases steadily from the sierozem-like soils which show no accumulation of soluble salts but have some accumulation of carbonates in the subsoil; to the Brown Forest and Páramo-like soils which have slightly to moderately acid reaction throughout the profile and show incipient iron-oxide coating around the rock fragments of the lower subsoil. Upward movement of soluble salts has not been detected in the region.

A considerable number of the soils are derived from volcanic ash, ranging from coarse pumiceous sand to finely divided andesitic and basaltic ash materials. In no part of the cordillera is there a well-developed, uniform mantle of volcanic ash; the thickest depth of ash (mainly pumiceous) is found on some small intermontane plains of the central sector of the region (far inland from Chañaral). Many of the volcanic ash derived soils are somewhat younger than the general soils of the region, and their profiles are rather less developed; pumiceous soils in particular show some accumulation of silica in the subsoil horizon (appendix profile No. 27).

Processes associated with the soil organic regime have a considerable influence on the development of many profiles: soil insects and earthworms are often present and responsible for considerable soil mixing. Most soils show strong incorporation of humus, and the Páramo-like soils, in particular, are very strongly melanised.

As would be expected in a region of steep slopes, the processes of the drift regime are very active; it is difficult to find a stable soil site for studying the true impact of the environment on soil formation. Most soils are somewhat unstable and eroding.

(vi) Soil classification

For purposes of general classification suitable for the small-scale map, the whole area is best regarded as a transitional zone in which lithosols and steepland soils related to Minimal Brown Forest soils are predominant. Many of these soils are identical with the Weakly Weathered Steepland Yellow Brown Earths of the South Island of New Zealand; also known as Clini-Eldefulvic soils (Pohlen, 1962, Gibbs, 1962).

(vii) Agriculture

Land use in this area is largely limited by the prevalence of very steep slopes. Much of the terrace garden agriculture in the deep valleys has ceased; partly owing to diminishing supplies of spring water but more usually because of the declining population (especially the lack of young and agile farmers) which limits the amount of repair work possible on the terrace walls and irrigation canals. The region is still used for extensive grazing by herded flocks of llamas, alpacas, sheep, with occasional **goats** and some cattle. In the southern sector of the region, these areas of high mountain grazing are used only during the summer months, the flocks being removed to lower elevations before the onset of winter conditions.

Much of the area is suited to re-forestation projects, and such are often badly needed to conserve the landscape and regulate rainfall run-off in watersheds above lowland dam sites, but so much of the region is remote, difficult of access and without roads that the practical management and fire-control of planted forests would be virtually impossible in the present circumstances.

e) Steppe grassland soils of the Andean altiplano. (Map Unit 9.)

(i) Landscape

The landscape of this area includes the wide undulating to rolling steppe of the altiplano proper; the mountain ranges and volcanic peaks rising from the altiplano, and their associated skirt of colluvial and alluvial soils that partly bury the old altiplano surface; local peat bogs formed in the vicinity of emergent spring waters; and salares formed in drainage basins with no efficient egress for the accumulated waters.

(ii) Climate

Mean annual rainfall ranges from about 100 mm. over the southern altiplano to about 350 mm. over the northern altiplano, with much additional precipitation falling as snow. Most of the rain falls in December, January and March and the rest of the year is virtually rainless. The relative humidity of the air is often exceedingly low and very strong desiccating winds are a feature of this region. On many of the mountains, where from 1 to 2 meters of snow may fall in the autumn, much of the snow evaporates directly, forming characteristic snow pillars ("penitentes").

Heavy night frosts may be experienced at any time of the year and a daily range in temperature between -15°C and $+30^{\circ}\text{C}$ (i.e. 45°C) is not uncommon. No continuous temperature records are available for this region, and reliable figures for annual precipitation are likewise scarce.

(iii) Vegetation

The vegetation pattern of the area is simple. The altiplano surface has about a 60% coverage with stipa (stipa ichu) low tussock grassland, and parts are covered with short tola (Baccharis tola) scrub. Stipa grassland extends up the lower slopes of the altiplano mountains to about 15,000 ft., intermingled with very large cushions of Llareta compacta and many sub-alpine herbaceous plants. Above about 16,500 ft. the ground is mainly bare of vegetation.

The bog areas (fig. 33) are mainly composed of cushion-bog species and grasses (Wright, in press).

(iv) Soils

There is considerable variation between the altiplano soils of the drier southern altiplano and the wetter northern altiplano; the variety of soils is also in part due to the presence of volcano ash of various ages and mineralogical composition. In general, the soils have brown to dark brown topsoil colours, sharply demarcated from the pale yellowish-brown subsoils. There is a moderate amount of clay present in the older soils but textures seldom are heavier than light clay loams. Some soils show heavier subsoil textures due to a small amount of clay eluviation. Most soils are non-calcareous in the topsoil but many give reaction with hydrochloric acid in the subsoil. Some soils show subsoil mottling, and even the initial stages of iron accumulation may appear in the lower subsoil.

A large majority of the soils are derived from volcanic ash, usually a fine or coarse pumiceous sand which gives rise to rather uniform soils over wide areas: more local are the soils derived from andesitic ash and basaltic sands. None of these soils are sufficiently weathered to have an appreciable content of allophane, although some of the oldest, buried, layers of andesitic ash are beginning to yield allophane in quantity, and this clay is being washed down and accumulating in fissures of the underlying rhyolitic lava in some localities. In general, however, there is no sharp distinction between the soils derived from volcanic ash and those derived from other parent materials.

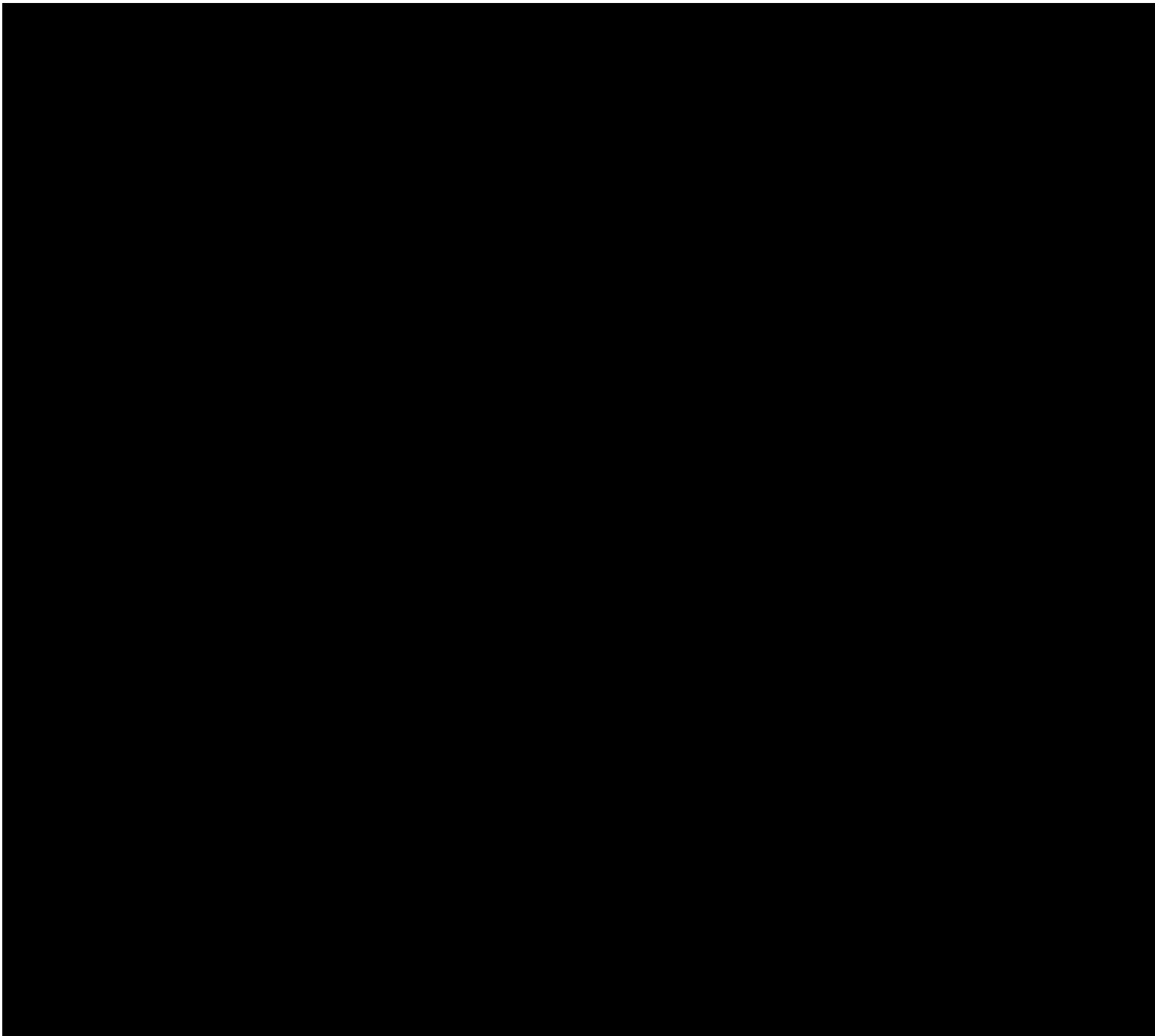
Over the whole altiplano system, there is a very wide range of soil profiles, and only a few of the more typical examples can be given in the appendix. Appendix profile No. 28 illustrates a very common profile of the northernmost altiplano at 13,000 ft., where the rainfall approaches its maximum for the Chilean sector of the altiplano (probably slightly over 350 mm.); profile No. 29 is a related hill soil from the foothills of the ranges rising on the altiplano recorded from an altitude of 14,000 ft; and profile No. 30 is from the sub-alpine zone nearby, at an elevation of 16,000 ft. Profile No. 31 is an example of a soil derived from pumiceous volcanic ash at 14,000 ft. from the same northern sector of the altiplano. A typical profile derived from recent pumiceous ash in the central altiplano sector is given in profile No. 32; and one from coarse andesitic volcanic ash (not so recent) in profile No. 33.

Springs emerging from near the foot of the ranges rising from the altiplano are fairly common on the northernmost altiplano, and in the vicinity of these springs interesting bog soils known locally as "bofedales" are developed - some of which are strongly alkaline peat soils. Two typical bog soil profiles are given in the appendix (profiles Nos. 34 and 35). Lowerlying places in the altiplano landscape are often occupied by salars (fig. 34) and in the vicinity of these salars there are solonchaks and takyr-like soils. Some of the salars are very rich in borax and in carbonates. A few of the streams rising near the foot of volcanic ranges have water rich in sulphuric acid; in the case of the Lluta Valley in the Department of Arica, this acidity persists in the river water right down to the Pacific Ocean. (Melendes and Wright, in press.)

(v) Soil processes

The weathering process is relatively weak in operation in the soils of this area, but the leaching process is more effective than in any of the foregoing areas described. There is no visible upward movement of salts, despite the strong evaporation factor, except in the case of certain peat bogs where the surface of the peat may become encrusted with salt crystals, (Wright, in press). In most of the non-organic soils soluble salts appear to be leached completely from the soil profile.

The processes of the organic regime are active, but under the very cold conditions which prevail for much of the time, the organic residues tend to accumulate in rather raw form - some



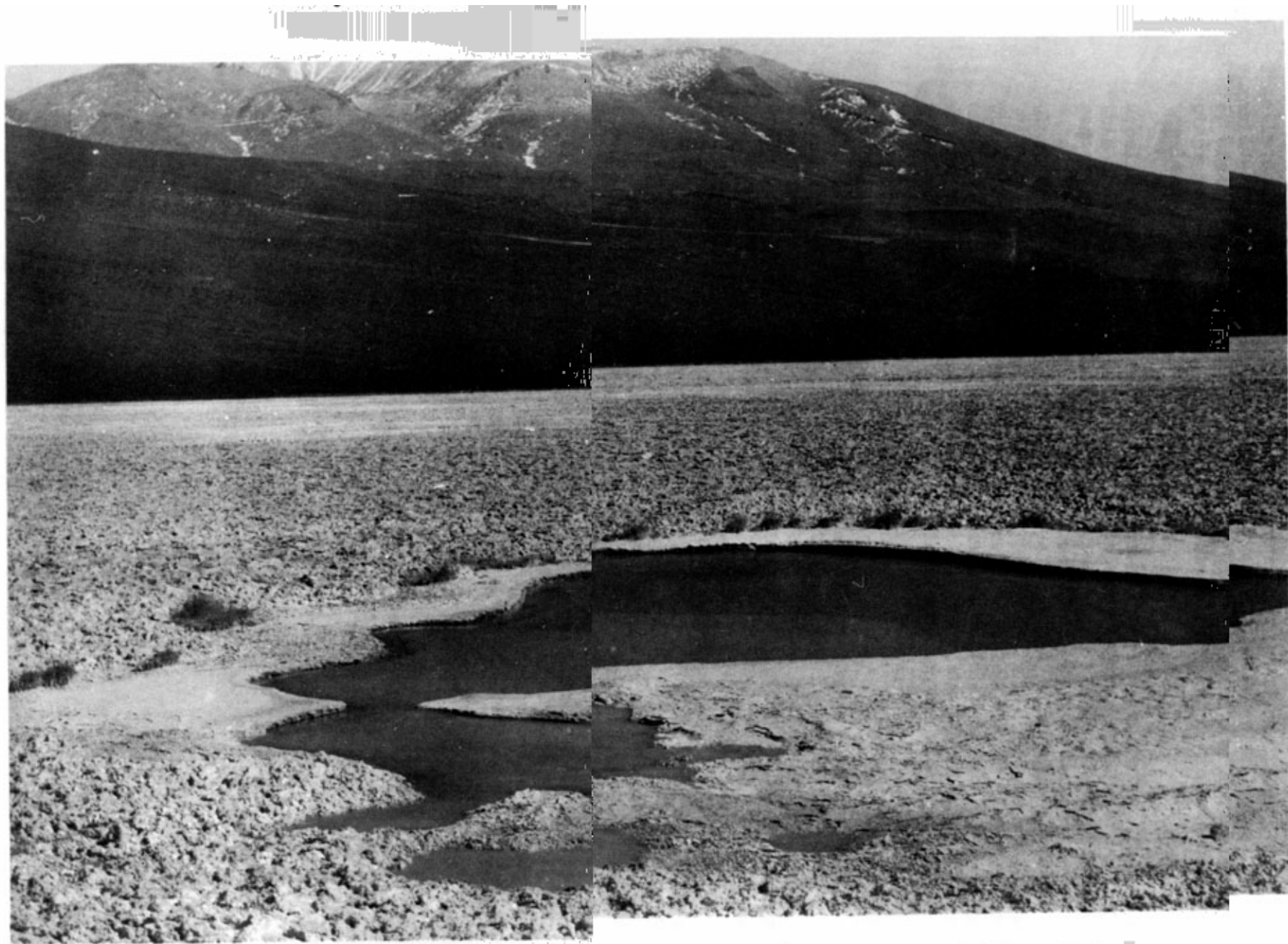


Fig. 34 - Salar Ascotán and Araral volcano, Antofagasta Province, Altitude about 12,000 ft., central sector of Chilean altiplano.

soils show 1 to 3 cm. of a surface accumulation of raw plant residues and beneath llareta cushions there may be up to 15 cm. of undecomposed dead plant remains. This tendency to accumulate plant residues on the soil surface undoubtedly helps to intensify the leaching process.

Locally some soils show the operation of gleying processes, but this is associated more with basin topography than with the general climatic conditions. No areas with permanently frozen subsoils were encountered, but most soils on the northern altiplano commonly freeze to a depth of 4 to 8 cm. on winter nights.

The processes of the drift regime are rather local in action, and seldom intense. Wind erosion has some effect on the younger volcanic ash soils of the southern altiplano, and both wind and water erosion modify the soils of the slopes of the mountain arising on the altiplano.

(vi) Soil classification

It is difficult to assign these soils to one or more of the World Soil Groups without further study. In the main they are weakly weathered, slight-to-moderately leached soils developing under semi-arid, cold (extreme) climatic conditions. It has been suggested that they may equate with the grey desert soils of the United States (Roberts, pers. comm. 1959) or to the Tibetan steppe soils of Asia (V. Kovda, pers. comm. 1962).

(vii) Agriculture

The only agriculture carried on in this area is extensive grazing by nomadic flocks of llamas, alpacas and sheep. During the drier months, grazing is concentrated on the "bofedales" (fig. 35); but after the summer rains, the flocks are dispersed more on the sectors where the showers have been most abundant. At this season, whole families of Aymara Indians may move and camp with their flocks on the better grazing areas.

ENVIRONMENTAL CHARACTERISTICS OF THE SEVEN SEMI-ARID
SOIL ASSEMBLAGES OF THE SEMI-DESERTIC
ENVIRONMENTS OF NORTH-CENTRAL AND CENTRAL CHILE

1. Region of the Calcic Brown Soils of the Transverse Valleys.
(Map Unit 10.)

(i) Landscape

The landscape of this region is characterised by the close approach of the Andean foothills to the actual coast, resulting in the virtual disappearance of the Central Vale and the presence of deeply dissected transverse valleys occupied by relatively small rivers and streams. The mean altitude of the enclosing hills is not greater than 2,500 m. and the slopes sweep down towards the coast and to the valley bottoms which are occupied by terraces, by alluvial and colluvial formations, with youthful soils and many examples of buried soils.

(ii) Climate

From north to south, the mean annual precipitation ranges from 80 mm. to about 140 mm. over the lowlands, and perhaps rises to 250 mm. on the hills. The rains occur during a brief period of four or five months, during the winter, while the remainder of the year is hot and dry. Mean January temperatures range from 17°C to 22°C; and mean July temperatures from 8°C to 11°C. During much of the year, especially from late autumn to early spring, skies are cloudy from late afternoon to late in the morning, and many days in the winter are totally obscured. This cloud takes the form of sea-fog ('camachacas') which flows inland at a height of some 600 m. above sea-level. During the presence of these fogs there is heavy condensation of moisture, important in itself for the individual plants but by no means adequate or equivalent to the irrigation water required in the production of crops. It has been calculated that the condensed moisture may amount to as much as 8 to 15 litres daily in the case of individual plants, fluctuating according to the atmospheric conditions (especially wind) and with the form of the plants (plants with a high degree of branching and numerous small leaves are more efficient condensers of this moisture). In general, the "camachacas" are reckoned to be a factor dampening and reducing loss of moisture by transpiration and evaporation.

Frosts are common inland in the valleys but are seldom experienced in the sectors near the coast. In severe winters, snow falls on the higher hills of the interior valleys but never on the coastal hills or lowlands.

(iii) Vegetation

The vegetation of the hills is predominantly shrubby, but of no great height and showing a marked differentiation in growth according to the aspect (north or south) of the slope. On northern slopes, where there is greater exposure to the sun during the whole year, the vegetation is sparser and of very low height; on southern slopes, on the other hand, with less evaporation and greater exposure to cold winds, there is denser growth of vegetation and also greater development of annual herbaceous plants. The general character of the vegetation is xeromorphic, and cacti are amongst the more abundant species present.

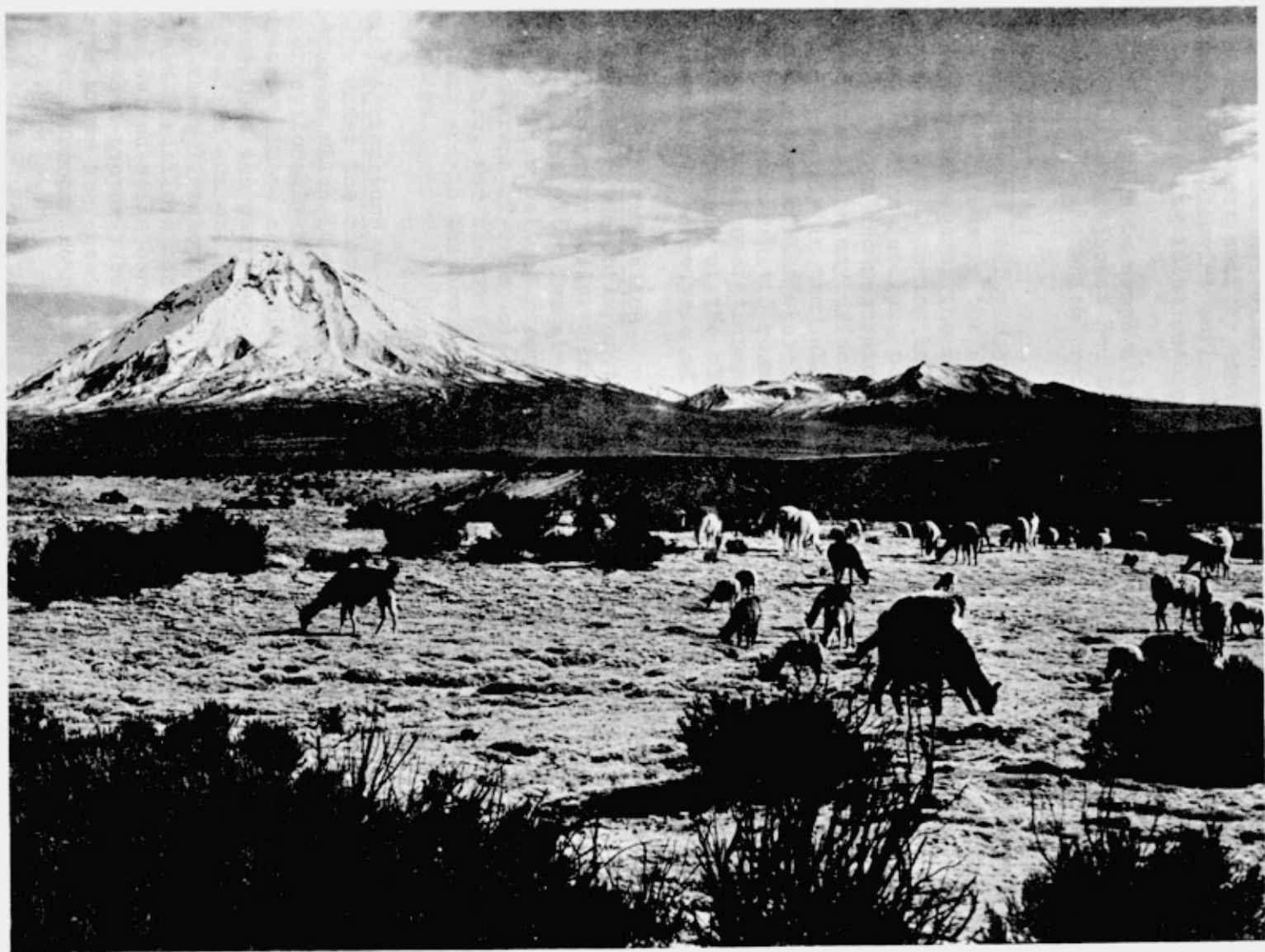


Fig. 35 - Aymara livestock (llamas, alpacas and sheep) concentrated on the "bofedal" near the foot of Tacora volcano during the month of June. Northern sector, Chilean altiplano, Tarapacá Province.

(iv) Soils

In well-drained localities, the commonest soils are Calcic Brown soils, and in more poorly drained sites the soils are mainly Humic Gleys and Calcareous Gleys. Towards the south of this region there are Grumosols and Rendzinas. Where the valleys are narrow, and the streams flow most swiftly, there is considerable development of Recent Alluvial and Colluvial soils, mainly without profile development but in places showing relationship with the zonal soils of the region.

The whole region is comparatively small in extent, and shows intergrade with the adjacent Red Desert soils in the north and the Non-Calcic Brown soils which predominate in the next region to the south.

(v) Soil processes

The dominant soil process of the soils of the plains, terraces and valley bottoms is the accumulation of calcium carbonate. Weathering throughout the region is adequate to release an abundance of cations, yet leaching is only adequate to remove the most mobile of these cations (sodium, potash) completely from the soil profile, whereas calcium and magnesium tend to accumulate in the soil profile. This accumulation may affect the whole soil profile, or may be localised mainly in the subsoil. On hill slopes, the soils over the upper part of the slope may be only weakly calcareous (especially in the case of granitic rocks) but in the soils of the lower slopes a great accumulation of transported calcium carbonate may be found. In the most recent of the alluvial soils in the valley bottom carbonates may be restricted to the latest accumulated materials.

(vi) Soil classification

Formerly the soils of this region were classified as Brown Soils and Calcic Brown Soils. The latter are indeed the dominant soils, but there are extensive areas of related stepland soils, related lithosols, as well as Recent Alluvial and Colluvial soils, and more limited areas of Grumosols and Gley soils. The soils of the hill slopes are, for the most part, severely eroded owing to overgrazing by goats and to the sowing of wheat crops after ploughing by oxen and mules.

(vii) Agriculture

Under the natural dry conditions, the soils support only poor pasturage, which is green and succulent only for a few months after an exceptionally wet winter, and which dries up entirely in a normal summer. These seasonal pastures are used for grazing goats and sheep, but the carrying capacity is severely limited by the shortage of feed in summer. Many farmers have no other alternative but to send their livestock each summer to the natural pastures of the high Andean cordillera meadows - even into Argentina. Under irrigation, the lowland soils can be used for all classes of crops, including some that properly belong to sub-tropical regions. The dominant crops grown are wheat, alfalfa, red pepper and tomato. Amongst the fruit crops grown are apricots, peaches, papayas and chirimoyas.

2. Region of Semi-Arid Soils with Neutral to Slightly Acid Reaction

This region extends from north of Santiago to as far south as Los Angeles, and is bounded on the east by the Andean cordillera, and on the west by the Pacific Ocean. It thus occupies the greater part of the provinces of Central Chile, extending from about latitude 33°20'S to almost 37°30'S, at which latitude the semi-arid soils of Chile merge with the sub-humid and humid soils of the south-central and southern Provinces.

Within this large region, there are four well-defined sub-regions. The first of these consists of a narrow coastal strip occupied mainly by "coastal prairie" soils developed on marine terraces. The second occupies most of the coastal range, hilly and steep land. The third sub-region occupies the lowland depression between the coastal hills and the Andean foothills, popularly known as the Central Vale of Chile. In this sub-region there are three distinct soil assemblages. Finally, there is a sub-region consisting of soils developed on the foothills and higher ranges of the Andean cordillera.

a) Sub-region of "coastal prairie" soils. (Map Unit 11.)

(i) Landscape

The landscape associated with these soils is mainly undulating to rolling, with occasional flattish but gently sloping areas where the old marine terrace surfaces are still undissected.

(ii) Climate

The climate associated with these soils is a type of mediterranean climate, with the main rainfall occurring in winter, and only a small amount of additional moisture received in summer, mainly from light drizzle associated with the advent of heavy sea fogs. The humidity of the air is somewhat higher than occurs in adjacent inland localities.

(iii) Vegetation

The original vegetation was coastal forest over the southern part of this sub-region, and probably dense tall shrubland over the northern part.

(iv) Soils

The soils of this sub-region have not been adequately studied but have been provisionally identified (Roberts and Diaz, *ibid.*) as a kind of "coastal prairie" soil, although not formed under grassland vegetation. The soils show a characteristic deep and dark melanisation usually associated with the "Coastal Prairie" soil group. It is possible that this is also associated with the high salt content (cyclic salt) of the environment.

(v) Soil processes

The soils are mainly neutral in reaction and are probably only very slightly leached. Any loss of soil cations may be partially replaced by wind-blown sodium and potassium from the Pacific Ocean, and the dark colour of the topsoils may be due to reaction between these elements and the forest humus. Weathering is slight-to-moderate.

(vi) Soil classification

As indicated, these soils have not yet been adequately classified.

(vii) Agriculture

Under naturally dry conditions these soils are difficult to farm, possibly owing to mineral unbalance. When irrigated, they are quite good farming soils and support a variety of crops.

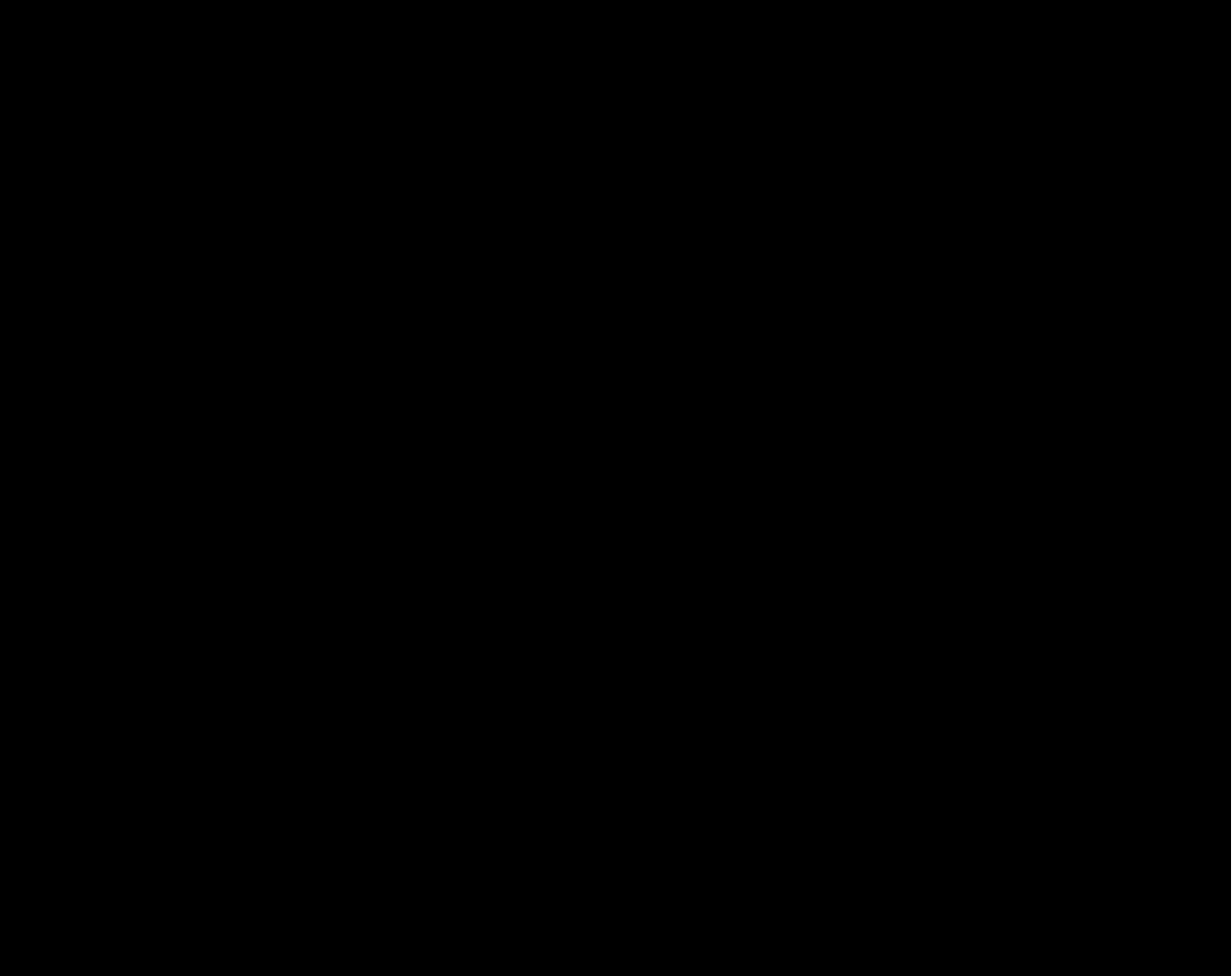
b) Sub-region of the Red-Brown Lateritic soils and the Red-Yellow Podzolic soils of the coastal hills. (Map Unit 12.)

(i) Landscape

This is a sub-region of relatively low hills, of a mean altitude of about 800 m., with a few peaks reaching to 2,000m. A large part of the area consists of strongly rolling landforms, with long gentle slopes. Most of these ranges are cut transversely by the larger rivers flowing from the Andes, but in addition there are many small streams originating in the coastal hills themselves.

(ii) Climate

The climate of this sub-region is diverse, for there is a distinct difference between the rainfall of the coastal side, and that



Much of the original plant cover has been greatly modified by burning, grazing and clearing for agricultural purposes. On the eastern slopes grassy induced vegetation appears after the winter rains amongst the shrubby vegetation, but it matures and dries off by December or January; whereas, on the coastal slopes, the grassy cover persists far longer, and in some areas is replaced by permanent grass species.

(iv) Soils

The main rock type in the coastal ranges as far south as Talca is granitic; further south mica schists become more common. Both kinds of rock give rise to red clay soils with well-developed profiles, in which there is a distinct "B" horizon in the subsoil, recognisable by its texture, structure and colour, placing the soils in either the Red-Brown Lateritic or the Red-Yellow Podzolic group. Both kinds of soil appear to be present, as well as intergrades, and the lack of more precise information is in part due to the low agricultural value of the region, to the difficulty of finding soils that have not been partly destroyed by accelerated erosion, and in part due to the very rapid variation in soil profiles corresponding to the climatic and topographic diversity associated with local micro-climates.

Associated soils on flat land include Grumosols, and towards the south there are soils with more distinct lateritic characteristics, as well as Recent Alluvial and Colluvial soils.

(v) Soil processes

Weathering and leaching are active soil processes, and, where wheat cropping has long been practised, erosion has been very active. Many soils have been severely truncated, and the present soil actually represents a new soil forming in old subsoil materials. On the coastal slopes of the ranges, the presence of wind-blown salt crystals can be demonstrated on the vegetation and it is likely that this compound slightly conditions the leaching processes. Weathering has penetrated deeply in the soils, producing the deep reddish subsoil colours; leaching accounts for the bleached topsoil colours of many soils, and for the eluviation of clay into the subsoil.

(vi) Agriculture

In the main, agriculture is restricted to the lowland plains that are interspersed amongst the hills, and there is some scarcity of water for irrigation. Wheat is still grown on many of the hill slopes but yields are very low in comparison with lowland crops. Maize, as well as orchard crops (citrus, avocado pear, apricots, etc.), and dairy pastures and vineyards are found on the plains; and many vineyards are found on the lower slopes of the hills. The higher slopes are often left in natural forest, or have been recently planted in *Pinus insignis* and species of *Eucalyptus*. On many of the drier eastern slopes, sheep grazing is practised, but the selection of durable pasture and legume species for these dry conditions is still a major problem.

c) Sub-region of Non-Calcic Brown and related transitional soils, and Regosols, of the Central Vale

- Soil assemblage dominated by Non-Calcic Brown soils. (Map Unit 13.)

(i) Landscape

The landscape of this assemblage is best described as an interrupted plain surrounded by hills of a maximum elevation of 600 m. in the north, and 300 m. in the south. Small island hills occur in the centre of the plain, and outliers of the surrounding hills extend in places right across the plain. The micro-topography of the plain is varied, with systems of alluvial terraces flanking the major rivers, and, in some sectors, as in the part north of Santiago, between Batuco and Colina, extensive areas with poor drainage formed by the ponding action of the levees built by the main rivers. In the latter situations saline soils are often produced.

(ii) Climate

In this area semi-desertic climatic conditions gradually give way to a type of mediterranean climate, with all the rainfall concentrated into a period of 4 or 5 winter months, yielding a total of between 300 and 600 mm. per annum. Temperatures are relatively high, in summer usually averaging 27°C to 29°C, and in winter averaging (in July) 8° to 12°C. The absolute maximum temperatures usually reach 34° to 36°C in summer, and the winter absolute minima are about 4° to 6°C. Intense frosts are common in winter. Although mediterranean in general form, the climate has much in common with inter-montane valley climates.

Another important climatic characteristic is the strong fluctuation in temperature between midday and midnight; the diurnal fluctuation often amounts to 20°C.

Usually the atmosphere is dry, with relative humidities quite low except in winter. From spring to autumn the air is clear and dry. Near the larger cities, and especially in the case of Santiago, an artificial atmospheric environment has been created by the accumulation of smoke (smog), whose effect on the biological components of the area has yet to be studied.

(iii) Vegetation

The natural vegetation originally consisted of bushes and small trees, but most of these have disappeared. Some species have been exploited for their bark and for firewood; some, like quillay, for the production of saponin; some, like espino, for the production of charcoal; some, like boldo, for medicinal purposes. In the present day, areas not actually under irrigation for crops are occupied by rough seasonal pastures that carry feed for livestock for only a brief period in the winter and spring.

(iv) Soils

The predominant soils in the assemblage are Non-Calcic Brown soils, characterised by a topsoil some 20 to 40 cm. in depth, neutral in reaction, weakly structured, and usually very hard when dry. The subsoil commences with a more reddish and more acid horizon characterised by a weak blocky structure that is also quite hard when dry. Topsoils characteristically have a very fine vesicular structure.

Grumosols are found in many of the ancient swampy depressions, and often the adjacent hills are formed from calcareous rocks and carry Rendzinas. Towards the south, soils transitional to Red-Brown Lateritic soils appear on the hill slopes and on some of the older terraces. Elsewhere, on the lowlands, the soils are mainly Recent Alluvial soils.

(v) Soil processes

Weathering and leaching are more active than in preceding regions and, in particular, there is considerable movement of silica in these soils which is responsible for the hardening of the soil profile. This hardness appears with the onset of the dry summer conditions, but disappears when the soils are moistened by the winter rains. Weathering reaches far enough into the subsoils to produce the increased reddish colours typical of the mobilisation of iron compounds. Carbonates and other divalent cations are leached to a considerable degree, while more mobile elements are completely leached from the profiles during the winter.

(vi) Agriculture

Under irrigation, the soils of this assemblage are capable of very diverse production. Vineyards are a characteristic feature of agriculture in this zone in situations where irrigation is available. Non-irrigated land is mainly occupied by pastures of low quality and low feeding value, and considerable difficulty is being experienced in finding perennial species of grasses and legumes that can withstand the long summer drought, or annual species that can effectively set seed in the hardened, cement-like topsoil.

- Assemblage of soils transitional between Non-Calcic Brown and Red-Brown Lateritic soils of the Central Vale. (Map Unit 14.)

This area has its maximum development between Talca and Linares and is characterised by the development of better topsoil structures, and subsoil structures intermediate between the Non-Calcic Brown and Red-Brown Lateritic soils. Soil reactions are more acid, especially in the subsoils. General characteristics: the nature, potential and actual management of these soils is very similar to that described for the last assemblage, and the chief difference lies in the climate which has a mean annual precipitation between 600 and 1,000 mm. and temperatures are rather lower. The mean July temperature lies between 8° and 9°C, and the mean January temperature lies between 18° and 22°C. Winter frosts are often very severe. The soils are a mixture of those showing marked semi-aridity owing to physical or other properties, and those showing weak or no semi-arid characteristics from the point of view of farming. In addition, there are areas of Gley soils and of Grumosols formed in the lowest-lying parts of the plain. As would be expected from such a soil pattern, agriculture is highly diversified, but similar in general characteristics to that of the preceding area.

- Assemblage of Regosols and related soils derived from basaltic sand in the Central Vale. (Map Unit 15.)

Although this soil assemblage experiences a comparatively sub-humid climate - moister than that normally associated with semi-arid soil development - nevertheless the soils are so sandy and porous that, taken as a farming unit, the assemblage is certainly within the definition of semi-arid soils.

(i) Landscape

This area is formed by a great alluvial fan spreading out from the Laja valley where it leaves the Andean cordillera and empties over the Central Vale. The extension of the sandy soils clearly shows that they were deposited during an immense inundation, possibly connected with the breaking out of an ancient lake formed at the foot of Antuco volcano, during which catastrophe basaltic volcanic sand swept down over the lowlands filling the basin of the Laja and Bio-bio lowlands and even tipping over into the Itata and other rivers. This deposit has a gently undulating micro-relief, except in places where subsequent wind action heaped the sand into dunes. These continental dunes decrease in size from south to north, but are still eroded by winds in the summer that have the local name of "voladores". In this area there are also terraces with gently inclined slopes.

(ii) Climate

Mean annual rainfall lies between 1,000 mm. and 3,000 mm. Mean January temperatures lie between 18° and 22°C, and mean July temperatures between 8° and 10°C. The dry summer period is shorter than in other parts of region 2, amounting to some 4 months; the annual rainfall being spread over the remaining 8 months, although most of it falls in the months of May to September.

(iii) Vegetation

The natural plant cover of this area is characterised by bushes and low trees, highly xeromorphic in form and of exceedingly slow growth. Between the scattered bushes, various kinds of annual grasses are found, and in general aspect the vegetation has far more in common with the area to the north than to the adjacent region to the south. The plant cover is composed almost entirely of typical xerophytic species, although this characteristic does not include the most xerophytic plants of the more distant north; in this respect, this sub-region forms a most distinct southern boundary to the extension of the semi-arid conditions in northern and central Chile.

(iv) Soils

The soils are little more than stratified sands with little or no profile evolution. The topsoil alone is distinguished from the rest of the profile by its slightly darker grey or brownish grey colour, although the content of organic matter is very low. Occasionally reddish-brown streaks can be seen along root channels in the subsoil, and in places where the sand has a local impervious or slow-draining horizon, sparse mottles may be found in the subsoil.

(v) Soil processes

Weathering and leaching are operative in these youthful soil materials but as yet there is little evidence of their intensity. Only along the root channels of planted Pinus trees, where the effect of soil weathering is reinforced by organic acids, and in local wet places where there is some seasonal accumulation of perched groundwater, can the effects of weathering and the release of iron compounds be seen. In wet places there is some development of an incipient illuvial horizon, and some accumulation of organic matter.

The aridity of these soils is the result of their loose and sandy texture, reinforced by the erosive action of the wind during the dry summer months.

(vi) Soil classification

The soils have been classified as Regosols, although in some areas of minor extent they may possibly be regarded as Lithosols.

(vii) Agriculture

Without irrigation these soils can only maintain a weak vegetative cover. The natural growth of trees is clearly somewhat better where the sand is of finer particle size. Many areas have been planted to Pinus insignis, and growth is sufficiently good to allow hopes of the development of a cellulose industry in the area.

Under irrigation excellent crops of wheat, maize, and excellent pastures can be grown. Apple orchards have also been planted. The main hope for this zone, apart from afforestation, appears to lie in the development of a dairy industry and in breeding race horses. Grapes planted in non-irrigated soils make good vegetative growth but alcohol production is much lower than in other semi-arid areas.

The natural fertility of the soils is derived from the weathering of the basaltic sands, and the chief requirements with regard to fertilizer is the application of adequate dressings of phosphate and nitrogen. Another problem of production in irrigated soils is the high rate of infiltration of irrigation water. Finally, there is the ever-present problem of the control of wind erosion, especially in the dry summer months.

d) Sub-region of Lithosols and Minimal Brown Forest steepland soils, and associated soils of the Andean foothills and ranges. (Map Unit 16.)

(i) Landscape

This sub-region is largely mountainous. The Andean ranges rise to over 6,000 m. in the northern half of this sub-region, declining to about 4,000 m. in the southern half. In the northern half, the mean altitude of the hills is about 4,500 m., deeply dissected by narrow valleys with swift-flowing streams. In the southern half the mean height of the hills is about 2,000 m. and the valleys are wider and the valley sides are less steep. Here the streams are less steeply-inclined in their beds and flow less swiftly. At the

headwaters of these southern streams there are several volcanoes with intermittent activity, and the volcanic products are to be found in the stream and river sediments and also as an ash mantle over the hills themselves.

In front of the Andes proper, there is a piedmont sector, formed of terraces of various age and at different heights above sea-level, on which, in the southern half of this sub-region, there are deep deposits of volcanic material of aeolian origin.

(ii) Climate

Precipitation ranges from about 400 mm. to over 1,000 mm. in the northern half of this sub-region, and much of the winter precipitation is in the form of snow. Temperature ranges are very great, and day-time temperatures of over 25°C are common in summer. Frosts are very intense and may remain in the soil for several months in winter. A feature of this northern sector is the almost complete lack of summer rainfall, or rain falling only in the form of brief but heavy thunder-showers.

By comparison, the precipitation over the southern half is more widely distributed through the year, although long periods without rain in the summer are still frequent. Mean annual temperatures are somewhat lower, and, to compensate for the greater moisture factor in the environment, the soils are frozen for long periods in winter.

Conditions are less severe towards the pre-cordillera sector, but nowhere does an essentially humid environment develop.

(iii) Vegetation

The original vegetation over the northern sector of this sub-region was probably shrubby with patches of forest in sheltered gulleys and in some of the wider river valleys. Forest became more general towards the southern limit of the sub-region, but was probably nowhere dense. At altitudes above about 3,500 m. the forest gave way to natural tussock grassland. Owing to the long summer droughts that often develop over this part of the Andes, much of the original vegetation has been destroyed by fire, and the regenerating vegetation has been further modified by the browsing activities of goats, sheep, etc.

(iv) Soils

The predominant soils in this sub-region are Lithosols and eroded steep-land soils related to Minimal Brown Forest soils. At higher altitudes a kind of Minimal Prairie soil is developed. In the valleys there is strong development of Recent Alluvial and Colluvial soils, and soils developing in erosion talus. In the southern sector, there is some development of weakly weathered Trumao soils, but the ash mantle is usually patchy owing to the absence of a well-developed forest vegetation which is needed before volcanic dust can successfully accumulate on steep slopes. The piedmont terraces of the southern sector are more thickly covered with Trumao soils derived mainly from sub-aerial deposits and from re-deposited aeolian materials ("volcanic loess"). Recent Volcanic Ash soils are found in the vicinity of some of the more recently active volcanoes.

(v) Soil processes

Processes associated with the drift regime (erosion, accumulation, slope movement and mixing, solifluction, etc.) are very active in this sub-region, and as a result the great majority of the soils are of high fertility, but thin and unstable by nature. Weathering and leaching show their effects only in the minute patches of relatively stable soil; for the most part the soils are extremely weakly developed in their profiles. The volcanic ash soils all show very weak weathering and leaching in this sub-region, even those derived largely from rhyolitic pumice.

(vi) Agriculture

Agricultural endeavour is mainly restricted to extensive grazing; and, owing to the virtual disappearance of edible pasture plants during the dry summer months, most farmers move their livestock to the high mountain natural pastures where they remain from December until the onset of the winter snows. The piedmont agriculture in this sub-region also suffers badly from summer drought, and, in addition, the farmers with Trumac soils on their properties have to contend with extremely low phosphate and low nitrogen levels in their soils. Added phosphate is largely made unavailable to plant roots through the "fixing" action of the allophanic clays. The deficiency of nitrogen is associated with the low humus content of the soils.

ENVIRONMENTAL CHARACTERISTICS OF THE TWO SEMI-ARID
SOIL ASSEMBLAGES OF THE PATAGONIAN ARID ZONE

1. Region of Soils Rich in Calcium. (Map Unit 17.)

(i) Landscape

The landscape of this area ranges from flattish to gently rolling with occasional areas more strongly rolling and hilly. This relief is carved mainly in ancient glacial sediments, and is in places mantled with loess-like deposits of partly volcanic origin. Geographically, it forms the western margin of the Patagonian steppe.

(ii) Climate

The climate may be summed up as being equivalent to a cold steppe regime with a mean annual temperature of 6° to 7°C; with mean January temperatures between 11° and 16°C, and mean July temperatures as low as 2°C. Precipitation is of the order of 250 mm. to 300 mm. annually, and up to one-fifth of this may fall as snow in the winter months. Rainfall is highest in the autumn and spring months, but as much as 25% of the total precipitation may fall in the summer months. The relative humidity of the air ranges between 60% and 80%, and shows a decrease towards the east. Strong cold winds are a feature of the region.

(iii) Vegetation

The plant cover consists almost entirely of Gramineae, with only local patches of dwarf shrubs, many of which are xeromorphic in form. The dominant grasses are of tussock form, and are species of *Stipa* (e.g. *Stipa speciosa*) and *Festuca* (e.g. *Festuca palescens*, and *F. gracillina*) mainly. Shrubby plants include species of *Berberis*, *Verbena*, *Senecio*, *Adesmia*, etc.

(iv) Soils

The dominant soils belong to the world soil group known as Chestnut soils, but many profiles show a minimum stage of development. Associated soils include Calcic Brown soils, Solonchaks, and small areas of Half-Bog and Bog soils.

(v) Soil processes

Weathering in these soils is a process having only a weak impact on soil development, whereas leaching is a much stronger process. The effects of leaching are in part nullified by the strong activity of the soil drift regime, and by the high rate of evaporation during the intermittent dry periods, which permits some upward capillary movement of soluble salts. The presence of small areas of Calcic Brown soils in this region indicates the state of the general balance between leaching, weathering and capillary movement. The most active process of the drift regime is the accumulation of fine dust on the lowlands and wind erosion of exposed soil from the higher parts of the landscape.

(vi) Agriculture

The main agricultural endeavour is sheep-raising, based on the exploitation of the natural grasslands.

2. Region of Semi-Arid to Sub-Humid Soils of Neutral Reaction of the Patagonian Desert Margin. (Map Unit 18.)

Immediately to the west of region 12 there is a narrow flanking region of rather similar landscape and vegetative characteristics, but experiencing more humid climatic conditions and possessing distinctly different soils.

In this region the mean annual precipitation rises to over 450 mm. and about one-sixth of this falls as winter snow. Mean annual temperatures are about 7°C, and the mean summer (January) temperatures are about 16°C. Mean winter temperatures are slightly lower than in region 12.

Landscapes are generally similar to those of the preceding region but there is a higher proportion of hilly and very strongly rolling relief, and in places the landscape is strongly dissected by glacial valleys, lined with terraces.

Festuca and *Stipa* form the dominant species of the natural tussock grassland, but in general there was a more prominent development of shrubby and dwarf tree vegetation than in the preceding region. Today, the whole of the natural cover has been greatly modified by grazing and burning and most of these non-graminaceous plants have been eliminated.

The soils are similar to Prairie soils and Planosols, but with minimal development of the profile characteristics of these soils. In Aisén Province there are considerable areas of soil derived from andesitic volcanic ash, but the profiles are but weakly developed, and provisionally they can best be referred to as Brown Volcanic Sands.

The soil processes operating are more distinctly biased in favour of leaching than in the case of Chestnut soils. The organic matter content of the topsoils; the aggregation of both topsoil and subsoil; and the greater proportion of soil clay, all indicate that weathering processes are stronger than in the preceding region. Upward movement of soluble salts is less evident in this region. Additions of volcanic dust have probably contributed some allophane to the composition of these soils, but the amount is probably not significant to affect their agricultural behaviour.

Agriculture is dedicated to sheep-raising, employing both the natural tussock grasslands and improved pastures achieved by the use of selected grass and legume varieties, adequate fertilizing, and careful management.

REFERENCES

1. DIAZ, C. 1959 : "Sistemas de Regadío Empleados en el Norte de Chile" Agricultura Técnica, Años XIX y XX, p. 206-212.
2. DIMENNA, 1963 : pers. comm.
3. GIBBS, H.S., 1962 : "Steepland Soils and their Problems", Proc. International Soil Conf., New Zealand.
4. I.N.T.A. (Inst. Nac. de Tecnología Agropecuaria), 1961 : "Mapa de Asociaciones de Suelos de Argentina", Buenos Aires, Argentina.
5. KOVDA, V., 1962 : pers. comm.
6. POHLEN, I.J., 1962 : "Soil Classification in New Zealand", Proc. International Soil Conf., New Zealand.
7. ROBERTS, R.C., and DIAZ, C., 1959 : "The Great Soil Groups of Chile", Agricultura Técnica, Años XIX y XX, p. 7-37, Santiago, Chile.
8. ROBERTS, R.C., 1958 : pers. comm.
9. TAYLOR, N.H. and POHLEN, I.J., 1962 : "Soil Survey Handbook", Wellington, New Zealand.
10. WRIGHT, A.C.S. and ESPINOZA, J., 1962 : "Environment and Soil Processes in the Chilean Sector of the West Coast of South America", Proc. International Soil Conf., New Zealand.
11. WRIGHT, A.C.S. and MELENDEZ, E., : in press. ("Soils of Department of Arica").
12. WRIGHT, A.C.S., 1963 : "Soil Processes and the Origins of Agriculture in Northern Chile". Pacific Viewpoint, Vol. 4, No. 1.
13. WRIGHT, A.C.S., : in press ("Los Bofedales: Alkaline Peat Bogs of the Chilean Altiplano").

Table 1. Summary of broad soil characteristics of the eight arid zone regions of Northern Chile: Soil data selected from the more developed soil profiles on the most stable land surfaces.

| Region | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|-------------------------------|-----|-----|-----|-----|-----|-----|-----|--------|
| Mean annual rainfall (mm) | 50 | x | x | x | x | 80 | 150 | 250 |
| Mean annual temperature (°C) | 15 | 17 | 18 | 19 | 20 | 15 | 12 | 12 |
| Mean max., warmest month (°C) | 20 | 25 | 25 | 27 | 28 | 22 | 21 | 24 |
| Mean min., coldest month (°C) | 12 | 10 | 10 | 16 | 15 | 9 | 8 | 6 |
| Dew condensation | s | s | + | ++ | +++ | s | - | - |
| Plant cover | s | - | - | - | s | s/+ | + | + |
| Desert pavement | + | ++ | + | s | s | - | - | - |
| Desert varnish | + | ++ | + | s | - | - | - | - |
| Surface salt accumulation | - | ++ | ++ | +++ | s | - | - | - |
| Topsoil colour (Munsell: YR) | 7.5 | 10 | 7.5 | 7.5 | 7.5 | 5 | 10 | 7.5/10 |
| Topsoil vesicles | +++ | + | s | - | ++ | + | - | - |
| Topsoil weathering | s | - | - | s | + | + | ++ | + |
| Topsoil leaching | - | s | - | - | s | + | ++ | + |
| Topsoil salt accumulation | s | ++ | +++ | +++ | s | s | - | - |
| Topsoil crystal segregation | - | + | ++ | +++ | + | - | - | - |
| Topsoil calcareousness | - | - | - | - | - | + | - | - |
| Topsoil organic matter | + | - | - | + | + | ++ | +++ | ++ |
| Subsoil colour (Munsell: YR) | 5 | 7.5 | 10 | 5 | 7.5 | 2.5 | 7.5 | 7.5/10 |
| Subsoil vesicles | s | - | - | - | - | - | - | - |
| Subsoil weathering | ++ | - | - | - | - | + | ++ | s |
| Subsoil leaching | - | - | - | - | - | s | + | + |
| Subsoil clay movement | - | - | - | - | - | - | s | s |
| Subsoil salt accumulation | + | s | - | - | - | s | - | - |
| Subsoil iron accumulation | - | - | - | - | - | - | s | + |
| Subsoil calcareousness | ++ | s | - | - | s | ++ | - | s |
| Subsoil organic matter | s | - | - | - | - | s | ++ | + |

- = none
- x = extremely rare and irregular (in respect of rainfall only)
- s = slight
- + = moderate
- ++ = strong
- +++ = very strong

APPENDIX: DESCRIPTIONS OF SOIL PROFILES REFERRED TO IN THE TEXT

Profile No. 1 - "Salitrous Desert Soil"

Tentative series name - Humberstone crusted sand

Location : Humberstone nitrate plant
Relief : flattish
Elevation : about 1100 m
Vegetation : barren
Climate : most years rainless, perhaps mean annual precipitation
about 15 mm; mean annual temperature about 14°C.

Profile

0 - 1 cm Pinkish grey (7.5 YR 6/2, dry; brown, 7.5 YR 4/2, moist)
firm crust; weakly calcareous and no digestion with
H₂O₂; this crust also coats exposed cuts and road
banks; pH 7.8,
1 - 1.5 cm White (7.5 YR 8/2, dry; pinkish grey, 7.5 YR 6/2, moist)
salt lenses,
1.5 - 60 cm + Light grey (10 YR 6/1, dry; dark grey, 10 YR 4/1, moist)
massive "Caliche" rock-salt containing micro-crystals
of sodium nitrate as well as other salts and fine sand
grains; this layer dissolves very, very slowly in water.

Profile No. 2 - "Recent Soil of Salitrous Desert Region"

Tentative series name - Tamarugal

Long strip of soil developed on Pampa del Tamarugal from Quebrada Tiviliche south to near Pintados. Soils formed of alternate fine and coarse recent alluvial sediments formed where fan system along western flank of andean cordillera are coalescent and overlapping. Formerly occupied by Tamaruga open "forest". Altitude about 1100 - 1200 m. Relief - flattish.

Soil profiles markedly stratified with alternate thin layers of silt and sand:

(surface with thin layer of Tamaruga leaves - pH 7.6)

- 0 - 20 cm Grey (10 YR 5/1, moist) sand, and light grey (10 YR 7/2, moist) silt, in laminations about 1.0 to 2.5 cm thick; friable; silt layers very weakly cemented (frangipan) but sand layers very friable and loose; single grain structure; non-sticky and non-plastic (silt layers very slightly plastic) when moist; boundary distinct; (pH 7.8),
- 20 - 70 cm Grey (10 YR 5/1, moist) laminated loamy coarse sand; friable, single grain structure; non-sticky and non-plastic when moist; boundary merging; (pH 7.8),
- on.. (100 cm +) light grey (10 YR 7/2) to grey (10 YR 5/1) laminated loamy coarse sand; friable, but slight frangipan development in silty layers; non-sticky and non-plastic when moist; boundary not seen; (pH 8.0).

Profile No. 3 - "Recent Soil of Salitrous Desert Region"

Tentative series name - Huara

These soils occur adjacent but slightly downslope to the Tamaruga soils between Zapiga and Pintados - a long narrow strip of predominantly silty soils, with an appreciable amount of clay in fine layers in the subsoil. Probably very few Tamaruga trees ever grew in this soil and the remnants of the natural vegetation suggest that the natural cover was formerly tall xerophytic shrubs and some grasses. Present plant cover is almost non-existent - only a very few scattered bushes and ephemeral herbs. Altitude about 1000-1100 m.

Tentative series - Huara silty clay

(the soil surface has a silt crust which has become curled into individual leaf-like pieces; pH of soil surface, 7.6)

- | | |
|------------|--|
| 0 - 30 cm | Pinkish white to pinkish grey (7.5 YR 8/2 - 7/2 dry) silty clay, friable-to-firm; strong fine laminar structure within this horizon; slightly sticky and moderately-to-strongly plastic when moist; boundary merging (pH 8.0), |
| 30 - 40 cm | Pinkish grey (7.5 YR 7/2, dry) silty clay; firm; very strong fine laminar structure; slightly sticky but strongly plastic when moist; boundary diffuse, (pH 8.0), |
| on.. | Similar material but very firm when dry (almost cemented); slight root mottling visible; weak digestion with H ₂ O ₂ , (pH 7.8). |

Profile No. 4 - "Crusted Salitrous Desert Soil"

Tentative series name - Pintados

These are salt crusts rather than soil and occur on both sides of the Pan-American highway between the Iquique junction and Pintados, and at many other points in Tarapaca Province. Altitude range about 950-1050 metres; and generally flat but with very irregular micro-relief, no natural vegetation, but a few algarrobo trees have become established on these soils.

Profile

- 0 - 2 cm Surface layer of white crystals impregnating a dark reddish brown fine sand and silt; colour 2.5 YR 3/2, moist (weak red, 2.5 YR 5/2, dry); weakly cemented crust that curls upwards around very irregular polygonal fissure pattern; non-calcareous; (pH 8.4); boundary sharp,
- 2 - 35 cm Dark reddish brown (2.5 YR 3/4) moist; (red brown 2.5 YR 5/4, dry) predominantly coarse sand but with fine layers of silt and clay; firm-to-friable; laminar structure; sandy part loose and with a single grain structure, clay and silt layers slightly cemented; white spots of soft CaCO₃ (effervescence with HCl) in lower part of horizon; non-sticky and slightly plastic when moist; boundary distinct; (pH 8.2),
- 35 - 56 cm Dark reddish brown (2.5 YR 3/4, moist; red-brown, 5 YR 5/3, dry) heavy silt loam to silty clay loam; firm-to-friable; weakly developed laminar structure which breaks under pressure to granules and single grains; very slightly sticky, moderate-to-strongly plastic when moist; calcareous; boundary diffuse (pH 8.2),
- 56 - 90 cm Red brown (5 YR 4/3, moist; red brown, 5 YR 5/3, dry) silty clay; firm; massive structure breaking to fine blocks, granules and crumbs; slightly sticky and strongly plastic when moist; CaCO₃ occurs in diffuse, pale-coloured patches; boundary distinct; (pH 8.2),
- 90 - 140 cm Red brown (5 YR 4/3, moist; light red brown, 5 YR 6/3, dry) very fine sandy clay; very firm; strongly developed coarse blocky structure, almost prismatic - breaking to fine blocks and coarse granules; repeated layers of faintly yellowish, needle-like crystals in lower part of horizon (about 7 layers, 2 to 5 cm in thickness in places); moderately sticky and strongly plastic when moist; boundary merging (pH 8.4) crystal layers, pH 7.8,

(profile No. 4 - continued)

on.. Red-brown (5 YR 4/3, moist; light reddish brown, 5 YR 6/3, dry) silty clay; very firm; massive structure breaking with difficulty to large blocks and coarse granules; slightly sticky and very strongly plastic; boundary not seen; (pH 8.4).

Profile No. 5 - "Medial Saline Desert Soil"

Tentative series name - Chiza sand

Locality: Near junction of Ticnamar Rd. with Pan-American Highway - about 20 km south of Arica; altitude 1250 m; no natural vegetation.

The most characteristic feature of the soil is the ease with which a superficial crust of salt crystallises and cements together the sand grains of the soil surface. This is a feature which warrants further study to determine the exact mechanism, but it seems logical to suppose that salt in the soil which has deliquesced under the influence of the "camanchacas", subsequently recrystallises in the surface sand. Normally the crust is only 0.25 mm to 1 cm thick, and under certain conditions appears to partially break down, leaving curved flakes like shrivelled leaves on the desert surface. A typical profile of the soil in this region is given below:

Horizon thickness

| | |
|----------|---|
| 0. 25 cm | Brown sand, cemented by salt but partly broken into small flakes, |
| 0. 5 cm | Stratified brown and fine sand, |
| 10 cm | Soft white powdery material resembling mirabillite, like chalk but crystalline; no reactions with HCl, but dissolves readily in water; contains hard irregular lumps but no visible sign of organic structures; also this horizon includes small pockets of strong brown and reddish-yellow sand (7.5 YR 7/4, 7.5 YR 5/6) which give weak effervescence with H ₂ O ₂ ; boundary sharp but very irregular, |
| 3.5 cm | Salt-cemented greyish brown sand with soft pockets of whitish powder; pH 8.1; boundary sharp but irregular, |
| 4.0 cm | Alternating layers of cemented sand and loose brown sand, |
| 2.5 cm | Reddish-brown sand; loose; slight effervescence with H ₂ O ₂ ; pH 7.9; boundary distinct, |
| 1.5 cm | White powder with pockets of pale brown sand to loamy coarse sand, |
| 2.0 cm | Cemented greyish brown sand with smooth upper surface and honeycomb lower surface; fine salt "stalactites" hanging from lower side of crust; pH 8.0; boundary sharp and irregular, |
| 1.0 cm | Pink (5 YR 7/3) sand with loose salt crystals, |
| 1.5 cm | Greyish brown cemented sand, |

(profile No. 5 - continued)

0.5 cm

Loose pale brown sand,

on..

Pinkish-grey (5 YR 6/2) very strongly cemented sand showing concentric pattern of salt crystallisation; it proved impossible to penetrate this horizon, possibly explosives would be necessary.

Profile No. 6 - "Saline Desert Hill Soil"

Tentative name - Camaraca hill soils, gravelly and stony sands

Location : 5 km north-east from Caleta Vitor
Altitude : 780 metres
Relief : moderately steep rocky slope; slope at site 22°
Parent material : Jurassic sedimentary rock ("greywacke")
Plant cover : bare ground with occasional lichens or larger rocks.

Profile

- 0 - 1 mm Pale brownish grey (10 YR 6/2) dry, or brown (7.5 YR 4/2) moist, slightly loamy sand with fine gravel; weakly cemented to form a surface crust; friable; non-sticky, very slightly plastic when moist; laminar structure breaking readily to very fine granules and single grains; pH 7.9; non-calcareous; very slight reaction to hydrogen peroxide; boundary distinct,
- 1 mm - 2.4 cm Brown (7.5 YR 5/4) dry, or brown to reddish-brown (5 YR - 7.5 YR 4/4) moist, very gravelly loamy sand mixed with non-plastic; loose single grain structure; pH 7.7; non-calcareous; no reaction to hydrogen peroxide; boundary abrupt but most irregular,
- 2.4 - 6 cm Pinkish-white (7.5 YR 8/2) dry, or pale brown (7.5 YR 6/4) moist, very stony sand mixed with a large amount of sodium sulphate in fine crystalline form; non-sticky, non-plastic; powdery single grain structure; pH 7.8; no reaction to hydrogen peroxide; non-calcareous; boundary merging,
- on.. Loose angular rock fragments grading into shattered rock in situ with loose salt crystals and with salt cementation below 25 cm.

Profile No. 7 - "Lithosolic Saline Desert Soil"

Tentative name - Junin steep lithosols; stony coarse sands

Location : 4 km north-east of Camaraca peak, 18 km SE of Arica city
Altitude : 850 metres
Relief : steep slope of about 38°, site near top of slope
Parent material : granite
Plant cover : bare ground with various kinds of lichen on the larger rocks.

Profile

(surface covered with small slabs of granite, the finer chips tending to form vertical striations up and down the slope)

- 0 - 1 mm Pale reddish-brown (5 YR 6/3) dry, or dark reddish-grey (5 YR 4/2) moist, coarse sand; weakly cemented with salt; non-sticky, non-plastic; breaks readily to single grains; pH 7.5; non-calcareous; no reaction to hydrogen peroxide; boundary abrupt,
- 1 mm - 2 cm Pink (5 YR 7/3) dry, or reddish-brown (5 YR 5/4) moist, loamy coarse sand, mixed with irregular patches of pinkish-white (5 YR 8/2) dry, or pinkish-grey (5 YR 6/2) moist, fine sulphate crystals; powdery and loose; non-sticky and non-plastic; single grain structure; pH 7.8; non-calcareous; no reaction to hydrogen peroxide; boundary indistinct,
- 2 cm - 15 cm Sharp shattered rock fragments, apparently shattered in place from parent rock; fissures filled with salt crystals; not cemented; pH 7.9; non-calcareous; no reaction to hydrogen peroxide; boundary indistinct,
- on.. Shattered rock with fragments cemented together with salt crystals.

Profile No. 8 - "Regosolic Saline Desert Soil" - 1000 1000

Tentative name - Lobos gravelly sand

Location : 7 km north-east from Caleta Vitor
Altitude : 650 metres
Relief : broad, gently sloping alluvial-colluvial fan;
slope at site 4°
Parent materials: mainly alluvial materials derived from Jurassic
sediments
Plant cover : completely bare ground

Profile

0 - 1.5 cm Light brown (7.5 YR 6/4) dry, or brown grading to strong
brown (7.5 YR 5/4 - 5/6) moist, sand with very fine dark
grey gravel; loose, apart from a very slight salt
cementation in the uppermost 1 mm; non-sticky and non-
plastic; single grain structure; pH 7.9; very slightly
calcareous; no reaction to hydrogen peroxide; boundary
distinct,

1.5 - 7 cm Pink (7.5 YR 8/4) dry, or pinkish-grey (7.5 YR 6/2)
moist, sand mixed with very fine sulphate crystals;
very weakly cemented; non-sticky and non-plastic; single
grain structure; pH 7.8; no reaction to hydrogen
peroxide; boundary diffuse,

7 - 12 cm Pink (7.5 YR 7/4) dry, or light brown (7.5 YR 6/4)
moist, gravelly sand; weakly to moderately cemented by
salt; non-sticky and non-plastic; single grain structure;
pH 8.0; no reaction to hydrogen peroxide; boundary
indistinct,

on.. Sand and gravel with abundant salt crystals but not
cemented; loose.

Profile No. 9 - "Red Desert Soil"

Tentative series name - Victoria sandy loam

Location : 3 km south of Vallenar, Province of Atacama
Elevation : about 450 m
Relief : nearly level, old terrace surface
Vegetation : cacti, small xerophytic shrubs, and some ephemeral plants
Parent materials: gravelly sands, probably of alluvial origin
Climate : about 70 mm annual rainfall; mean annual temperature 15.3°C

Profile

0 - 10 cm Brown (7.5 YR 4/4; dark brown, 7.5 YR 4/4 moist); slightly sticky sandy loam that has a tendency to be weak, fine platy, but breaks to weak fine subangular blocky structure; slightly hard when dry, friable when moist; moderate digestion with H₂O₂, but very few roots; noncalcareous, but pH 8.2,

10 - 17 cm Reddish-brown (5 YR 5/4; dark reddish-brown, 5 YR 3/4, moist; moderate medium platy, moderately plastic, moderately sticky loam; with pink or greyish specks (7.5 YR 7/4); very weak digestion with H₂O₂, but many roots; noncalcareous but pH 8.0,

17 - 30 cm Reddish-brown (5 YR 4/4; dark reddish-brown, 5 YR 3/4, moist); weak medium prismatic, that readily breaks to weak very fine subangular blocky light clay loam to light sandy clay loam, which is moderately sticky and moderately plastic; slightly hard when dry, friable when moist; pH 8.2, and no digestion with H₂O₂; a few roots present,

30 - 80 cm Reddish-brown (5 YR 5/4; reddish-brown, 5 YR 4/4, moist); moderate fine subangular blocky gravelly loam which is slightly sticky and slightly plastic; soft and friable; highly calcareous; pH 8.2; some effervescence with H₂O₂,

80 cm Similar to layer above but much less lime, and coarser texture, pH 8.0.

Profile No. 10 - "Red Desert Hill Soil"

Tentative series name - Tataro hill soils

Location : 20 km north of Vallenar, Atacama Province
Elevation : about 550 m
Relief : hilly, 20% slope
Vegetation : a few ephemeral plants, and occasional cacti
Parent materials: basic indurated sediments
Climate : about 60 mm annual rainfall; mean annual temperature 15°C

Profile

0 - 4 cm Pinkish grey (7.5 YR 6/2 dry; brown, 7.5 YR 4/2, moist); friable sandy loam which is weakly vesicular and weakly fine platy; slightly plastic; pH 8.0; no digestion with H₂O₂,

4 - 8 cm Reddish-grey (5 YR 5/2; dark reddish-grey, 5 YR 4/2, moist); plastic, sticky clay loam; weakly prismatic structure which readily breaks to weak medium subangular blocky structure; some visible lime; pH 8.0,

o - - - Reddish-grey (5 YR 5/2), basic rock, pH 8.0.

Profile No. 11 - "Lithosolic Red Desert Soil"

Tentative series name - Chinchado steepland soils

Location : 13 km south-west of Llampos, Atacama Province
Elevation : about 1100 m
Relief : fairly steep hills, profile recorded on 30° slope
Vegetation : barren
Parent materials: tuffaceous indurated sediments of Lower Cretaceous age
Climate : about 20 mm mean annual rainfall; mean annual temperature 15°C

Profile

(Slopes of hill completely mantled with small angular rock fragments arranged with slightly striated pattern, aligned down slope)

0 - 4 cm Fine rock chips,

4 - 6 cm Pinkish grey (5 YR 7/2, dry; reddish brown, 5 YR 4/4, moist); slightly gravelly fine sandy loam; slightly firm when dry; very weak fine subangular blocky structure with highly porous peds, powdering down under slight pressure to granules and crumbs; non-sticky and almost non-plastic when moist; boundary diffuse; no reaction with hydrogen peroxide or hydrochloric acid; boundary diffuse,

6 - 16 cm Pink to pinkish grey (5 YR 7/3 to 7.5 YR 7/2, dry; pale reddish-brown to brown, 5 YR 6/4 to 5/4, moist) fine sandy loam with fine gravel; no visible structure in place, but breaks under gentle pressure to very weak coarse subangular blocky structure and some granules; very friable; peds less porous than last horizon; non-sticky and non-plastic when moist; no reaction to hydrogen peroxide, weak reaction to hydrochloric acid; boundary merging,

16 - 36 cm Pinkish grey (7.5 YR 6/2, dry; reddish-brown, 5 YR 5/4, moist); gravelly sandy loam, cemented firmly with salts; several large cavities left by removal of salt crystals; boundary indistinct,

On.. Cemented rock chips and coarse sand overlying unbroken rock.

Profile No.12 - "Regosolic Red Desert Soil"

Tentative series name - Abra (Chuquicamata Association)

Location : 39 km west of Chuquicamata
Elevation : about 1500 m
Relief : gently sloping alluvial fan, about 4° slope
Vegetation : barren
Parent materials: mixed alluvium
Climate : no regular rainfall, mean annual precipitation probably less than 10 mm; mean annual temperature about 12°C, very wide daily temperature range, about 35°C.

Profile

0 - 5 cm Pinkish grey (7.5 YR 6/2; brown, 7.5 YR 5/2, moist) light sandy loam with lots of gravel; this horizon is hard and semi-cemented with salt, but it breaks into crumb-like structure, comprising a mixture of cluster of salt crystals and mineral soil; crumbs break readily into single grains; this layer slakes slowly in water and H₂O₂; no digestion with H₂O₂, and no visible lime; calcareous; pH 8.5,

5 - 20 cm Light reddish brown (5 YR 6/4; reddish brown, 5 YR 5/4, moist) slightly hard gravelly sandy loam, single grain structure; no visible lime, either on soil or gravel; no reaction with H₂O₂; pH 8.2,

On.. Similar material with layers of alluvial gravel.

Profile No. 13 - "Young Colluvial Soil Related to Minimal Red Desert Soils"

Tentative series name - Tarapaca

Location : approximately 35 km east of Huara, Tarapaca Province
Relief : flattish basin area at toe of old alluvial fan
Elevation : about 1250 m
Vegetation : almost barren; a few dead ephemeral plants and very occasional *Atriplex* shrubs
Parent material : outwash alluvium
Climate : usually rainless, perhaps about 15 mm mean annual rainfall; mean annual temperature about 14°C.

Profile

0 - 8 cm Grey (10 YR 6/1, dry) coarse sand; loose; single grain structure; non-sticky and non-plastic when moist; topsoil sand slightly cemented with salt crystals; boundary distinct; (pH 7.4),

8 - 14 cm Stratified fine sand and loamy coarse sand with white crystalline substance between individual layers; colour light grey (5 YR 7/1, dry); very slightly sticky and slightly plastic when moist; very weak laminar structure; boundary distinct; (pH 5.0),

14 - 20 cm Grey (10 YR 6/1, dry) and pinkish grey (7.5 YR 7/2) coarse sand and sand; white crystalline material in irregular blocks separated by tongues of grey sand; non-sticky and non-plastic when moist; boundary diffuse; (pH 8.4),

on.. Cemented and salt-impregnated sand and gravel - somewhat open and porous in upper 5 cm but increasing in density and cementation below; colour mainly light brownish grey (10 YR 6/2, dry).

Profile No.14 - "Red Desert Soil, Transitional to Saline Desert Soil"

Tentative series name - Chuño sand

Location : 30 km from Pan-American highway, on road to Ticnamar,
Tarapaca Province
Elevation : about 1420 m
Relief : gently undulating ancient piedmont plain surface
Vegetation : barren
Climate : rainless in most years, perhaps mean annual rainfall
about 5 mm; mean annual temperature about 16°C

Profile

(surface erosion pavement consisting of small and large sand-blasted stones)

0 - 2 mm Very weakly cemented, fragmental, curled, leaf-like sandy crust,

2 mm - 2 cm Reddish yellow, loose, slightly loamy fine sand; effervesces slightly with H₂O₂; pH 7.8; boundary sharp,

2 - 7 cm Pale brown (10 YR 6/3, moistened) cemented sand; salt crystals show vertical orientation above but honeycomb arrangement below; cementation lacking in region of fissures and colour brighter (5 YR 4/4, moistened); pH 8.0; no digestion with H₂O₂ but some effervescence where colours brighter; boundary sharp, except in region of fissures, where merging,

7 - 11 cm White powdery, crystalline substance like mirabillite, somewhat chalky; pH 7.8; boundary merging,

11 - 46 cm Light grey (10 YR 7/1.5) cemented sand with honeycomb structure containing pockets of white crystalline substance, tending to disintegrate in region of fissure, at first with faint prismatic structure but adjacent to actual crack takes on a laminar (vertically orientated) structure; centre of fissure occupied by bright brown sand; pH of horizon, 8.0, pH of fissure material 7.8; boundary of horizon distinct,

46 - 76 cm Similar to last horizon but exceedingly strongly cemented; porcelain-like and without honeycomb structure; some embedded gravel; pH 7.9; boundary distinct,

76 - 111 cm Laminated gravels and coarse sands, some layers fairly loose, others slightly cemented; light brownish grey colours predominate (10 YR 6/2, moistened); pH 8.0; boundary sharp,

on.. Alternating layers of coarse sand and gravel; in part cemented; pH 7.9 decreasing to 7.8 at 130 cm.

Profile No. 15 - "Minimal Red Desert Soil"

Tentative name - Llampos silty clay loam

Location : about 20 km south-west of Llampos, near overpass
of railway
Elevation : 1050 m
Relief : flattish, ancient piedmont surface
Vegetation : barren
Parent materials: ancient piedmont gravels
Climate : about 20 mm annual rainfall; mean annual
temperature, 14°C.

Profile

(surface covered with large (100 cm) subangular boulders and small (1 cm) rounded gravel, all of which have highly polished exposed surfaces; some bare ground between stones having pronounced pink colour (7.5 YR 5/4) when dry.)

- 0 - 1 cm Pale reddish brown (7.5 YR 6/4), dry; reddish brown, (2.5 YR 4/4, moist) silty clay loam with very fine gravel; without visible structure apart from very numerous rounded vesicles; somewhat firm when dry, but powdering readily under pressure to very fine slightly rounded granules; brittleness resembles a very weak frangipan; non-sticky but very slightly plastic when moist; boundary distinct,
- 1 - 18 cm Pale reddish brown to reddish brown (2.5 YR 6/4 to 5/4, dry; reddish brown, 2.5 YR 4/4 moist) slightly gravelly loam; friable; very weakly developed coarse blocky structure, breaking to very strong, very fine blocks and granules; slightly sticky and plastic when moist; boundary diffuse,
- 18 - 33 cm As above, but not gravelly,
- 33 - 80 cm Greyish fine gravel composed of rounded material, very weakly cemented with carbonate,
- on.. Strongly cemented gravels and sand, calcareous.

Profile No. 16 - "Coastal Desert Soil"

Tentative name - Humbolt fine sandy loam

Location : 3.5 km north of Caleta Vitor
Altitude : 700 metres
Relief : flattish ledge on long, steep slope down to shore.
Angle of slope on site 17°
Parent material : tertiary gravel beds near junction with Jurassic sediments
Plant cover : bare ground with a thin covering of orange-coloured lichen.

Profile

0 - 4 mm Pinkish-grey (7.5 YR 6/2 dry) or brown (7.5 YR 4/2) moist, fine sandy loam with some very fine gravel; lightly compacted and weakly cemented; friable; non-sticky, slightly plastic; flakey, laminar structure with fine elongated vesicles, breaking readily to fine granules and crumbs; pH 6.7; non-calcareous; moderate reaction with hydrogen peroxide; boundary distinct,

4 mm - 2.5 cm Brown (7.5 YR 5/2) dry or reddish-brown (5 YR 4/3) moist, gravelly sandy loam; friable; very slightly sticky, moderately plastic, massive and porous breaking to medium sub-angular blocks, and further to very fine blocks, granules and crumbs under slight pressure; pH 7.3; slightly calcareous; moderate reaction with hydrogen peroxide; boundary distinct,

2.5 - 12 cm Pink (7.5 YR 7/4) dry, or light brown (7.5 YR 6/4) moist, loamy sand; powdery, somewhat slippery when moistened, non-sticky; non-plastic; single grain with clusters of small gypsum crystals; pH 7.5; very weak reaction to hydrochloric acid and no reaction to hydrogen peroxide; boundary merging,

12 - 30 cm Somewhat vari-coloured, brown (7 YR 5/2) and pinkish-grey (7.5 YR 6/2) in dry condition; gravelly sand with gypsum and salt crystals; weakly cemented; non-sticky, non-plastic; highly vesicular, almost honeycomb; structure with crystals lining cavities; pH 7.7; non-calcareous; no reaction with hydrogen peroxide; boundary indistinct,

on.. Greyish-brown salt-cemented gravel and salt.

Profile No. 17 - "Young Coastal Desert Soil"

Tentative name - Concordia gravelly sand

Location : 1.3 km east of Saucache Bridge, entrance to
Azapa Valley
Altitude : About 90 metres
Relief : flattish sloping plain, undulating micro-relief;
angle of slope at site, 2°
Parent materials: coastal plain sediments, mainly alluvial
Plant cover : completely bare ground.

Profile

0 - 1 cm Light brownish-grey (10 YR 6/2) dry, or greyish-brown
(10 YR 5/2) moist, gravelly sand; loose; non-sticky
and non-plastic; single grain structure; pH 7.8; non-
calcareous; no reaction with hydrogen peroxide;
boundary distinct,

1 - 3 cm Similar material cemented by salt; pH 7.8: no
reaction with hydrochloric acid or hydrogen peroxide;
boundary distinct,

3 - 8 cm Light brownish-grey (10 YR 6/2) dry, or brown to dark
brown (10 YR 4/3) moist, sand; loose; non-sticky and
non-plastic; single grain structure; pH 7.8; no
reaction with hydrogen peroxide; boundary distinct,

8 - 22 cm Grey (10 YR 5/1) dry, or greyish-brown (10 YR 5/2)
moist, sand; moderately and strongly cemented with
salt in various narrow laminar bands; non-sticky and
non-plastic; laminar structure; pH 7.8; no reaction
to hydrochloric acid or hydrogen peroxide; boundary
distinct,

22 - 38 cm Light brownish-grey (10 YR 6/2) dry, or brown to dark
brown (10 YR 4/3) moist; loamy fine sand; lightly
cemented but breaks readily under pressure; non-
sticky and very slightly plastic when moistened;
pH 7.8; non-calcareous; no reaction to hydrogen
peroxide; boundary distinct,

38 - 48 cm Light-greyish-brown (10 YR 6/2) dry, or greyish-brown
(10 YR 5/2) moist, sand and gravel; strongly cemented
with salt; non-sticky and non-plastic when moistened;
pH 7.8; non-calcareous; no reaction to hydrogen
peroxide; boundary distinct,

on.. Strongly stratified gravels and sands, with occasional
fine layers of silt and clay; several of the gravel
layers are strongly impregnated with salt, and cemented.

Profile No. 18 - "Sierozem"

Tentative name - Mamiña hill soils

Location : about 2 km east of Mamiña township
Elevation : about 2500 m
Relief : slightly rounded summit of range of hills
Vegetation : mainly Cacti (several species)
Climate : no data available; probably mean annual rainfall about 40 mm, mean annual temperature probably less than 12°C.

Profile

- 0 - 5 cm Pink (5 YR 7/3, dry; dark reddish-grey, 5 YR 4/2, moist) fine sandy loam with gravel; very friable to friable; somewhat laminar structure but breaks under gentle pressure to fine angular blocks; peds very porous; non-sticky and very slightly plastic when moist; boundary distinct,
- 5 - 10 cm Pale reddish brown (5 YR 6/3, dry; reddish brown, 5 YR 4/4, moist) sandy loam with a little very fine gravel, very friable; weakly developed medium, fine and very fine angular blocky structure breaking readily to soft granules; larger peds finely porous; non-sticky and very slightly plastic when moist; boundary distinct,
- 10 - 15 cm Reddish-brown (2.5 YR 4/4, dry; reddish-brown, 5 YR 4/4, moist) streaked with reddish grey (10 R 6/1, dry; reddish-brown to yellowish-red, 5 YR 5/5, moist) heavy sandy loam; firm, wealy cemented frangipan when dry; no recognisable structure in the mass, but breaks with difficulty when dry to irregular angular blocks; whole mass finely porous; non-sticky but slightly to moderately plastic when moist; very slightly calcareous; boundary distinct,
- 15 - 19 cm Weak red (10 R 5/3, dry; reddish-brown, 2.5 YR 4/4, moist), clearly speckled pale red (10 R 6/1, dry; weak red, 2.5 YR 5/2, moist) heavy silt loam; friable; very strongly developed fine and very fine angular blocky structure breaking to coarse and fine granules; non-sticky and very slightly plastic when moist; boundary distinct,
- 19 - 27 cm Reddish-brown (5 YR 5/4, dry; yellowish-red, 5 YR 4/6, moist) heavy fine sandy loam to loam; friable to very friable; very strongly developed medium to fine granular structure; non-sticky and very slightly plastic when moist; slightly calcareous; boundary merging,

(Profile No. 18 - continued)

- 27 - 50 cm Reddish-yellow (5 YR 7/6, dry) slightly gravelly loam; very friable; fine granular structure; non-sticky and very slightly plastic when moist; highly calcareous; boundary merging,
- 50 - 80 cm Pink (5 YR 7/4, dry; reddish-brown, 5 YR 5/4, moist) gravelly loamy sand; friable; no visible structure in the mass; non-sticky and non-plastic when moist; about 95% gravel, but sand between gravel is definitely loamy; calcareous; boundary merging,
- on.. Similar gravelly material, colour pinkish-grey.

Profile No. 19 - "Minimal Sierozem lithosolic steepland soil"

Tentative name - Corallones lithosolic steepland soil

Location : 25 km west of Ticnamar, Tarapaca Province
Elevation : 2750 m
Relief : steep rocky slopes, mainly rhyolitic rocks
Vegetation : Cactus (candelabra form) and scattered annual plants
Climate : no reliable data; possibly about 100 mm annual rainfall.

Profile

0 - 3 cm Gritty loamy sand; pale brown (7.5 YR 6/4, dry; dark reddish-grey, 5 YR 4/3, moist); somewhat firm when dry, but powders readily under pressure; friable when moist; granular and crumb structure after crushing; porous; non-sticky and non-plastic when moist; boundary diffuse,

3 - 7 cm Stony heavy fine sandy loam; reddish-yellow (5 YR 6/6, dry; yellowish-red, 5 YR 4/6, moist); fragipan when dry, but friable when moist; breaks to weakly developed medium angular blocky structure, with slight prismatic cleavage; non-sticky and very slightly plastic when moist; boundary distinct,

7 - 10 cm Pink (7.5 YR 7/4, dry; yellowish-red, 5 YR 6/4, moist) very stony fine sandy clay loam; weakly developed angular blocky structure; non-sticky, slightly plastic when moist; boundary distinct,

on.. Shattered rhyolitic rock.

Profile No. 20 - "Minimal Sierozem steepland soil"

Tentative name - Chacaya steepland soils

Location : 30 km east of Codpa, Tarapaca Province
Elevation : 2900 m
Relief : long steep, smooth slopes of Andean foothills;
30° angle of slope
Vegetation : mainly Cacti, with some tola and other xerophytic shrubs
Climate : probably up to 150 mm rainfall per annum; mean annual
temperatures in the vicinity of 15°C.

Profile

0 - 2 cm Pale reddish-brown (5 YR 6/4, dry; reddish-brown, 5 YR 5/4, moist) fine sandy loam with considerable gravel; firm, hard when dry, friable when moist; no structure in the mass but very porous; breaks into strong fine subangular (nut) peds, and, under more pressure, to very fine granules and crumbs; non-sticky and non-plastic when moist; boundary sharp,

2 - 14 cm Reddish-yellow (5 YR 6/6, dry; yellowish red, 5 YR 4/6, moist) stony very fine sandy loam; slightly hard when dry, friable when moist; no recognisable structure in the mass but under strong pressure powders down to very fine angular blocks and granules; peds finely porous; non-sticky and very slightly plastic when moist; boundary distinct,

14 - 27 cm Pink (7.5 YR 7/4, dry; yellowish red, 5 YR 5/6, moist) very stony loam; firm to friable; breaks into laminar plates at first, and then into coarse blocks with slight prismatic alignment, eventually crumbles to very fine granules; peds finely porous; non-sticky and very slightly plastic when moist; rather difficult to wet; boundary merging,

on.. Somewhat varicoloured, reddish and pinkish, very stony light clay loam or heavy loam; fairly friable; breaks to coarse granular structure; non-sticky and slightly plastic when moist; merging into slightly weathered rhyolitic rocks.

Profile No. 21 - "Sierozem-like steepland soil"

Tentative series name - Epizchaca steepland soils

At 3300 m near Sapahuira, under open "tolar" formation, on a 28° slope:

- 0 - 10 cm Brown stony loamy sand; firm; more or less massive with vertical fissuring developing; highly vesicular; non-sticky and non-plastic when moist; pH 6.4; moderate digestion with hydrogen peroxide, and very weak effervescence; boundary distinct,
- 10 - 18 cm Pale reddish-brown stony coarse sandy loam; friable-to-firm; weakly developed fine subangular blocky structure breaking to granules; non-sticky and very slightly plastic when moist; pH 6.6; moderate digestion with H₂O₂ and moderate-to-strong effervescence; boundary diffuse,
- on.. Pale yellowish grey stony loam with many fragments of weathering siltstone and shale.

Profile No. 22 - "Calcic Brown steepland soil"

Tentative name - Ticnamar steepland soils

Location : 5 km south-east of Ticnamar township
Altitude : about 3000 m
Relief : steep slopes of the Andean cordillera
Vegetation : mainly tola scrubland; many different species of xerophytic plants present, plus occasional cacti
Parent material : indurated sediments, in part calcareous.

Profile

0 - 7 cm Brown (7.5 YR 5/4, dry; dark brown, 7.5 YR 4/4, moist) stony loam; friable; strongly developed fine subangular blocky structure breaking to coarse granules; very slightly sticky and slightly plastic when moist; boundary distinct,

7 - 15 cm Reddish-brown (5 YR 4/4, dry; dark reddish-brown, 5 YR 3/4, moist) clay loam with many angular fragments of rock; strongly developed medium angular blocky structure, with faint prismatic alignment; peds very finely porous and pores filled with calcium carbonate; very slightly sticky and moderately plastic when moist; boundary merging,

15 - 21 cm Yellowish-red (5 YR 5/6, dry; yellowish-red, 5 YR 4/6, moist) very stony light clay loam; firm; weakly developed coarse angular blocky structure with white filaments of calcium carbonate between the peds, which themselves are non-porous; highly calcareous; slightly sticky and moderately plastic when moist; boundary merging,

on.. Weathering rock fragments and a little yellowish-red clay in the rock fissures.

Profile No. 23 - "Calcic Brown lithosolic steepland soil"

Tentative name - Ticnamar lithosolic steepland soils

Location : 7 km east of Ticnamar township, Tarapaca Province
Elevation : about 3100 m
Relief : very steep, rocky slopes
Vegetation : dense ground cover of small xerophytic shrubs
Parent materials: calcareous indurated sediments, slightly tuffaceous.

Profile

0 - 2 cm Dark grey very stony loam; friable; slightly hard when dry; very strongly granular structure; non-sticky and slightly plastic when moist; boundary distinct,

2 - 9 cm Brown very stony clay loam; firm to friable; rather without any well defined structure in the mass but finely porous throughout, breaks under firm pressure to moderately developed angular blocks; slightly calcareous; non-sticky and slightly plastic when moist; boundary merging,

9 - 13 cm Reddish-brown very stony clay loam or heavy loam; fairly firm when dry, friable when moist; irregular blocky structure with calcium carbonate deposition around the peds; highly calcareous; very slightly sticky and moderately plastic when moist; boundary merging,

on.. Weathering rock fragments with calcium carbonate veins.

Profile No. 24 - "Non-calcic Brown steepland soil"

Tentative name - Sitilca lithosolic steepland soil

Location : 3 km south of Caritaya reservoir, Tarapaca Province
Altitude : about 3600 m
Relief : very steep rugged mountain slopes
Vegetation : mainly cacti, with some tola and other xerophytic bushes
Parent materials: mainly rhyolitic rocks with some very fine pumiceous ash.

Profile

0 - 3 cm Brown (7.5 YR 4/2, dry; dark brown, 7.5 YR 3/2, moist) very stony loam; firm, very hard when dry; no distinct structure in the mass but breaks to fine irregular blocks and granules under strong pressure; peds porous; very friable when moist; soil cracks markedly when dry but fissures are irregular; moderately sticky and plastic when moist; boundary distinct,

3 - 8 cm Reddish-brown (5 YR 3/4, dry; dark reddish-brown, 2.5 YR 3/4, moist) silty or very fine sandy loam; hard when dry but extremely friable when wet; slakes readily in water; weakly developed prismatic structure which breaks further to irregular granules; slightly sticky and moderately plastic when moist; boundary merging,

on.. Slightly cemented (silica?) zone of shattered rhyolitic rock fragments with tongues of reddish-brown clay loam penetrating to about 15 cm.

Profile No. 25 - "Minimal Brown Forest, hill soil"

Tentative series name - Sapahuira hill soils

At 3550 m 15 km east of Sapahuira, under dense "tolar" scrub (dominated by *Baccharis tola*, but associated with *Fabiana denudata*, *Adesmia hystrix*, *Ephedra andina*, *Senecio graveolens* and *Calendrina* and *Artemisia* sp.), on a 15° slope:

- 0 - 15 cm Dark brown (10 YR 3/3, moist) stony loamy sand; friable-to-firm; weakly developed coarse sub-angular blocky structure breaking to fine granules and crumbs; distinct vertical fissures in soil in place; vesicular; non-plastic and non-sticky when moist; pH 5.8; very strong digestion, weak effervescence with H₂O₂; boundary sharp,
- 15 - 27 cm Brown (10 YR 4/3, moist) coarse sandy clay loam; firm; very weakly developed irregular medium blocky structure breaking to very fine blocks and granules; very slightly plastic and sticky when moist; pH 6.0; strong digestion and moderate to strong effervescence with H₂O₂; boundary diffuse,
- 27 - 31 cm Somewhat varicoloured (pale brown and light reddish-brown), faintly mottled stony loam; friable, irregular blocky structure; slightly sticky and plastic when moist; pH 6.0; very weak digestion but strong effervescence with H₂O₂; boundary merging,
- on.. Weathering Jurassic sediments.

Profile No. 26 - "Páramo-like soil"

Tentative series name - Pachama hill soils

At 3750 m 23 km east of Sapahuira, under dense tola scrub with scattered quínoá (*Chuquiragua oppositifolia*) trees; on a 26° slope, facing west:

- 0 - 20 cm Very dark grey (peaty) sandy loam; friable; moderately developed medium nutty structure breaking readily to crumbs; very sticky and slightly plastic when moist; pH 5.4; strong digestion with H₂O₂; boundary sharp,
- 20 - 28 cm Brown sandy loam grading to loamy sand; friable; very weakly developed coarse blocky structure breaking to fine blocks; non-sticky and very slightly plastic when moist; pH 5.3; weak digestion with H₂O₂; slight to moderate effervescence; boundary diffuse,
- 28 - 43 cm Varicoloured, mainly grey, diffusely mottled strong brown, fine sandy clay loam; friable-to-firm; weakly prismatic to strongly developed coarse blocky structure breaking to very fine laminar blocks and flattened granules; slightly sticky and moderately plastic when moist; pH 5.6; very weak digestion with H₂O₂ and strong effervescence; boundary merging,
- on.. Strong brown gravelly clay loam with many fragments of weathering siltstone and shale; pH 5.8; moderate digestion and strong effervescence with H₂O₂; reddish-yellow iron coating evidently on surface of rock fragments.

Profile No. 27 - "Sierozem-like" pumiceous steep land soil

Tentative name - Campanani steepland soils

Location : about 8 km south-west of Sapahuira, Tarapaca Province
Elevation : 3150 m
Relief : mainly steep slopes with small mesa-like plateaux
Vegetation : open tola scrubland
Parent materials: pumiceous volcanic ash

Profile

0 - 2 cm Very pale brown (10 YR 7/4, dry; dark brown, 7.5 YR 3/2, moist) very slightly loamy coarse sand; weakly developed laminar structure; non-sticky and non-plastic when moist; boundary distinct,

2 - 9 cm Reddish-brown (5 YR 5/4, dry) coarse loamy sand with fragments of decomposing rhyolitic rock; fairly firm when dry, friable when moist; weakly developed medium blocky structure; very slightly calcareous; non-sticky and very slightly plastic when moist; boundary merging,

9 - 18 cm Yellowish red coarse sandy loam; fragipan when dry, fairly friable when moist; somewhat coloured owing to iron-staining on some of the pumice and rhyolite fragments; breaks under pressure into fine angular blocks, also faintly stained light red on surfaces; non-sticky and almost non-plastic when moistened; boundary distinct;

18 - 22 cm Pinkish-white rather compact and weakly cemented coarse pumice sand and gravel; possibly slightly cemented by silica; boundary diffuse,

on.. Whitish pumice gravel, fairly compact in place but quite loose when disturbed.

Profile No. 28 - "Steppe soil of the Andean altiplano"

Tentative series name - Putani sand

A soil near General Lagos, approaching the upper limit of the Altiplano "High plain" ecological unit at an altitude of 4260 m. under a modified plant cover consisting mainly of Baccharis, Erigeron and small Laretia plants; on a gently undulating plain inclined slightly towards the north, showed the following features:-

surface very stony with some pale grey sand and grains

- 0 - 2 mm Dark brown (7.5 YR 3/2; pinkish grey, 7.5 YR 5/2 when dry) medium and fine sand; loose; single grains; boundary sharp; pH 7.4; fine flakes of organic matter visible and some digestion occurs with hydrogen peroxide,
- 2 mm - 5 cm Dark reddish-brown (between 7.5 YR and 5 YR 3/3) loamy fine sand with occasional stones; very friable and porous; very weakly developed medium to fine subangular blocky structure breaking readily to fine crumbs; non-sticky and non-plastic when moist; boundary diffuse; pH 7.6; moderate digestion with H₂O₂,
- 5 cm - 12 cm Dark reddish-brown (7.5 YR 3/4) heavy sand loam; friable; tendency to be massive in place but very porous and breaks into very weakly developed medium-sized blocks which break further to irregular granules; slight-to-moderately sticky and moderately plastic when moist; boundary diffuse; pH 7.7; moderate digestion with H₂O₂,
- 12 - 22 cm Brown (7.5 YR 4/4) heavy clay with abundant stones; firm-to-friable; strongly developed medium to fine subangular blocky structure which breaks to coarse and fine granules; sticky and plastic when moist; clayskins appear on surface of both large and small peds; boundary diffuse; pH 7.8; moderate digestion with H₂O₂;
- on.. Reddish-brown (5 YR 4/6) grading to brown (7.5 YR 4/4) gravelly clay; friable-to-firm; moderately developed coarse blocky structure with abundant clayskins; moderately-to-strongly plastic when moist; pH 7.8;. weak digestion with H₂O₂.

Profile No. 29 - "Steppe hill soil of the Andean altiplano"

Tentative name - Caracani hill soils

These are the commonest hill soils of Chilean altiplano in the Dept. of Arica and occur on slopes ranging from 15° to 30°. Soils are nearly bouldery or stony; with a pronounced erosion pavement formed by overlapping rhyolite slabs. Vegetation mainly Llaretia and Stipa but much of ground is bare of vegetation for most of year and is occupied only by ephemeral grasses and herbs after December-March rains.

General profile

(Surface erosion pavement of rock slabs)

- | | |
|-------------|--|
| 0 - 0.5 cm | Erosion surface of white sand and fine gravel (pH 6.2) |
| 0.5 - 12 cm | Grey (10 YR 5/1) coarse sand and fine gravel dark brown, 10 YR 3/3, when moist; friable; structureless; non-sticky and non-plastic when moist; boundary diffuse, (pH 6.5), |
| 12 - 37 cm | Dark brown (7.5 YR 3/2 - moist) coarse sand and fine gravel; weak irregular blocky structure, friable to firm; non-sticky and non-plastic when moist; boundary distinct (pH 7.2), |
| 37 - 52 cm | Brown to dark brown (7.5 YR 4/2 - 5/2, moist) sandy clay loam; firm to friable; very weakly developed fine nut structure breaking to granules; very slightly sticky and non-plastic when moist, boundary diffuse (pH 7.3), |
| on.. | Brown gravelly clay loam (7.5 YR 5/4, moist), firm; strongly developed very fine blocky and coarse granular structure; slightly sticky and slight-to-moderately plastic when moist; boundary not seen, (pH 7.4). |

Profile No. 30 - "Sub-alpine steepland soil of the Andean altiplano"

Tentative name - Cosapilla steepland soils

Association of steepland soils, developed on slopes usually in excess of 30° (often over 100°), located in the altiplano region of Tarapaca Province. Soils mainly derived from acid and intermediate-acid volcanic rocks; usually shallow and rocky but with patches of deeper soil formed through colluvial movement and solifluction. Natural vegetation often very scanty but in part covered with Llaretia and sub-alpine small herbs. Occasional patches of snow on sheltered slopes with southernly aspect, even during the summer. Extends from about 4500 m up to the permanent snowline.

Profile recorded and sampled from flanks of Volcán Tarapaca, north-east of Putre. Altitude 4700 m. Mainly bare ground (a few llaretia clumps and about 1% cover of annual herbs) with a patterned erosion pavement (stone stripes and concentric solifluction areas), and occasional loose boulders on surface. Sloping ridge with about 21% slope - soil described below is rather deeper than typical for soils in this association.

Tentative name - Tarapaca steepland stony loamy sand

- 0 - 3 cm Dark brown (7.5 YR 3/2, moist; pinkish grey, 7.5 YR 6/2, dry) coarse sand and gravel; friable when thawed out; single grain structure; non-sticky and non-plastic when moist; boundary distinct; (pH 6.4, strong digestion with H₂O₂ but no reaction to HCL).
- 3 - 9 cm Very dark grey-brown to very dark brown (10 YR 3/2 - 2/2; light brownish-grey - 10 YR 6/2 - dry) loamy coarse sand with fine gravel; friable when thawed out; weakly developed crumb structure; non-sticky and very slightly plastic when moist; very porous, with ice-filled pores when frozen; boundary sharp; pH 6.3; slight digestion with H₂O₂; no reaction to HCL,
- ~~9 - 16 cm Dark brown to brown (10 YR 4/2, moist; pinkish-grey - 7.5 YR 6/2 dry) gravelly sandy loam; friable when thawed; very porous soil with ice crystals separating aggregates; weakly developed, irregular, fine nutty structure breaking on thawing to granules and crumbs; slightly sticky and plastic when moist and thawed out; boundary merging; (pH 6.6; slight digestion but some effervescence with H₂O₂; no reaction to HCL),~~
- 16 - 20 cm Somewhat varicoloured very gravelly sandy clay loam; colours when moist mainly 7.5 YR 4/4 and 5/4 (brown and dark brown), with weak development of coarse mottling, mainly strong brown (7.5 YR 5/6) and reddish-brown;

friable to firm; very strongly developed very fine sub-angular blocky structure breaking to granules and crumbs; aggregates are well coated with clay skins - even around the fragments of stone in the soil; general appearance of soil on thawing is one of moderate porosity; slightly sticky and moderately plastic when thawed out; boundary diffuse; colour dry mainly pinkish grey (7.5 YR 7/2); (pH 6.8; very little digestion but some effervescence with H_2O_2 ; no reaction to HCL),

20 - 40 cm

Strong brown (7.5 YR 5/6) very gravelly and stony sandy clay loam; friable when thawed; very strongly developed fine granular structure in patches between abundant stones; clay skins very marked around aggregates and on surface of stones; soil contains less ice when frozen than horizons above - less porous; slightly sticky and plastic on thawing; boundary merging; (pH 6.6; no digestion with H_2O_2 but strong effervescence, especially around surface of stones; no reaction with HCL),

on..

Compact gravel with plastic sandy clay between stones. Colour of clay when moist - 7.5 YR 5/6 - strong brown. pH 6.6.

Profile No. 31 - "Steppe soil of the Andean altiplano derived from rhyolitic pumiceous volcanic ash"

Tentative series name - Pujullane sand

Gently rolling upland plain covered with sub-aerial pumiceous volcanic ash and (possibly) colluvial materials, forming a strongly stratified soil parent material. This laminated type of soil profile is characteristic of part of the Upper Lauca section of the altiplano between Chapiquina Irrigation Headquarters and Parinacota.

A typical soil profile at about 5 km NE of the Chapiquina-Putre and Chapiquina-Parinacota road fork; at an altitude of 4300 m on a gently rolling landscape; growing mainly stipa (20%), tola (5%), with much bare exposed ground (75%).

- | | |
|-------------|--|
| 0 - 3 cm | Grey to light grey-brown (10 YR 6/1 dry; 10 YR 3/1 moist) sand and fine gravel; loose and very friable; structureless; non-sticky and non-plastic when moist; boundary distinct; pH 7.4, |
| 3 - 10 cm | Dark grey-brown (10 YR 4/3, moist) gravelly sandy clay loam; friable-to-firm; strongly developed medium nutty structure; slightly sticky and moderately plastic when moist; boundary diffuse; pH 7.4, |
| 10 - 20 cm | Dark brown (10 YR 3/2, moist) coarse sand and fine gravel; very friable very weakly developed crumb structure; non-sticky and non-plastic when moist; boundary sharp (pH 7.6), |
| 20 - 40 cm | Brown (10 YR 4/3, moist) loamy coarse sand with fine, soft pumice stones, mixed with some hard andesitic and basaltic fragments; firm; weakly developed, irregular coarse blocky structure breaking readily under pressure to very fine blocks and granules; non-sticky and very slightly plastic when moist; boundary diffuse (pH 7.6), |
| 40 - 70 cm | Light yellowish-brown (10 YR 6/4) gravelly sandy clay loam; very firm, almost weakly cemented as if a frangipan forming; massive, breaking to laminar-fine blocky structure with very strong development of clay skins; slightly sticky and moderately plastic when moist; boundary sharp; pH 7.8, |
| 70 - 110 cm | Brown (7.5 YR 5/4; pink, 7.5 YR 8/4 when dry) pumice sand mixed with black gravel; cemented hard; massive but with some vertical cracks filled with yellowish brown (allophane) clay; non-plastic and non-sticky when moist; boundary merging (pH 7.0), |

(Profile No. 31 - continued)

110 - 160 cm Pinkish-grey (7.5 YR 5/4; 7.5 YR 7/2, dry) pumice sand and coarse black gravel; cemented,

on.. Pinkish-grey cemented tuff or breccia.

Profile No. 32 - "Recent soil of the Andean altiplano derived from pumiceous volcanic ash"

Tentative name - Lascar gravelly sand

Location : 5 km west of Lascar volcano, Antofagasta Province
Elevation : about 3000 m
Relief : strongly rolling lower slopes of volcano
Vegetation : sparse cover of tola and cacti
Parent materials: mainly pumiceous volcanic ash (recent).

Profile

0 - 15 cm Reddish-grey (5 YR 5/2, dry; dark brown, 7.5 YR 3/2, moist) gravelly sand; without structure; non-sticky and non-plastic when moist; boundary diffuse,

15 - 30 cm Brown (7.5 YR 5/4, dry; reddish-brown, 5 YR 3/3, moist) sand; grading to coarse loamy sand towards lower part of this horizon; very friable; somewhat compact in place and without recognisable structure, but breaks under gentle pressure to irregular subangular blocks and granules; non-sticky and non-plastic when moist; boundary diffuse,

30 - 45 cm Reddish-brown (5 YR 5/4, dry; dark reddish-brown, 5 YR 3/4, moist) slightly gravelly loamy sand; weakly developed medium and fine subangular blocky structure, which breaks further to granules and crumbs; non-sticky and very slightly plastic when moist; boundary abrupt,

on.. Hard rhyolitic lava sheet with fissures containing yellowish brown silty clay loam with pronounced "greasy" feel when moist (allophane?).

Profile No. 33 - "Steppe soil of the Andean altiplano derived from andesitic volcanic ash"

Tentative name - San Martín sand

Location : saddle between Salar San Martín and Salar Ascotán, Antofagasta Province
Elevation : 3800 m
Relief : undulating
Vegetation : tola scrub with Stipa tussocks
Parent materials: mainly andesitic volcanic ash (fairly recent).

Profile

- 0 - 2 cm Pale brown (10 YR 6/3, dry) fine sand and a little silt; very friable; fairly compact in place but with weakly developed laminar structure and weak development of short vertical fissures; breaks into rather square medium blocks; non-sticky and non-plastic when moist; boundary distinct,
- 2 - 10 cm Brown (7.5 YR 5/4, dry) gravelly loamy sand; very friable to loose, very fine subangular blocky structure breaking to granules; fine white threads of calcium carbonate near root channels; non-sticky and non-plastic when moist; boundary distinct,
- 10 - 16 cm Pink (7.5 YR 7/4, dry) coarse loamy sand with much pumice gravel; firm in place but crumbles readily when displaced; no regular structure; non-sticky and non-plastic when moist; boundary merging,
- 16 - 36 cm Pinkish-white (7.5 YR 8/2, dry) pumice gravel (andesitic); rather compact and perhaps weakly cemented in place; breaks to single lumps of pumice and loose sand; non-sticky and non-plastic when moist; boundary distinct,
- 36 - 45 cm Dark grey (7.5 YR 4/0, dry) black basaltic sand; cemented; slightly fissured and cracks stained reddish yellow; boundary abrupt,
- 45 - 50 cm Pale yellow (2.5 YR 7/4, dry) coarse pumiceous sand; weakly cemented.
- on.. Moderately cemented pumiceous gravels alternating with dark brown basaltic sand.

Profile No. 34 - "Peat bog soil of the Andean altiplano"

Tentative series name - Parinacota fibrous peat

Very gently sloping bogland, 3 km north of Parinacota village. Altitude 4275 metres. Microrelief hummocky with some wide fissures in the peat; general slope of bog about 2° towards west. Bog plants alive in patches, elsewhere moribund and slightly encrusted with white saline efflorescence; colour of bog surface, pale brown, dark brown and greyish-white. Sluggish flowing water encountered at about 1 metre depth; pH 8.0.

- 0 - 20 cm Very dark brown (10 YR 2/2, moist) fibrous peat consisting partly of live plant tissues, partly of moribund tissues and partly of dead material; squeezes almost clear water; pH 8.4; some salt crystal visible throughout this horizon, with marked concentration of crystals on surface; boundary distinct,
- 20 - 50 cm Dark brown (10 YR 4/2, moist) fibrous peat consisting mainly of dead stem bases and leaf sheathes, with about 10% living fine roots; squeezes pale brown turbid water; no visible salt crystals; pH 7.8; boundary distinct,
- 50 - 70 cm Reddish-brown (5 YR 3/4) fibrous loamy peat with no living tissues but clearly recognisable plant remains; squeezes brown turbid water; pH 7.4; boundary distinct,
- 70 - 95 cm Dark brown (10 YR 3/4, moist) slightly sandy loamy peat with few recognisable plant remains; strongly reducing conditions prevailing; squeezes dark brown, very turbid water and tendency for peat mass to squeeze through fingers; pH 7.8; boundary diffuse,
- on.. Dark grey loamy peaty sand (10 YR 3/1) with very strong reducing (stagnant) smell; no recognisable plant remains; peaty material thoroughly decomposed; pH 8.0.

Profile No. 35 - "Peat bog soil of the Andean altiplano"

Tentative series name - Uncaliri fibrous peat

Gently sloping bogland about 5 km, east of Gualletiri village. Altitude 4350 m. Microrelief sharply hummocky, with deep fissures separating individual peat "hags"; general slope of valley about 3° towards west. Marginal site on long narrow bog which began to dry out about three years ago following renewal of activity of Gualletiri volcano at head of valley. Peat deposit over 2 m in depth and no groundwater encountered in soil pit.

- 0 - 10 cm Dark yellow-brown (10 YR 3/4 - 4/4) very tough fibrous peat consisting wholly of dead "paco" plants; material dead but very slightly decomposed; extremely tight, and with a bleached pale-coloured surface; no salt crystals visible; pH 5.8; boundary distinct,
- 10 - 20 cm Yellowish-red (5 YR 4/6, moist) fairly compact, moderately tight fibrous peat consisting of "paco" stem and leaf bases; very slightly decomposed; squeezes pale brownish water; pH 5.4; boundary sharp,
- 20 - 30 cm Very dusky red (2.5 YR 2/2, moist) very loose, slightly fibrous loamy peat; very spongy horizon consisting of old leaf sheath bases and dead roots, all well decomposed but still recognisable plant tissues; squeezes brown turbid water; pH 5.8; boundary distinct,
- 30 - 37 cm Very dusky red to black (2.5 YR 2/2 - 2/1) slightly more compact fibrous loamy peat; plant remains just identifiable and are mainly fibres; squeezes dark brown turbid water and part of peat passes through fingers; pH 5.4; boundary distinct,
- 37 - 50 cm Dark brown (7.5 YR 3/2) and brown (7.5 YR 4/2) somewhat varicoloured, slightly sandy loamy peat; patches of pumiceous sand incorporated in well-decomposed peat; squeezes turbid brown water; pH 5.6; boundary sharp,
- 50 - 70 cm Brown to strong brown (7.5 YR 4/4 - 5/6, moist) very tight, fibrous loamy peat; no recognisable plant remains apart from mass of root fibres; squeezes yellowish-brown, fairly clear water; strong reducing smell; pH 5.8; boundary sharp,
- 70 - 75 cm Light brownish grey (10 YR 6/2, moist) slightly slippery pumiceous sand, peat stained but not peaty; boundary sharp; pH 6.0,

(Profile No. 35 - continued)

- 75 - 100 cm Brown (7.5 - 10 YR 4/4, moist) sandy loamy peat grading to peaty loam; tight and "cheesy" consistency; no visible plant remains; squeezes between fingers; pH 6.1; boundary sharp,
- 100 - 120 cm Dark grey-brown (10 YR 4/2, moist), loamy coarse sand and pumice gravel; peat-stained but not peaty; pH 6.2; boundary sharp,
- on.. Dark brown (10 YR 4/2) "cheesy" peaty loam; well decomposed and no recognisable plant remains; pH 6.1.

NOTICE

Soil profiles of characteristic areas of semi-arid zones are not described herein, because they have been published in the Chilean Journal of "Agricultura Técnica", Vol. XVIII - 2nd part, 1958 and Vol. XIX-XX, 1960 - published by the Dirección General de Agricultura, Santiago, Chile.