

REPORT ON THE SOILS OF BOLIVIA

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NOTES ON THE SOILS OF BOLIVIA

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5. Report of the Fourth Session of the Working Party on Soil Classification and Survey (Subcommission on Land and Water Use of the European Commission on Agriculture), Lisbon, Portugal, 6-10 March 1963.
6. Report of the Second Meeting of the Advisory Panel on the Soil Map of the World, Rome, 9-11 July 1963.
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- CONTENTS -

	PAGES
I. PHYSICAL CHARACTERISTICS OF BOLIVIA	1
II. RANGE OF SOIL FORMING PARENT MATERIALS	8
III. RANGE OF CLIMATIC FACTORS	9
IV. VARIATIONS IN PLANT COVER	11
V. MAIN ENVIRONMENTAL REGIONS AND SOIL PROCESSES OPERATING	14
VI. PROBABLE NATURE AND CLASSIFICATION OF THE SOILS; A TENTATIVE SOIL MAP SHOWING THE SOILS OF BOLIVIA CLASSIFIED ACCORDING TO THE WORLD SOIL RESOURCES OFFICE SCHEME PREPARED FOR THE SECOND DRAFT OF THE LATIN AMERICAN SOIL MAP.	47
A - RECENT ALLUVIAL SOILS	47
B - HYDROMORPHIC SOILS	47
C - LITHOSOLS AND MOUNTAIN SOILS	48
D - REGOSOLS - None of major extent: Occur mainly with Chestnut soils	
E - ALTIPLANO SOILS	48
F - DESERT AND SEMI-DESERT SOILS	
G - BROWN SOILS	49
H - CHESTNUT SOILS	49
I - PRAIRIE SOILS - Probably none in Bolivia apart from those of Altiplano	
J - BROWN FOREST SOILS - Included with Lithosols	
K - RED AND BROWN MEDITERRANEAN SOILS, AND RELATED SOILS	50
1. Non-Calciic Brown Soils	50
2. "Grey Wooded" Soils	
3. "Grey Forest" Soils	
4. Intergrades to Red Yellow Podzolic Soils	
L - GRUMUSOLS - Probably none of wide extent in Bolivia	
M - RED- YELLOW PODZOLIC SOILS AND REDDISH-BROWN LATERITIC SOILS	
N - LATOSOLS	51
VII. REFERENCES	52
VIII. LIST OF TEXT FIGURES	54

I. THE PHYSICAL CHARACTERISTICS OF BOLIVIA

Bolivia, the only completely land-locked country in South America, covers a total area of 415,000 sq. miles; situated astride the central sector of the Andean mountain system and extending down to the central lowlands. In the latter portion, Bolivia has common frontiers with Brazil, Peru, Paraguay and Argentina. In the mountainous sector it has common frontiers with Chile, Peru and Argentina.

There are three obvious physiographic divisions to Bolivia: the Altiplano and adjacent highlands, representing about 14% of the country; the east facing Andean slopes and intermontane valleys, occupying about 29% of the country; and, finally, the eastern plains representing some 57% of the total area of the country. Each of these major physiographic divisions can be divided into 3 subregions (Fig. 1).

a. The Eastern or "Altiplano", physiographic division consists of wide, flat plains of undulated to rolling glacial landforms, and a number of hills and mountain ranges elevated high above the main base level of the Altiplano. The mean altitude of the Altiplano is about 4,000 m., whereas some of the higher mountains rise to over 7,000 m. Some of the landforms appear to have been preserved almost intact from early Tertiary time, before the great orogeny; but the greater part of the Altiplano landscape was modified extensively during four glacial periods in Quaternary time, and further modified by erosion and accumulation in recent time. A conspicuous feature of the Altiplano landscape is the wide, flat plain once occupied by a chain of lakes and lagoons. Thus the western physiographic division has within it at least three distinct physiographic subregions:-

i. Northern Altiplano region

The northern subregion has the higher proportion of land of rolling relief than the rest of the Altiplano, and enjoys a somewhat less rigorous climate owing to ameliorating influence of Lake Titicaca which forms its northern boundary. The climatic regime may best be described as "dry subhumid, Altiplano". The landscape was probably once covered with dense tussock grassland and patches of xerophytic shrubs, although little of this now remains owing to centuries of intensive potato and quinoa cultivation and grazing by llamas and other indigenous livestock. Even today, practically every hectare of soil is used for crops of wheat, barley, beans, potatoes and other vegetable crops; only the most stony and shallow soils are uncultivated and used for grazing by sheep, cattle, llamas and alpacas. The present landscape is characterised by small cultivated plots surrounded by stone walls. In this region, the mean annual rainfall is between 500 and 700 mm. and mean annual temperatures are in the vicinity of 10°C. Occasional, severe frosts do great damage to crops in the flattish basin areas, but are less of a hazard to crops on the rolling downlands.

The soils range from shallow stony sandy loams to deeper gray and reddish-brown clays, and are locally calcareous in the subsoil. Saline soils are restricted to small areas in the centre of basin topography. There is a deficit of soil moisture from August to October, but over the whole year there is an excess of precipitation over evaporation.

ii. Central Altiplano region

The central Altiplano subregion is characteristically formed of wide, flattish plains, formerly occupied by lagoons, surrounded by a narrow fringe of rolling land, which, in turn, is enclosed by a ring of mountains. The climatic regime is markedly drier (mean annual rainfall between 200 and 400 mm), with very strong and cold dry winds during much of the year. Frosts are intense during winter, spring and autumn months, so that cropping is restricted mainly to the steeper slopes of the rolling downland and to the lower slopes of the mountains. The main annual temperature is probably about 6°C. The total climatic regime can be described as "semi-arid Altiplano". The agricultural pattern is predominantly pastoral, with llamas far more common than alpacas, and sheep more common than cattle. Although greatly modified by centuries of pastoral farming, enough remains of the natural vegetation to suggest that the original plant cover was mainly low tussock grassland with wind-sheared xerophytic scrub on the more bouldery and stony soils.

Soils range from bouldery loams to calcareous heavy clays, with saline soils common on the plains. Evaporation rates are very high during most of the year, and for five months of the year there is a marked deficiency of soil moisture; the total annual moisture deficit is of the order of 250 mm. During the intense rains of January to March, there is much sheet erosion and mass flow of the topsoils. Wind erosion is also very active as an agency for redistributing topsoil materials, especially in the western sector where the soils are forming from fine pumiceous volcanic ash.

iii. Southern Altiplano region

The third and most southerly of the Altiplano physiographic subregions has a still drier climate, - best described as "desertic Altiplano". Over much of the region there is a marked moisture deficit throughout the year and the total annual rainfall is in the vicinity of 100 mm. In some years no appreciable rain is recorded. Owing to the very high evaporation rates, rainfall brings little relief to the dry soils. Very severe frosts are common and may occur at any time of the year, with the result that crop production is restricted to especially favourable sloping and sheltered locations. The mean annual temperature may be as low as 3°C, although the diurnal range is very wide. Much of the landscape is occupied by broad barren salt plains ("salars"); elsewhere the plant cover is scanty and restricted mainly to open, low tussock grassland. Agriculture is mainly pastoral; sheep and llama flocks being herded across the plains to localities where a little rain has freshened the natural tussock pasture. The soils are typically desertic in character.

b. The Central, (or "Sierra") physiographic division

This division consists almost entirely of steep slopes enclosing narrow inter-montane valleys. In this division, there is a great complexity of micro-climates within different valleys, within sectors of the same valley, or even between opposite slopes of the same sector of a single valley. The chief factors involved in the formation of these local climatic conditions are the altitude of the valley floor, the general trend of the valley system, and the length and width of any particular sector. In about the centre of this physiographic division, the main axis of the Andean chain bends from its general north-south direction, and takes on a northeast-southeast trend. Thus, all the valleys carved in the flanks of the Bolivian Andes in the northern sector follow a general northeast direction and they become funnels whereby the hot, moist air from the Amazon climatic system can travel up to the edge of the Altiplano. By contrast, the valleys carved in the flanks of the southern sector of the Bolivian Andes have an easterly or southeasterly trend, less directly affected by the flow of the Amazonian air masses, and are much more affected by the advances of cold air masses from the south. Between the two regions lies the central sector of the Bolivian Andes which comes under the influence of both regimes but to only a moderate degree. This is the, admittedly, oversimplified basis for dividing the Central physiographic region into northern, central and southern physiographic subregions:-

i. Northern Sierra subregion

These are locally known as "yuñigas". They commence at the point where the warm, moist tropical air from the lowlands meets the colder, drier air of the Altiplano system, forming an almost permanent cloud belt. This usually takes place at an altitude between 2300 m. and 3700 m. depending on local topographic conditions. Above this point, the valley heads and mountain ridges have a cold, moist-to-dry subhumid environment.

In the majority of areas the cloud belt none occurs at 3300 m. Here the air is cool and strongly charged with moisture, the vegetation is a dwarf forest of gnarled, wind-shorn trees thickly hung with lichens and epiphytes. The soils are shallow and strongly acidified beneath a thick layer of raw forest humus that increases in depth on the broader mountain ridges to form small peat bogs. The environment is unattractive of little interest to farmers and foresters alike: - a matter of some importance, for if the natural vegetation should be extensively disturbed, massive sheet erosion would remove the whole of the thin soil mantle. Immediately below the cloud forest belt, there begins an upper montane forest belt with taller and straighter trees of modest girth, draped with lichens, ferns and mosses, and interspersed with arborescent ferns. The climate is still cool and moist, but the air is less saturated and moisture condensation is diminishing. Here the mantle of soil and weathering rock on the steep slopes is somewhat deeper (averaging perhaps 30 cm.); and even under natural conditions, long slip-scars mark the places where some of the larger and older trees have torn loose from the mountainside and started debris avalanches. As with the zone above, the environment is fortunately unattractive to farmers and to commercial foresters.

The lower montane forest belt appears next, with trees of greater height and girth rooted in a mantle of soils weathering rock that often exceeds 50 cm. even on very steep slopes. The climate is warmer and locally somewhat drier (as on the north-facing lower slopes of some of the deeper valleys). Under natural conditions erosion is not particularly active, but accelerates rapidly when large-scale timber extraction is practised, and may become spectacular in places where pioneer farmers have tried to carve cropland from the forested steep slopes. In most areas, the lesson has been quickly learned, and few farmers have remained permanently in this belt.

Below this latter belt begins the true rain forest, passing successively from warm temperate to sub-tropical and tropical facies as the temperature increases with increasing elevation. Concurrently with changes in the forest composition, the mantle of soil and weathered rock on the steep slopes increases in depth and both the colour of the soils and the nature of the soil clays show progressive change, in the direction of reddish soils of predominantly kaolinitic composition. The subtropical belt appears to have been most attractive to pioneer settlers, and from this zone they have spread upward into the temperate belt and downward into the tropical belt, commencing first on the lower slopes of the valley sides and extending upwards on to all but the most precipitous slopes. Under natural conditions, erosion is not very evident, but intensive cropping has reduced many areas to bare rock. Most farmers have been forced into a system of shifting agriculture, with increasingly long intervals between crops and an everlasting search for new forest land to balance declining crop yields. Shifting cultivation of indigenous Indian farmers in the humid tropics depends for its success on a nice balance between exploitation of accumulated fertility in forest residues (plus some renewal of fertility through slightly accelerated erosion) and the modest demands of a purely subsistence economy. When the demands are increased by the need to grow crops in quantity beyond the immediate subsistence requirements of the farmers, shifting cultivation leads to greatly accelerated erosion and the ultimate ruination of the soils. In the "jungas" of Bolivia, this situation is compounded by the lack of inherited, indigenous skills for dealing with this type of problem: the farmers are, for the most part, recent immigrants into the region. The situation would be less serious if production was based from the outset on such tree crops as coffee, citrus, papayas and mangos; and the land thenceforth kept permanently under their shade. However, a very high proportion of the land is used for maize, mandioca ("yuca"), coca, and other raw crops, and, as a result, large areas have passed out of production other than casual livestock grazing.

ii. Central Sierra subregion

In this region, the belt of maximum condensation is less marked and there is rarely any true cloudforest. The zones of slightly higher humidity and precipitation at high altitudes are indicated usually by light shrubby forest of quchuina (*Polylopiis incana*), and even this does not form a continuous belt but appears locally where cool and moist air condition prevail. There is no regular and well-defined sequence of vegetation belts as in the northern sector of the Bolivian Andes.

The valley-heads in this region extend back into the semi-arid region of the Altiplano, and the steep slopes are thinly covered with tussock grassland. Agricultural endeavour is restricted to nomadic grazing of the natural grassland. At first, with decreasing altitude and increasing precipitation, the tussock grassland thickens and small shrubs appear. Much of this belt has been overgrazed and periodically burned to promote new grass growth, with the result that much of the tussock grassland has been replaced by short turf of sedges and annual grasses. In this zone, indigenous farmers have exploited the lower valley sides for potato, quinoa and wheat production, and have been forced by growing population pressure to extend their cropping activities to the steeper slopes, thereby causing greatly accelerated erosion. This occurs approximately in the zone of maximum humidity in the higher altitudes, and scattered remnants of *Polylophus* scrub-forest are common. The soils are shallow, mainly somewhat acid and range in texture from loams to clays depending on parent material.

With decreasing elevation, microclimatic differences become very marked: the change may occur anywhere from 3300 m. to 3800 m.; with some valleys sections of valleys, or even opposite sides of valleys showing in swift succession changes from cool dry subhumid to warm dry subhumid, to very warm semi-arid conditions. In some areas, where warm, humid air from the "yungas" region impinges on the periphery of the central Sierra region, the sequence of climatic conditions is even more spectacular, running the gamut from cool, very humid to very warm, semi-arid in a distance of less than 20 Km. and over an altitudinal range of less than 1500 m. The vegetation patterns are a sure guide to climatic conditions and also fit well with soil categories; despite great textural range controlled by the nature of the soil parent materials. Decreasing rainfall and increasing temperature are paralleled by decreasing leaching of exchangeable bases and increasing movement of clay from the topsoil into the subsoil. This latter process reaches its maximum in the dry subhumid zones, and is less in evidence in the calcareous soils of the warm semi-arid zones.

At elevations approaching 100 m. and continuing down to the lowland plains, the environment becomes more uniformly humid and warmer. Here the vegetation pattern gains some measure of uniformity on all slopes, although variations in the soil pattern due to variations in soil parent material are somewhat more marked. This is a zone of semi-deciduous woodland growing in fertile soils showing distinct clay movement into the subsoil; a feature which is still retained to some degree when the forest changes to light tropical rainforest on the foothills in the immediate vicinity of the plains.

iii. Southern Sierra subregion

The valley-heads of the southern region of Andean slopes and intermontane valleys lead back into the saline and desertic region of the Altiplano. The upper montane slopes and high valleys are decidedly semi-arid and are used only for seasonal pasturage on the sparse *Stipa* tussock grasses. With decreasing elevation, a zone of dry subhumid xerophytic scrubland and tussock grassland appears, but soon gives way to semi-arid conditions

generally with some valleys experiencing almost desortie conditions, with a strong development of saline soils on the valley floor. Conditions improve with further decrease in altitude, and the lower foothill zone enjoys subhumic climatic conditions which permit the growth of semi-deciduous woodland and, finally, near the start of the eastern plain, a mixed deciduous and evergreen forest. Soils of fair depth and natural fertility are to be found in this latter zone, but the length of the dry season has discouraged settlement.

c. The Eastern ("plains") physiographic division

The natural resources of this division are scarcely yet explored. Almost the whole of this natural unit consists of one vast alluvial plain built up as a wide apron of detrital material eroded from the flanks of the Andes after their uplift in the Late Tertiary time. This material almost fills the Chaco basin, extending right across the western limit of the Brazilian shield, and also contributes largely to the filling of the Amazon basin. In its final stages, the plain was built up by coalescing fans of rivers subject to seasonal flash flooding; their frequent changes of course can still be read in the anastomosing pattern of low sandy ridges and clay-filled shallow depressions. As the accumulation process diminished, many of the larger rivers developed lightly incised channels running northwards to the Amazon basin; while those from southern valleys continued their southeastern trend across the Chaco plains to join the Parana river system.

Although derived from alluvium, most of the plain is no longer subject to deposition of fresh alluvium from outside the area. Today, the process is more one of local redistribution of superficial soil material during the short but intense rainy season. For the most part they are old soils with a very marked degree of clay accumulation in the subsoil. Rainwater can no longer penetrate readily and during the rainy season the surface of the plain becomes awash with ponded rainwater which moves slowly down the gentle slope of the plain, resorting and transporting some of the sandy material from the low ridges. In this process no new alluvial material is added. Only along the western margin of the plain are younger alluvial soils to be found, the centre and most of the eastern part of the plain are old soils with strongly differentiated profiles.

It is interesting to note that the nature of the sediments on this plain bear some relation to the river system of the Central physiographic division. For example, the northern sector of the plain has been built up by rivers flowing from a somewhat acid, strongly weathering environment and the sediments are mainly acid and kaolinitic; while the southern sector of the plain has been built up by alkaline and saline materials carrying less weathered clay minerals.

There are certainly more than three physiographic subregions in this plain, but for the purposes of this report, a very broad grouping into northern, central and southern regions will be sufficient.

i. Northern plains subregions

This region experiences a tropical climate with a mean annual temperature in excess of 26°C and with a mean annual rainfall in excess of 1500 mm. There is a long rainy season (October to April) followed by a very hot, dry winter season. The soils become markedly moisture-deficient from July to August owing to the high rate of evaporation and transpiration. Much of this northern plain is covered with species of coarse grasses, well-adapted to survive the extreme oscillations of soil moisture conditions. The natural grasslands serve as rangeland for an extensive beef cattle industry.

ii. Central plains subregion

The central plain experiences a mean annual rainfall of about 1000 mm. falling mainly between November and March. The mean annual temperature is in the vicinity of 23°C, and the relative humidity of the air is lower than in the northern plains region. Most soils are markedly deficient in moisture from July to October but in the rainy season a large part of the plain is inundated with "perched" water for weeks at a time. The natural vegetation is a mixture of grassland, chaparral scrub, and light forest, each vegetation type being accurate indicators of specific soil conditions. In the western sector of the central plains there are extensive areas of sandy soil, locally heaped by the wind to form low dunes. In the northeast sector, where the soils are derived from ancient metamorphic rocks of the Brazilian shield, a type of dry subtropical forest grows on soils that are old and leached. In the southeastern sector, there is a more thickly forested belt that experience an annual rainfall of about 1300 mm. and mean annual temperature of about 26°C.

iii. Southern plains subregion

This is in many ways comparable to the Chaco region of Paraguay. The mean annual rainfall is between 900 and 700 mm., falling mainly in the period January to March. Mean annual temperatures are thought to be in the vicinity of 27°C., with very hot summers and cool winters. The soils are subjected to a long period of moisture-deficiency followed by a brief period of inundation by "perched" water during the rainy season. The natural vegetation is mainly xerophytic woodland, with areas of open, grassy plains and many patches of swamp. Parts of the area are distinctly saline.

II. RANGE OF SOIL FORMING PARENT MATERIALS

The dominant soil forming parent materials are the sandstones and shales of the Andean system, and their derived sediments accumulated mainly in the Chaco and Amazon basins. The 'clayey' rocks (shales, claystones, phyllites, mudstones, etc.) on the one hand, and the quartz-rich sediments, on the other hand, form strongly contrasting soil forming parent materials throughout most of the "sierra" physiographic division. These two contrasting groups of sediments occur together in imbricate bedding patterns (Ahlfeld, 1946; Douglas, 1914) over much of the Andean systems. In Bolivia, the Andes have only a very small proportion of andesite, and indeed igneous rocks and any kind are relatively rare, - except on the Altiplano where rhyolitic and other acid volcanic rocks are more common. Many of the sedimentary rocks of the Andes are indurated or somewhat metamorphic and hence tend to resist weathering. On the other hand, there are considerable areas of hard rock crushed and split through faulting in which weathering processes often penetrate deeply. Shales and sandstones are the commonest soil parent materials in the Bolivian Andes.

Pre-Cambrian crystalline metamorphic rocks of the Brazilian shield system, and Mesozoic sandstones very rich in quartz, break through the ancient alluvial plains in the eastern region of Bolivia, near the Brazilian border. These are very ancient rocks, but the present landscapes are much less old, and only in rare local patches have the weathering products of these rocks been long enough in place to produce Latosols equivalent to those over the shield rocks of the Brazilian plateau.

The great depression of the Chaco and Amazon basins, between the youthful Andes and the ancient Brazilian shield, are almost levelled across into one continuous plain by the erosion products of both. The Andes made by far the greatest contribution during Quaternary times, but in most areas the sedimentation process has been on a minor scale in geologically Recent times. Today, the sediments from the Andes are mainly deposited over a narrow ribbon of lowland immediately along the foot of the Andes. The superficial material over the whole lowland plain is mainly ancient, or old, alluvial material that undergoes but minor re-sorting and re-distribution during the rainy season.

The old alluvial sediments of the northern part of the lowland plains are, in general, more kaolinitic and of finer grade than those of the central and southern sectors. This is not entirely due to differences in the existing climatic regimes, but also owes much to the much stronger weathering environment of the humid "Yungas" region, whence most of the later sediments of the northern lowlands have been derived.

Thick accumulations of volcanic ash are recorded only from the central and southern sectors of the Altiplano, where the climate is too dry for the volcanic glasses present in the ash to yield significant amounts of allophane clay on weathering. There are no known "Ando-Trumao" soils or "Andosols" in Bolivia.

The only complete geological map of Bolivia is that published by Oppenheim in 1954.

III. RANGE OF CLIMATIC FACTORS

The climate of Bolivia is exceptionally varied (fig. 2). It ranges from Altiplano desert regimes, where rainfall is negligible and mean annual temperatures are less than 5°C , to hot and humid tropical jungles. Between these extremes, there is a wide variety of semi-arid, dry and moist sub-humid, and humid moisture conditions, occurring with cold, cool and warm temperature conditions, and with sub-tropical and tropical conditions.

Bolivia owes this great diversity of climate to the great height and width of the Andean chain, to a sharp bend in the axis of the Andes near the centre of the country; and to the continual and fluctuating battle between two great air masses, - the outpouring of warm, moist air from the Amazon basin and the strong northward thrusts of colder and drier polar air. The latter periodically invades the southern part of Bolivian territory and sweeps along the eastern face of the Andes as far as the bend in the axis; the moist tropical air mass presses steadily against the north-western flanks of the Andes and, when the polar airstream is weak, creeps southward over the whole of the eastern lowlands. The frequent incursions of polar air as far north as Santa Cruz produces rapid fluctuations in air temperatures. Although mean annual temperatures may be high enough to qualify for classification as 'tropical', the mean daily fluctuations are so wide that the whole of the lowlands of southern and central Bolivia must be regarded as 'sub-tropical' rather than tropical. Only the northern third of the lowlands experiences a truly tropical climate.

The "heat pole" of South America is located in the south-eastern corner of Bolivia, and here, in the Bolivian Chaco, semi-arid subtropical conditions prevail. Here the mean annual rainfall falls as low as 700 mm. (fig. 3) and mean annual temperatures rise as high as 26.5°C . (fig. 4).

Surrounding this semi-arid region is a belt of dry sub-humid sub-tropical lowland. Towards the east, mean annual temperatures remain high (25°C - 26°C) but the mean annual rainfall increases to about 1200 mm. Rather similar conditions prevail in the west, along the foot of the Andes, although the mean annual rainfall scarcely reaches 1000 mm. North of the heat pole of the continent, there is a gradual transition from dry sub-humid to moist sub-humid conditions, with mean annual rainfall rising to about 1200 mm. and mean annual temperatures falling to 22.5°C . Throughout the whole of this sub-humid zone, there is a marked asymmetry in the distribution of rainfall. The greater part of the rain falls in the summer months (November to March), with little or no rain falls in the winter months.

Further to the north and west, mean annual rainfall over the lowlands increases to slightly over 25°C . This part of the lowlands is almost continuously within the influence of the Amazon air mass; daily temperature fluctuations are small, and the rainfall is distributed fairly evenly throughout the year. There are two small peaks in the annual rainfall graph, corresponding to the movement of the sun across the equator, but the only dry season recognised is a weakly defined one, occurring in the winter months.

On the flanks of the Andes, temperature regimes are mainly controlled by altitude, whereas moisture regimes are largely controlled by aspect and by position with respect to the Amazon air mass. Thus, on the north-eastern wall of the Andes, where most of the valleys open out towards the Amazon, the hot, humid air flows upwards across the foothills and up the valleys, cooling and condensing as it rises until, just below the level of the altiplano, it attains a belt of almost permanent mist with maximum condensation, marked by the development of characteristic cloud-forest. In this sector of the Bolivian Andes, there is a consistent sequence of climatic belts, from moist tropical, through moist sub-tropical, humid warm temperate, humid temperate, very humid cool temperate, to super-humid cool-to-cold temperate and humid tundra climate.

To the south of the bend in the axis of the Andes, the Andean valleys are more tortuous but follow a general easterly or south-easterly directions. The whole sector lies somewhat in a rain shadow formed by the bend in the axis of the Andes, and the overall moisture regimes range from dry to moist sub-humid. The climate is noticeably drier in the bottom of many of the more deeply incised valleys, and, in some, semi-arid to almost desertic conditions prevail. The driest of these intermontane valleys occur towards the east where sub-humid temperatures prevail. With increasing altitude there is a general sequence from semi-arid sub-tropical conditions, through dry sub-humid warm temperate, to moist sub-humid cool temperate conditions. However, in this strongly serrated region, with several thousand metres between valley bottoms and ridge tops, and with the valleys themselves making frequent twists and turns of 90° or more, the climatic belts are commonly telescoped and abrupt climatic changes may occur over comparatively short distances. Remnants of the natural plant cover, and soil profiles, often provide the best guide as to the prevailing climate in any particular spot.

In Bolivia cold climatic conditions usually commence at between 3500 m. and 4000 m. The whole of the altiplano and the surrounding mountain ranges experience cold to very cold tundra like conditions. The moisture regimes of the altiplano range from sub-humid in the vicinity of Lake Titicaca, through semi-arid in the central sector, to arid and desertic in the south. The surrounding mountain ranges experience very cold but relatively humid conditions in the north-east; very cold and moist sub-humid in the west, and very cold dry sub-humid to semi-arid in the south and south-east. The permanent snow-line is very high (often over 5500 m) owing to the high rate of direct evaporation of snow exposed to the strong desiccating westerly winds. The climate of the whole of this elevated part of Bolivia is dominated by these extremely strong, cold, dry winds. Frosts are severe and common throughout the year over the southern part of the altiplano profile, but diminish in intensity and frequency in the vicinity of Lake Titicaca. Cloud frequency increases from south to north and from west to east, but the whole of this highland region is subjected to relatively strong radiation.

Climatic maps for Bolivia have been prepared by Prada (1946) and Antezana (1958), and data from the altiplano has been analysed by Escobar (1948), by Stens (1950), and by Yelpe (1950). The microclimate of the Cochabamba valley has been discussed by Urquida (1954), and by Fernández (1961). For large areas of Bolivia, however, climatic information is incomplete. The accompanying sketch map (fig. 3) seeks to harmonise the existing published data, which is sometimes contradictory, and makes use of inferences drawn from the natural plant cover and the stage of development of the soils. In this sketch map, some 20 distinctive climatic regimes are indicated, although the boundaries shown will certainly prove to be inaccurate when more abundant and more reliable data is available.

LEGEND FOR FIG.5 : ENVIRONMENTAL UNITS

HIGHLAND ENVIRONMENTS

1. Very Humid Paramo and Humid Alpine Tundra
2. Subhumid Paramo and Humid Alpine Tundra, with Peat Bogs
3. Subhumid Subalpine Steppe, with Peat Bogs
4. Montaine Steppe
5. Montane Desertic Steppe and Humid Alpine Tundra
6. Desertic Tundra
7. Moist Subhumid Altiplano Steppe
8. Dry Subhumid to Semi-Arid Altiplano Steppe
9. Desertic Altiplano Steppe

SIERRA ENVIRONMENTS

10. Tropical Rainforest
11. Subtropical Rainforest
12. Lower Montane Rainforest
13. Montane Rainforest
14. Upper Montane Rainforest and Cloudforest
15. Lower Montane Dry Forest (semi-xerophytic)
16. Lower Montane Dry Forest and Thorny Woodland
17. Montane Dry Forest and Tall Chaparral
18. Upper Montane Polylepsis incana Forest and Grassland
19. Lower Montane Chaparral
20. Lower Montane Thorny Woodland, Chaparral and Cactus
21. Montane Low Chaparral, Xerophytic Forest and Grassland
22. Upper Montane Grassland with Polylepsis incana
23. Upper Montane Steppe and Paramo
24. Lower Montane Cactus Formations
25. Montane Dry Woodland and Cactus with Thorny Chaparral

LOWLAND PLAINS ENVIRONMENT

- 26a. Amazonian Rainforest of Downlands
- 26b. Amazonian Rainforest of Plains
27. Tropical Savanna
28. Bolivian Rainforest (Chaparé Formation)
- 29a. Upper Paraguay Subtropical Rainforest, on Crystalline Basement Rocks
- 29b. Upper Paraguay Subtropical Rainforest, on Alluvium and Basement Rocks
- 30a. Upper Paraguay Subtropical Rainforest, Drier facies, on Basement Rocks
- 30b. Upper Paraguay Subtropical Rainforest, Drier facies, on Alluvium and
Basement Rocks
- 30c. Upper Paraguay Subtropical Rainforest, Swamp facies, on Alluvium
- 31a. Subtropical Savanna
- 31b. Subtropical Savanna with Swamp Formations
- 31c. Subtropical Savanna and Dry Subtropical Forest
- 32a. Dry Subtropical Forest* on old Alluvium
- 32b. Dry Subtropical Forest on old Alluvium, and with Savanna
- 33a. Dry Subtropical Forest, on Crystalline Basement Rocks
- 33b. Dry Subtropical Forest, on Crystalline Basement Rocks with old Alluvium
34. Subtropical Thorny Woodland**
- 34a. Subtropical Thorny Woodland and Salt Flats
35. Subtropical Thorny Woodland and Savannas

* "Guaraya - Chiquitana" Formation.

** "Chaco" Formation.

IV. VARIATIONS IN PLANT COVER

No complete ecological survey has yet been made of Bolivian plant formations. It is estimated that, when such a survey is made, it will be found that there were formerly at least 35 important plant formations present in Bolivia. Many of these natural plant formations, especially those of the arid and subhumid regions, have been greatly modified by centuries of grazing and cropping, yet usually sufficient vestiges of the natural cover still remain to permit the construction of ecological maps.

The attached sketch map (fig. 5) attempts to show something of the ecological diversity of the Bolivian landscape. The units shown are more in the nature of ecological regions rather than plant formations or vegetation units, and the boundaries shown are certainly far from accurate. The more accuracy of the boundaries shown on this map have been taken from a map of the phytogeographical regions of Bolivia by Arce (fig. 6). This map is accompanied by a very brief report giving some of the characteristic plants found in each region. (Arce, 1963). An earlier phytogeographical map was prepared by Cármonas (fig. 7).

In the humid tropical lowlands, rainforests are characterised by the following species:-

Bertholletia excelsa, *Hovea brasiliensis*, *Machaerium allemani*, *Erythrina corallodendrum*; and various palms including *Iriartea exorrhiza* and *Carludovica palmata*.

On the savannas of the humid tropical region, Arce records grasses of the following genera:-

Sporobolus, *Pectotia*, *Paspalum*, *Panicum* and *Tripsacum*.

These savannas are broken by islands of rainforest and by gallery forests along the courses of the streams. In these forests, Arce mentions the presence of:-

Hymenaea courbaril, *Erythrina corallodendrum*, *Erythrina falcata*, *Erythrina cristagalli*, *Geoffraca pluviosa*, *Tecoma leucoxyllum*, *Bignonia* spp., *Bombax* spp., and *Caesalpinia* spp.

A large part of the subhumid subtropical lowlands are still covered with forest. This ranges from open broadleaf forest near the Upper Paraguay river to semi-deciduous mixed mesophytic and xerophytic forest of the Guaraya and Chiquitana region.

The Upper Paraguay forests are characterised, according to Arce, by:-

Amphurana ccarensis, *Piptadonia macrocarpa*, *Ficus indicus*, *Tabebuia* sp., and *Carimiana* sp.

Those of the Guaraya-Chiquitana region are characterised by the presence of:-

Astronium urundeuva, *Aspidosperma vargasii*, *Piptadenia macrocarpa*, *Jacaranda acrobifolia*, *Chorisia insignis*, *Tabebuia ipa*, *Tecoma* sp., *Inga* sp., and *Orbignia phalarata*.

Subtropical savanna grassland occur near the Paraguay river and in the vicinity. The former, called the San Matías savanna formation by Arce, resemble the tropical grasslands of the northern lowlands; while the Santa Cruz savannas have, in addition to grasses, isolated patches of semi-xerophytic woodland in which are found the following species:-

Piptadenia macrocarpa, *Ficus antihelminthica*, *Acrocomia totai*, *Cercidium praecox*, *Tabebuia* sp., *Tecoma* sp., and *Prosopis* sp.

Along the foot of the Andes, in a moist subtropical region where many rivers and streams converge to form the Marmoré river, and where many recent and young alluvial soils are present, Arce records the presence of the following species:-

Hura crepitans, *Taralea oppositifolia*, *Achras zapota*, *Switonia macrophylla*, *Terminalia amazonica*, *Spondia mombin*, *Aspidosperma tomentosum*, *Aspidosperma vargasii*, *Ancornia speciosa*, *Calophyllum inophyllum*, *Erythrina cristagalli*, *Hymenaea courbaril*, *Amburana coarzensis*, *Cedrela fissilis*, *Cedrela brasiliensis*, *Guarea trichillicoides*, *Byrsonima verbascifolia*, *Virola boliviensis*, *Lonchocarpus* sp., *Nectandra* sp., and *Ocotea* sp.

In the dry sub-humid to semi-arid Bolivian Chaco region a Xerophytic thorny woodland known as the Chaquena formation is characterised by the following species:-

Caesalpinia melanocarpa, *Bulnesia sarmentoi*, *Gourlois decorticans*, *Zizyphus mistol*, *Copernicia corifera*, *Schinopsis* spp., *Aspidosperma* spp., and *Prosopis* spp.

In the extreme south of Bolivia, in a moist subhumid region near the Argentinian border, Arce recognises a semi-deciduous Tucumano-Boliviano forest formation characterised by the following genera:-

Pithecolobium, *Acacia*, *Anterolobium*, *Piptadenia*, *Prosopis*, *Caesalpinia*, *Gloditsia*, *Erythrina*, *Miroxylon*, *Tipuana*, *Astronium*, *Schinopsis* and *Styrax*.

The general name given to the rainforests of the humid north-eastern flanks of the andes is the "Yungas" formation. These forests alter markedly in composition with increasing altitude. In the lower, humid subtropical to warm temperate belt, Arce records the following species:-

Hura crepitans, *Switonia macrophylla*, *Chorisia racemosa*, *Achras zapota*, *Amburana coarzensis*, *Cinchona callisaya* and *Ficus* sp.

In the middle elevations, under a humid temperate climate, the following trees appear:-

Cedrela lilloi, *Cedrela fissilis*, *Juglans Neotropica*, *Juglans del boliviana* and *Endlicheria sericea*.

At the higher altitudes, where the climate is superhumid cool temperate, the cloud-forest belt is characterised by the appearance of:-

Podocarpus parlatorei, *Podocarpus nubigena*, *Podocarpus oleifolius* and *Alnus jorullensis*.

The plant formations in the mesothermic valleys are many and various, often restricted to small microclimates. They range from semi-arid and desertic formations with abundant cacti, to semi-deciduous woodland and grassland. Arce records the general presence of the following genera:-

Schinus, *Schinopsis*, *Jacaranda*, *Mimosa*, *Prosopis*, *Acacia*, *Fagara*, *Caricacea*, and *Coulteria*.

Plant formations of the altiplano range from low, open tussock grass-land dominated by *Stipa icha* and *Stipa frigida* to low xerophytic shrubland. Arce records the following genera:-

Polylepis, *Buddleia*, *Lepidophyllum*, *Baccharis*, *Azorella*, *Margaricarpus*, *Polypogon*, *Muhlenbergia*, *Distichilis*, *Aristidis*, *Bromus*, *Astralagus*, *Festuca* and *Stipa*.

V. MAIN ENVIRONMENTAL REGIONS AND SOIL PROCESSES OPERATING

The main environmental regions that are shown somewhat schematically in Fig. 5, will serve well for a discussion on the various processes operating during soil formation in the different environmental regions of Bolivia.

Weathering dominates over all other soil processes on the northern lowlands (map units 26 and 27 in fig. 5) and over part of the adjacent foothill (map unit 10). However, latosols in the strict sense are not recorded as being everywhere the dominant soils, because many of the stable soils of the plains are of no great age, and the less stable soils of the foothills and downlands are subject to natural erosion and truncation which delays the development of primary latosols. Yellow and Red-yellow latosols have been reported from several places (Coulter, 1963, pers. comm.) and Arce, 1963, pers. comm.) in situations which suggest that they are developing on the oldest and highest parts of ancient alluvial terraces, but the prevalence of Red-Yellow Podzolic soils suggests that the landscape is not really old enough or sufficiently stable (in the case of the foothills) for the latosols to be widely developed.

It is very evident, from profile descriptions of young alluvial soils that the rate of weathering is intense and any weatherable mineral matter is rapidly destroyed with the formation of kaolinitic clay. There is further a strong tendency for this clay to be leached downwards and many young alluvial soils show a remarkably strong textural 'B' horizon. Where groundwater exists near the surface, the kaolinitic clays are rapidly converted to the plinthite characteristic of Groundwater Latosols. Although the region has but a weak dry season, temperatures are high, and under savanna grasses (map unit 27) the soils usually dry out as far as the upper part of the subsoil during July and August. During this period, the upper part of the kaolinitic subsoils hardens and gradually assumes the characteristics of plinthite, which further impedes the downward movement of water so that, when the rain commences in earnest, the savanna is flooded with ponded surface waters, and gley conditions prevail in the soil for from four to six months of the year. Under the tropical rainforest, the process is a slower one, but the frequency of yellow colours in the soil suggests that much of the iron in the soil remains in a hydrated and partially reduced condition.

Where the parent rocks or the old alluvial materials are notably rich in quartz, the soil maintain their permeability longer, and the downward leaching of bases and eluviation of clay from the topsoil produces typical Red-Yellow Podzolic soils. Nevertheless, Yellow Podzolic soils are far more common than Red Podzolic soils in this region, suggesting that the soils are fairly continuously moist. In many cases, where red colours do occur, they are inherited from the parent red sandstones and sandy shales.

In the foothills (map unit 10) the non-red sandstones and sandy mudstones give rise to Yellow Podzolic soils, while the red sandstones give rise to Red Podzolic soils. Commonly these rocks are interbedded with shales and mudstones (often slightly calcareous) of high clay content. These pre-weathered soil parent materials are usually not dominantly kaolinitic clays. When they take

part in the soil formation, they give rise initially to dark soils with a high proportion of expanding clays, such as montmorillonite, vermiculite, etc. In a low position on the landscape where they can maintain their base-rich condition by the passage of lateral run-off containing bases derived from decaying plant remains, they retain their dark-colour and good physical structure, even under tropical rainforest. However, where this process of enrichment is not operating, they change rapidly to heavy, dull grayish-brown, plastic and poorly drained soils: they remain with a higher base status than the surrounding Red-Yellow Podzolic soils because they leach with difficulty, but their poor physical condition makes them difficult to farm.

A third kind of soil is likely to be found in the tropical foothill region (map unit 10) in areas where basic igneous rocks or basic volcanic breccias outcrop. These are not likely to be of great extent (according to the geological maps of Ahfeld and Branisa (1960) and Oppenheim (1954), but should they occur, they may be expected to form Reddish-Brown Lateritic soils which, in stable positions, may become Latosols after a long interval of time.

The fertility of all these tropical soils will depend upon two groups of soil processes, one group forming the organic regime of the soil, and the other one known as the drift regime. The processes of the organic regime of importance in maintaining fertility in humid tropical soils, are those connected with the uptake of nutrients by the vegetation, and the subsequent fall and decay of the plant residues which produces a return of nutrient elements to the topsoil. Where soil weathering is intense (and hence mineral reserves in the soil are rapidly changed to soluble compounds) and where leaching is strong (and hence the soluble compounds are readily lost in the drainage water), any mechanism that temporarily withdraws plant nutrients and holds them in a form that is secure from the soil weathering and leaching processes, is an invaluable help in prolonging the fertile life of the soil. Thus it is important to maintain the soil constantly under an efficient type of plant cover. Species differ widely in their capacity for removing and returning essential nutrients such as calcium, potassium, magnesium and even phosphorus, but in general trees are more efficient than shrubs or grasses. Shrubs and grasses have an additional disadvantage that they become dry enough during a short dry season to be easily burned. When plant residues are burned, all the available mineral contents are made available suddenly usually in quantities far in excess of the capacity of the unburned vegetation to absorb them, and most of these invaluable nutrients are lost by leaching or slope wash long before a plant cover is re-established. Nature's own process of decomposition of organic material ensures a slow but steady release of plant nutrients. Even when the land is cleared without resort to fire, the rapid destruction of organic matter following exposure to the heat and light of the sun hastens the onset of sterility in the soil. For the farmer in the humid tropics, it is most advisable that he introduces his farming system with as little disturbance as possible of the natural processes of the soil organic regime. He should elect to plant arborescent tree crops (such as cocoa, coffee), if economically feasible; and these crops should be underplanted in natural forest after the larger hardwood trees have been felled. In a similar way, the conversion of forest to pastureland should take place without any intervening period of crop

farming and the forest should be felled (but not burned) and, after an interval of a few months, the area should be oversown with leguminous plants (such as kudzu, centrosema, etc.) which will provide some rough but nutritious grazing while the logs are decaying. For several years, regrowth of unwanted forest seedlings must be discouraged by hand chopping, and when the land is sufficiently free of logs, it can be close-grazed and sown down to the desired species of grass or legume. It is slow and it is untidy, but it is almost the only way to develop a pastoral farm in humid tropical regions remote from any source of fertilizer, and where mechanical equipment is not available.

The second group of natural processes that can be brought to the aid of the farmer in the humid tropics to help maintain soil fertility are the much discussed erosion processes. It is inevitable in the humid tropics that the greatest store of plant nutrients is to be found in the immediate vicinity of the decaying rock. Usually, this is far below the surface and cannot be readily tapped, - although some farmers have successfully made use of this principle by topdressing their land with crushed rock of a suitable type (basalt, andesitic, or calcareous sandstone) from a nearby road quarry. On sloping land in the humid tropics, controlled erosion can gradually reduce the overburden of leached and weathered soil, to the point where plant roots can feed directly from the weathering rock. This is one of the underlying principles of the shifting agriculture of indigenous farmers. It has certain inherent dangers (erosion can easily get out of hand) and it cannot be applied to all soils, but when used with tree crops that yield best without ground cover (coffee, for instance), a steady but slow measure of erosion is not to be despised. On the other hand, terracing in the humid tropics is usually without point unless the objective is to grow rice.

Returning now to the remainder of the Bolivian lowlands. Because of the wide diurnal and seasonal fluctuation in temperatures these are considered to be subtropical rather than tropical. The moisture regime ranges from semi-arid, along the greater part of the Paraguayan frontier, to humid along the foot of the Andean ranges from Santa Cruz northwestward. The central sector is mainly dry subhumid, trending to moist subhumid towards Matto Grosso in Brazil. Four distinct major plant formations (subtropical rainforest, semi-deciduous or dry forest, thorny woodland and savanna) occur on these subtropical lowlands. Soil parent materials are mainly old alluvial materials, but in the northeast several extensive areas of crystalline basement rocks (Precambrian gneissic formation and Mesozoic sandstones (similar to the Roraima formation in British Guiana) emerge through the alluvial mantle. The diversity of landscape factors, moisture regimes and variety of plant cover produces a rather large number of ecological divisions (map units 28 to 35), some of which could be further subdivided because of other climatic differences (range between mean maximum and minimum temperatures, length of dry season), or because of botanical differences due to long-established or anthropological factors.

In the humid subtropical region, the older soils of both the lowlands, and the adjacent Andean foothills are both strongly weathered and leached and many are undoubtedly Red-Yellow Podzolic soils. The younger soils derived from alluvium are usually prominently stratified and are often of a sandy loam texture. With increasing age, they may become less obviously stratified and show generally clay or sandy clay textures. In most cases there is moderate clay cluviation, leading to the development of a distinct textural 'B' horizon; and both in this dense horizon, and immediately above it, mottles become quite prominent. The oldest soils in this sequence, which are to be found on the high level terrace remnants near the foothills, are Red-Yellow Podzolic soils of low base status. Many are tending towards subtropical podzolised gley soils (or better, "pseudogleys", since they tend to dry out during the dry season which lasts for 3 to 5 months) owing to the slowness with which rainwater percolates through the heavy subsoil, producing a trend towards strong gleying in addition to leaching and weathering. This sequence can be illustrated by the following three profiles (abbreviated description):-

(i)

"Laloma Sandy Loam"

Approximately 4 Km. north of Gral. Saavedra Agricultural Experimental Station; 78 Km. north of Santa Cruz.

Altitude 300 m. Forested gently undulating plain. Site examined on higher part of landscape.

Profile:

- 20 cm. gray-brown sandy loam. pH 6.4.
 - 25 cm. dark gray brown heavy sandy loam to fine sandy clay loam Ph 6.2.
 - 30 cm. dark brown sandy clay loam pH 5.9
 - 80 cm. brown to strong brown loamy sand, slightly mottled reddish-yellow and dark gray
 - 40 cm. very compact dark reddish-brown, flecked and mottled dark red and greenish-gray heavy clay. Clay skins abundant
 - 30 cm. reddish-brown heavy coarse sandy loam
 - 35 cm. very dark reddish brown, strongly mottled light gray, very dark reddish gray and strong brown, very heavy plastic clay, with carbonate concretions (Krtorinas) in upper 15 cm.
- on... yellowish-brown loamy sand.

This soil would be regarded as a slightly enleached, moderately weathered, moderately melanised young soil from very strongly stratified mixed alluvium.

(ii)

"Saavedra Clay"

Within northern boundary of Gral. Saavedra Agricultural Experimental Station,
About 75 Km. North of Santa Cruz.
Forested, very slightly undulating plain.

Profile

A1	30 cm.	dark graybrown well-structured light clay
A3 (g)	30 cm.	brown, flecked orange well-structured clay
B1	20 cm.	slightly compact, pale yellowish-brown, strongly mottled clay
B2	30 cm.	strongbrown very compact mottled fine sandy clay, with fine ironstone concretions.
on...		pale brown plastic clay, strongly mottled; becoming more sandy at 150 cm., and with calcareous concretions.

This soil would be regarded as a moderately nleached, moderately-to-strongly weathered, moderately gloyed, slightly-to-moderately melanised young soil from mixed alluvium.

(iii)

"L1 Palmar Loamy Sand"

Approximately 25 Km. southwest from Santa Cruz.
Altitude about 215 m. Cut-over forest with occasional palms.
Site examined represents an old high-level terrace remnant.

Profile

A A1	25 cm.	dark brown loamy sand
A2	15 cm.	very pale grayish brown compact loamy sand
A3/B1g	35 cm.	very dark ray brown, mottled sandy clay loam
B2	50 cm.	very strongly mottled brown, pale brown, reddish brown and dark gray heavy (sandy) clay with ironstone concretions.
on...		pale brown heavy clay, plastic and mottled.

This soil would be regarded as a very strongly enleached, strongly weathered, moderately-to-strongly gleyed, moderately melanised mature soil from mixed sandy alluvium, trending towards a subtropical Gley Podzol.

Interspersed amongst these alluvial soils showing various stages of developing maturity, there are many areas of very dark gray strongly-structured clays. They always occur in a low position on the landscape and are clearly of higher natural fertility than the surrounding soils. They receive the drainage water from the surrounding landscape and are particularly favoured for non-irrigated rice farming. They have their origin in the clayey alluvium that settles in the backwaters of meandering streams. They are moderately weathered, but the argillisation process is more or less arrested in the expanding-clay stage by the seasonal replenishment of bases from inflowing surface water and also from the natural seasonal rise of the watertable. A common profile seen is that of:-

"Aroma Clay"

Near northern boundary of Gral. Saavedra Agricultural Experimental Station, about 75 Km. north of Santa Cruz.
Altitude 290 m. Forested. Gently undulating plain. Site examined represents lower part of landscape.

Profile

- 40 cm. very dark gray strongly-structured clay
- 25 cm. moderately mottled gray, strong brown and pale yellowish, heavy silty clay.
- 25 cm. strong brown silty clay with occasional iron and manganese oxide in the form of hard concretions.
- on.... pale gray-brown plastic clay.

This soil could be regarded as a young margallitic, strongly melanised, moderately 'B' gleyed, moderately flushed clay from clayey alluvium.

From the point of view of fertility, many of these soils of the subtropical humid regions (map unit 28) have a moderate (to high) reserve of plant nutrient of great importance for the farmer. Under natural conditions this fertility declines slowly but when brought under a regular cropping programme without supplementary fertilizers, the net loss of plant nutrients from leaching and harvesting crops is, in many soils, greater than the release of plant nutrients from normal soil weathering. Soils with a high proportion of quartz sand rapidly lose fertility and they regain fertility very slowly when abandoned to re-invasion by forest. The heavier soils are somewhat more enduring in respect of fertility but a new problem arises in that with continuous cropping (especially if the same crop is grown year after year, - as in the case of sugar cane farming), the natural

structure of the subsoil gradually deteriorates. It is a common experience to find, with soils of this type, an inevitable agricultural progression from cane farming at the outset, to cane farming alternating with rice growing, to continuous rice growing, and finally abandonment of the land to rough pasture, over a total time interval of about 60 years. This occurs even where fertilizers are used, and the fundamental problem is the combined effect of progressive soil weathering and clay eluviation in the part of the subsoil not greatly penetrated by the roots of the crops. This does not usually occur in the case of the dark margellitic clays where there is strong tendency to form deep cracks during the dry season and the over-all natural soil structure is strongly developed, but it is common in many other young alluvial soils.

In the moist subhumid subtropical soils, the relative length of the dry season and wet season and the mean soil temperatures while the soil is moist all become important factors in soil development. Most of the soils dry out during the dry season and both weathering and leaching are in abeyance during this period. When the rains return there is a marked tendency for clay and fine silt particles to be washed down from the topsoil into the subsoil, almost before normal leaching and weathering processes are properly operating. The nature of the soil parent material is of some significance, and the processes are greatly strengthened if the soil clay is in a highly flocculated condition. It is common to find soils that are slightly unleached (their pH and base status being high) yet moderately or even strongly eluviated (the subsoil pores and structural fissures are packed with clay derived from the topsoil). An additional factor is also operating. As the soils are drying out after the rainy season passes, the topsoil dries first and normal weathering ceases; but the subsoils remain moist for a much longer period, and during this time normal soil weathering continues. Both factors, eluviation and weathering, contribute to the formation of the strong textural 'B' horizon found in almost all these soils. As one would expect the moist subhumid subtropical soils show less intensity of clay illuviation and more indications of weathering 'in situ' than the soils of the dry subhumid subtropics, where clay eluviation is very pronounced. The process ultimately leads to the formation of a subsoil "clay pan".

On flat or flattish land, the processes of clay pan formation ultimately lead to the development of Planosols or "Pseudogleys";- soils which have their subsoil drainage impeded to the point where they cannot cope with the wet season rainfall, and as a result "perched" water lies on the surface for long intervals. If the parent materials still contain soluble salts, these may concentrate in the topsoil as the "perched" water evaporates.

Where the soil parent materials are sandy, and especially where the landscape is of rolling or hilly relief, leaching and weathering are still the dominant soil processes in the moist subhumid subtropical zone. Thus, over the Brazilian shield rocks and sandstones of the northeast sector of the lowlands (map unit 29a and 29b), it may be expected that Red-Yellow Podzolic soils will be found. These will probably be less weathered and less leached than those of the humid subtropics and tropics, and probably will prove to have a higher base status when in their natural condition. They will

however, be more erodable than their moister counterparts in the more humid regions, although this, in part, will be due to the greater irregularity and greater intensity of the rainfall itself. Normally, these soils will be dry for 4 to 5 months of the year; yet the total moisture deficiency over the whole year is not excessive.- it is chiefly a problem of getting rainfall into the subsoil once the textural 'B' horizon has formed.

Thus farming problems are mainly problems of efficient use of water. Not so much efficient use of irrigation water, which seldom can be cheaply arranged on the Bolivian lowlands, but the efficient conservation of natural soil moisture. Cropping should be restricted to the colluvial and alluvial soils of the region; hill slopes should be in tree crops or productive forests and the rolling land should be under very carefully managed pastures with a high proportion of deep-rooting species. Many of these soils are derived from old sandy alluvium (map unit 32a) and when the natural semi-deciduous forest is cleared, they will be found to be not only subject to the disadvantage of widely fluctuating moisture conditions, but to be of low fertility to boot. Unless considerable capital is available, they should not be regarded as particularly suitable for small farm development schemes. For longer pastoral development, initial use of fertilizers, careful selection of pasture species and very careful grazing management, will be essential.

Progressing next to the dry subhumid subtropical soils of the lowlands, and including with them certain related soils of the Andean foothills extending from the south of Santa Cruz to the Argentinian border, it is noticeable that the "clay pan" forming processes are much more active. From the extensive development of "clay skins" in the subsoils, much of the subsoil clay has apparently been derived by eluviation. These soils occur as a periphery to the "heat pole" of South America and they surround a semi-arid subtropical region where crystals of soluble salts are a common feature of the soil surface. It is tempting to consider that these very fine crystals (mainly sulphates and chlorides of sodium and magnesium) are to some extent redistributed by the wind over the surrounding landscape contributing to the defloculation of the topsoil clay, so promoting more rapid "clay pan" formation. Certainly "clay pan" features are much more pronounced in these dry subhumid soils.

An additional feature is that many of these soils are derived from alluvial material derived from the relatively dry flanks of the Andes and therefore may be expected to be richer in minerals capable of yielding soluble salts in quantity on weathering. Weathering is still an important process in soil formation (although limited to the 3 or 4 months in the year when the soils are sufficiently moist), while leaching is markedly restricted by the presence of the subsoil "clay pan". Commonly, almost all the lowland soils become submerged for days at a time beneath wide sheets of "perched" water during the wet season (December to March) and during this period gley processes are very active.

When this water evaporates, soluble salts are concentrated in the surface soil, in some cases to such an extent that the soils become both saline and alkaline Solonetz and Solonchak. This process is more evident in the semi-arid subtropical region, to be discussed next, but some trace of it is visible in very many of the soils of the dry subtropical region.

The soils derived from old alluvium are perhaps close to the world group known as Reddish Chestnut soils, although differing in the presence of an argillic 'B' horizon, and in their solonitoid features. Provisionally they are being classified as "Solonitoid Reddish Chestnut soils with strong argillic 'B' horizon". They always occur complexly associated with Solonetz, Soloth and related slightly saline hydromorphic soils.

A typical profile recorded by Arens (Pers. Comm. 1963) from Cocota, near Santa Cruz, under chaparral vegetation, showed:-

- 0 to 3 cm. dark reddish gray clayloam (5YR 4/2 when moist, 6/2 when dry) with many rootlets and some thick roots; compact, hard, massive structure with tendency to subangular blocky when dry; clear boundary.
- 3 to 25 cm. dark brown silty clay (7.5YR 4/2 when moist, 5/2 when dry) with gray mottling along root channels; very hard, compact, massive structure, subangular blocky when dry; irregular tongued boundary along channels of thick roots.
- 25 to 55 cm. dark reddish brown clay (2.5YR 3/4 when moist, 4/2 when dry) with gray and reddish gray mottles; very hard, strong, compact massive structure, columnar when dry.

Under forest in the same locality, he recorded two profiles:-

(i)

- 0 to 3 cm. humic reddish brown loamy fine sand with abundant rootlets and roots; loose, soft structure, clear boundary.
- 3 to 15 cm. dark reddish gray silty to loamy fine sand (5YR 4/2 when moist, 6/2 when dry), with abundant roots and rootlets; loose, massive structure, gradual boundary.
- 15 to 30 cm. dark reddish brown slightly compacted silty to loamy fine sand (5YR 3/2) when moist, 5/2 when dry), porous, massive with tendency to fine blocky structure; some roots; diffuse boundary.
- 30 to 65 cm. slightly mottled dark brown loamy sand (7.5YR 3/2 when moist, 6/2 when dry) with some roots; compacted, massive, tendency to blocky structure, diffuse boundary.

65 onwards reddish brown loamy sand to sandy loam (5YR 4/3 when moist, 6/3 when dry), compacted, slightly mottled, with some roots; porous, medium strong massive structure.

(ii)

- 0 to 10 cm. dark reddish brown fine sand (5YR 8/3 when moist, 6/2 when dry), loose, single-grain structure, gradual boundary.
- 10 to 25 cm. dark reddish brown to reddish brown fine sand (5YR 3/4 when moist, 3/2 when dry), slightly compacted, with many roots and rootlets; soft structure, clear boundary.
- 25 to 60 cm. reddish brown loamy sand (5YR 4/3 when moist, 6/3 when dry), compacted, with some reddish gray mottles; some roots, massive, strong structure, gradual boundary.
- 60 to 110 cm. reddish brown slightly mottled loamy sand to sandy loam (5YR 5/3 when moist, 6/3 when dry), compacted, with few rootlets, massive, strong structure, gradual boundary.
- 110 on.... light reddish brown loamy sand, compacted, slightly mottled, massive strong structure.

A rather similar profile was recorded from an area transitional between forest and chaparral, in the same locality:-

- 0 to 5 cm. dark brown loamy fine sand (7.5YR 3/2 when moist, 5/2 when dry), with many grass rootlets, slightly hard when dry; massive single grain structure, clear boundary.
- 5 to 20 cm. dark gray fine sandy loam (5YR 3/1 when moist, 6/1 when dry) hard, strong, fine subangular blocky structure when dry; clear boundary.
- 20 to 45 cm. reddish brown clay loam (5YR 4/3 when moist, 5/1 when dry), strong, columnar structure when dry, with some grayish mottles along root channels, diffuse boundary.
- 45 to 75 cm. reddish brown clay loam to clay (2.5YR 4/4 when moist, 5/4 when dry); strong, columnar structure when dry; with grayish to ochric mottles and some small concretions of ironstone, diffuse to gradual boundary.
- 75 on..... light reddish brown to pinkish gray clay with reddish and ochric mottles and some ironstone concretions; very hard, strong structure, subangular blocky.

These soils have many features of slightly degraded Solonetz (Soloth) soils.

The above profiles refer to the ecological region shown as map unit 3la, which is mainly an area of savanna grassland with patches and "islands" of chaparral and dry subtropical (semi-xerophytic) forest.

Arens has also recorded two profiles from the Cocota area, under savanna grasses.

(i)

- 0 to 4 cm. dark reddish brown humic medium sand (5YR 3/2 when moist, 6/2 when dry), loose single-granular with many grass rootlets, clear boundary.
- 4 to 25 cm. dark reddish gray medium sand (5YR 4/2 when moist, 6/2 when dry) loose, single grain structure, with some grass roots, clear boundary.
- 25 to 55 cm. dark reddish gray medium fine sand or loamy sand (5YR 4/2 when moist, 6/2 when dry), compacted and indurated, massive structure, diffuse boundary.
- 55 to 80 cm. reddish brown loose fine sand (5YR 5/3 when moist, 6/3 when dry) with slight grayish mottling; loose, single grain structure

(ii)

- 0 to 4 cm. reddish gray slightly humic medium fine sand (5YR 3/2 when moist 5/2 when dry), loose monogranular structure, with many grass rootlets; clear boundary.
- 4 to 30 cm. reddish gray medium fine sand to silty sand (5YR 3/2 when moist, 5/2 when dry), slightly compacted, with rootlets; massive, with tendency to soft fine blocky structure, clear boundary.
- 30 to 60 cm. pinkish gray medium fine silty sand (5YR 3/2 when moist, 6/2 when dry), compacted, massive soft structure, easily breaking into subangular blocks, diffuse boundary.
- 60 on.... light reddish brown fine sand (5YR 3/3 when moist, 6/3 when dry), very slightly compacted, massive single grain structure.

These are sandier soils but have many features in common with the forested and chaparral covered soils.

Arce (1963) has described somewhat similar savanna vegetation (map unit 31a and 31b) from the eastern region near the Paraguay river, but little information is available concerning the soils.

The soils of map units 32b, 34a, and 34b are expected to be somewhat similar to the soils described above although no observation are available.

There remains, in this group of dry subhumid subtropical soils, the soils of map units 30 (a, b and c), 33 (a, and b); 10 and 15. The differences are likely to be, in part, climatic and, in part, due to differences in the soil parent materials.

The areas covered by both 30 and 33, have Brazilian shield rocks either at the surface or close below the old alluvial materials which form the actual land surface. The climate has a more marked dry season and greater extremes of temperature over the region covered by map units 30 (a, b and c) than the region covered by 33 (a and b). Little information is available concerning the soils of these regions. They are expected to be Red-Yellow Podzolic soils in a much less strongly weathered state than normally, with stronger textural 'B' horizon, and, in places probably intergrade to Red-Yellow Mediterranean soils, such as are known to be formed in Paraguay under similar conditions. Map unit 30a and 33a represent areas where the relief is hilly or strongly rolling and the majority of the soils are formed directly from the underlying rocks. 33b and 30b are of more subdued relief and considerable areas of soil are formed from ancient alluvial materials. In map unit 30a the soils are probably formed mainly from alluvial materials. According to Arco (1963) map units 30 (a, b and c) and 33 (a and b) differ markedly in their natural plant cover. The latter support dry subtropical forest (the "Guaraya - Chiquitana" formation); while the former support subtropical rainforest (the "Alto Paraguay" formation).

The last of the dry subhumid subtropical regions (map units 15 and 19) are found along the Andean foothills and they support lower montane dry forest and lower montane chaparral (or shrub with cactus) respectively. Little information is available concerning the soils of the latter region, but the dry forest region is noteworthy for the brownish-gray colour of the soils when dry, and the presence of a well-developed, massive 'B' horizon with very pronounced "clay skins". The following profile was recorded in detail.

"Achiras clay loam", hill soil

Approximately 13 Km. east of Samaipata, 93 Km. west of Santa Cruz, on Cochabamba - Santa Cruz highway.

Altitude 1,075 m. Under semi-deciduous forest. Hill soil (23° slope).

Profile

- | | | |
|------|-------------|--|
| Al.1 | 0 to 3 cm. | clay loam (to loam); 7.5YR 4/2, dry; 7.5YR 3/2, moist; very friable, very strong biological activity, rounded very fine (sub-angular blocky) aggregates, breaking to crumbs and fine granules; non-sticky and very slightly plastic when moist, pH 7.2, boundary distinct. |
| Al.2 | 3 to 11 cm. | silty clay loam to light clay; 10YR 5/2, dry; 10YR 2/2, moist; very friable, mixed medium and fine subangular blocky (nutty) structure with coarse, medium and fine granules and crumbs, very strong biological activity; non sticky and slightly plastic when moist; pH 6.6; distinct boundary. |

- A3/B1 11 to 23 cm. clay; 10YR 6/2, dry; 10YR 3/3, moist; firm-to-friable, slightly hard when dry; moderately developed medium and fine angular blocky structure breaking to very fine angular blocks and coarse granules; weak clay skin development around larger peds; moderately sticky and strongly plastic when moist; pH 6.0; boundary gradual.
- B2 23 to 60 cm. silty clay; 10YR 6/3, dry; 10YR 3/4, moist; firm, fairly hard when dry, strongly developed coarse angular blocky structure breaking to fine angular blocks and coarse granules, very distinct clay skins; strongly sticky and very strongly plastic when moist; pH 5.2; diffuse boundary.
- BC 60 to 90 cm. silty clay with occasional small fragments of weathering shale; 10YR 5/4, moist; with weak mottling (10YR 5/6 and 10YR 4/3, moist) mainly 10YR 5/2 dry; firm-to-friable irregular coarse angular blocky structure, breaking to medium and fine angular blocks and coarse granules; very strongly sticky and plastic when moist; pH 5.8; boundary distinct.
- C 90 on..... weathering laminated shale.

This soil could be regarded as a weakly enleached, moderately-to-strongly clay illuvial, moderately melanised, very slightly gleyed soil from pre-weathered illitic clay after shale. It has many of the features of the Grey Forest-soils described from Russia (Vilyams, 1960).

Very similar soils have been described by Etcheverry (pers. comm. 1963) from the Tartagal-San Pedro area of Argentina, - a region that is just across the Bolivian border, enjoying very similar moisture regimes but slightly lower mean annual temperatures.

With regard to fertility, most of the dry subhumid subtropical soils of Bolivia are likely to have a high base status and a good reserve of plant nutrients: they are neither strongly weathered nor leached. From the farming point of view, they have an almost unmanageable soil moisture regime and this, in conjunction with the occasional tendency to accumulate soluble salts in the topsoils, definitely limits the range of the plants that can be grown. The basic problem in these soils is to find a way to counteract the natural processes that lead to the formation of the "clay pan" and to incorporate these techniques in a cheap farm management system. If this cannot be done, the farmers are faced with no alternative but the restriction of their farming to the relatively thin layer of soil above the "clay pan" and they must remain at the mercy of the vagaries of the weather. Clearly there is a great field for experimentation applicable to most of the dry subhumid subtropical soils of the centre of the continent.

The operation of natural soils forming processes has divided the upper part of the ancient alluvial plain into three principal horizons: (i) a sodium-rich topsoil, usually of usable tilth and friability; (ii) a clay-plugged upper subsoil, almost universally rejected by the roots of growing crops and by many pasture plants; and, (iii) a calcareous deeper subsoil horizon, often of light texture and quite permeable but usually with some soluble salts. The formation of the "clay pan" has cut the farmer off from the main body of his soils and left him only the upper part which is too dry for two-thirds of the year and under water for the remainder of the time. Clearly science has to come to the aid of these farmers and find a way to connect the surface soil directly with the less-weathered deeper soil horizons, - or else turn the soil upside-down.

It is doubtful if any known mechanical device can be used to break up the tough "clay pan" in its entirety. Explosives will probably be of little value because there is no resistant surface below the pan and experience has shown (in a rather similar problem in Chile) that the small fissures produced by the explosions soon become clogged anew as the normal soil processes continue their operations.

The following experimental treatment might be of interest: select a piece of land of gently undulating relief and with a bull-dozer open a large sump pit at the lower end of the property and keep carefully to one side all the subsoil material from below the clay pan. Then with the bull-dozer, throw up a long earth barrier partially encircling one of the larger depressions at the upper end of the property, to form a reservoir that will fill during the rainy season. The remainder of the work can be done with a medium tractor. Mole drains should be then drawn in a herring-bone pattern through the whole area between the upper pond and the lower sump in such a way that the 'mole' is drawn through the uppermost layer of the "clay pan" horizon. Shallow, narrow open surface drains should be cut down until they intersect the mole tunnels. The general direction of these open drains should be towards the sump pit. Finally, the land should be topdressed with the carbonate sandy subsoil material, from the heap collected during the preparation of the sump. A variety of experimental crops and grasses can be tried in the long strips between the open drains, but at first cropping will have to be restricted to the season when the soil is naturally moist; As the pond fills during successive rainy seasons, water can be pumped into the drains which can then be used in a limited way as irrigation channels. The purpose of all this is, however, not to prove that the land can be used for irrigated farming; but, by drawing new mole drains several centimeters deeper in each successive year, demonstrating that the "clay pan" can be gradually destroyed, provided the sodium in the surface soil is replaced by calcium derived from the 'topdressing' of sandy calcareous subsoil material. Normal root action, especially from grasses of a deep-rooting habit, will gradually induce structural aggregation in the "clay pan" material as conditions improve after the penetration of the mole drains.

These are matters for experiment on a small-scale pilot project - such as might be carried out at Cocota - and if the results provide some clues to the successful manipulation of the natural soil processes, a very large area of potentially fertile soil will become available for colonisation, and, moreover, the landscape is suited to large-scale operation by heavy machinery.

Without progressive destruction of the existing "clay pan" and some deflection of normal soil processes, the only successful form of permanent land use is likely to be rice farming; and for this, up to the present, sufficient water of adequate quality has not been discovered in the area. Apart from this limited potential most of the soils are likely to be useful for nothing better than the present rough grazing with occasional shifting subsistence cropping.

The remaining area of soil on the lowlands (map unit 35) has a semi-arid subtropical climate and is covered with a mixture of dry thorny woodland ("Chaco" formation) with loads of open savanna grassland. The soil processes are similar to those of many of the soils of the dry subhumid subtropical lowlands, but sodium and soluble salts (mainly sulphates and chlorides) are much more in evidence. "Salt spots" are quite common; the zonal Brown soil is in many places strongly solonchic and complexly associated with alkaline Solonetz soils and related saline-alkaline soils. In many places rainfall is less than 600 mm. per annum and mean annual temperatures are in excess of 26°C. In some parts the region is practically desertic for much of the year.

In the lower lying situations of the landscape, gray and dark gray heavy clays of high fertility but poor physical structure offer some attraction to farmers. Drainage is one problem on these soils, and salt accumulation is another problem, but of even more importance is the development and maintenance of a friable topsoil structure so that rainwater and floodwater may percolate more efficiently into the subsoil. Because of lack of penetration through the expanded clays of the surface layer, large areas of these potentially valuable soils become ponds for "perched" water during the wet season; yet a few weeks after the rains cease they become too droughty for plant growth. In some cases the soil material within 40 cm. of the surface remains permanently below wilting point; - there is thus no available reserve of water for plant growth. Some improvement could be made in these soils if the sodium of the clay could be replaced by calcium (which is often present as calcium carbonate concretions in the deeper subsoil horizons), but something might also be achieved by replacing the palm forest with structure-building grasses and salt-tolerant shrubs.

However, the climatic conditions of this region are undoubtedly extreme, and the development of agriculture should be deferred until the more tractable soils of other Bolivian environments have been fully colonised.

Proceeding next from the lowlands to the Andean system of mountain slopes and inter-montane valleys (collectively known as the "Sierra" physiographic division of Bolivia), the soil pattern becomes vastly more intricate. This is depicted on the sketch map (fig. 5) of environmental regions in a general way, but the true complexity of this physiographic division is such that maps on a scale of at least 1:250,000 are needed as a basis for the production of meaningful soil or ecological maps.

85% to 90% of this physiographic division consists of steep or very hilly land, and at least 70% of the soils are lithosolic. On the north-eastern flanks of the Andes, where the valleys trend more or less uniformly towards the Amazon basin, the climatic belts are well-marked and there is a fairly regular progression from lithosolic humid tropical and subtropical soils to the superhumid cool temperate soils of the permanently cloudy belt. Above this limit, cloud-forest gives way to open moorland and subalpine vegetation. The whole region is humid and even in the deepest and narrowest valley bottoms the soils are seldom dry for any length of time.

The situation is very different to the south of a line connecting Santa Cruz to Cochabamba to La Paz. South of this line the climate ranges from moist subhumid to dry subhumid, with local enclaves in the larger valleys of semi-arid microclimates. Towards the foothills, in the warm temperate temperature belt, valley bottom conditions occasionally verge on the desertic. The environmental pattern is extremely intricate, and the altitudinal temperature belts do not form a simple pattern suitable for presentation on a map of a scale of 1:5,000,000. This complex area is also extremely deficient in meteorological stations and much of the natural plant cover (which could serve as a guide 'in lieu' of meteorological data) has been much modified by centuries of extensive farming.

To take this more complex central and southern part of the Sierra physiographic division first, the first point of note is that most soils show the same widespread tendency to develop a heavy and compact 'B' horizon as was evident on the southern and central lowlands; - although the process rarely reaches the stage of forming a true 'clay pan'. This tendency is least marked under the moist subhumid moisture regimes of all temperature belts, reached a maximum in the dry subhumid regime of the temperate belt, and declines progressively towards the cool to cold temperate highlands. The process of clay oluviation (or differential weathering of subsoil clay 'in situ') is here of greater significance in soil profile development than either general weathering or normal leaching. Only the soils of the cool and cold temperate belt are at all strongly and universally melanised; the remainder range from very slightly to moderately melanised. The operation of gleying processes becomes visible in the soil profiles only in the moist subhumid, cool temperate zone, and this feature increases with progression into the colder regions, even though the moisture regime may become drier.

The soil pattern is considerably complicated by the presence of two major contrasting kinds of parent rock. There are an abundance of sandy, quartz-rich rocks (sandstones, sandy mudstones, quartzites, etc.) intricately associated with indurated, and sometimes with soft, clayey rocks (shales, phyllites, siltstones, and claystones). The former group contains a large amount of almost unweatherable quartz sand, while the latter group are extremely rich in fine silt and clay, and are often slightly to strongly calcareous. Commencing with inherent difference in penetration of moisture at the start of the rock decay processes, the nature of the weathering process continues to diverge throughout soil formation. The sandy rocks yield soils that are, at least in the early stages, permeable to rainwater; and the leaching processes operate normally, taking effect on the development of distinctive soil horizons even in soils profiles on steep slopes. On the other hand, the release of pre-weathered clay during the decay of the clayey rocks, and the nature of the argillisation process which yields expanding types of clay, both combine to restrict the normal leaching processes. Thus, over comparatively short distances, there are abrupt changes from leached, relatively infertile pale-coloured sandy soils; to weakly leached, very fertile dark-coloured clay soils. This holds true even on steep slopes where lithosolic soils prevail, and it is only on the broad upland ridge crests that the clay soils begin to show distinct evidence of leaching. This usually takes the form of a lightening of the topsoil colour, and the development of harsh, coarse prismatic (or even columnar) structures in the subsoil. Very often, in the moist sub-humid cool temperate zone, these moderately-to-strongly acid heavy clays are found in association with Quichuina forest (*Polylopis incana*) whose resin-filled litter occasionally has a pH of 4.7, and probably is a strong conditioning factor in the leaching process.

The following profiles illustrate, in a general way, the development sequence in soils derived from pre-weathered illitic and montmorillonitic clay forming after siltstone, claystone or shale:

(i) Humid to moist subhumid warm temperate environment

"G arayos silty clay"

Approximately 10 Km. west of Pojo, on road to Santa Cruz.
Altitude 2.250 m., 10° slope. Formerly dry semi-deciduous low forest but now under pasture. Somewhat colluvial.

Profile:

A1.1 0 to 18 cm. gray silty clay; 10YR 5/2, dry; 10YR 3/2, moist; firm; hard when dry, coarse angular blocky structure breaking to coarse granules; slightly sticky and moderately to strongly plastic when moist; pH 6.3; boundary indistinct.

- Al.2 18 to 28 cm. light gray heavy silty clay; 10YR 2.5Y 6.5/2, dry; 2.5Y 4/1, moist; very strongly developed; very coarse angular blocky (almost prismatic) structure breaking to medium and fine angular blocks and coarse granules; moderately sticky and strongly plastic when moist; pH 6.2; boundary distinct.
- B 28 to 55 cm. mottled heavy clay (with fine sand); uppermost 5 cm. 10YR 6/2, dry; 10YR 4/2, moist; lower part varicoloured 10YR 5/2, and 7.5YR 5/6, dry; 10YR 4/1 - 10YR 5/6 and 5YR 5/6, moist; mottles coarse and diffuse, abundant; occasional fine, hard iron-oxide concretions; very strongly developed, very coarse angular blocky structure breaking to medium and fine angular blocks, and coarse granules; slightly sticky and very strongly plastic when moist; pH 6.0; boundary merging.
- C on..... decomposing slightly calcareous shale.

This soil could be regarded as a slightly unleached, strongly melanised soils from pre-weathered illitic or montmorillonitic clay after slightly calcareous shale. Associated soils from sandstone are moderately weathered, moderately leached Brown Forest soils.

(ii) Humid-to-moist subhumid cool temperate environment

"Payrumani silty clay loam"

Approximately 91 km from Cochabamba on road to Santa Cruz.
Altitude 2,950 m. Rainfall about 800 mm but high humidity due to nearness of cloudbelt.

Profile:

- A 0 - 25 cm silty clay loam (or light silty clay); 10YR 4/4 dry; 7.5YR 4/2, moist; very firm, very hard indeed when dry; very strongly developed fine subangular blocky structure breaking to fine granules; non-sticky and very slightly plastic when moist; pH 6.6; boundary distinct.
- B₁ 25 - 38cm silty clay; 7.5YR 4/3, dry; 5YR 3/3, moist; friable-to-firm, slightly hard when dry; porous; irregular coarse angular blocky structure breaking to very fine flattened granules; slightly sticky and moderately plastic when moist; pH 6.2; boundary gradual.
- B₂ 38 - 50 cm heavy clay; 5YR 4/4 (outside of peds) and 5YR 5/6 (inside of peds), dry; 5YR 3.5/4, moist; firm, very hard when dry; strongly developed coarse angular blocky structure, almost impossible to break further when dry, but breaks to fine granules when moist; peds coated thickly with skins and also slightly coated with iron-oxides; interior of peds visibly porous; moderately sticky and very strongly plastic when moist, pH 6.4; boundary gradual.
- on .. very hard, well-structured, dense clay from clayey siltstone and mudstone.

This soil could be regarded as a moderately enleached, weakly melanised soils from pre-weathered illitic clay after siltstone. Associate soils from sandstone are weakly weathered, rather strongly enleached intergrades between red-yellow podzolic soils and podzols.

(iii) Moist subhumid cool temperate environment, under Quehuíña (*Polylepis incana*) low forest.

"Tiraquechico silt loam"

18 km east of Totora road junction on main highway to Santa Cruz, near top of hill opening on to rolling uplands.
Altitude 3,000 m. Quehuíña forest (*Polylepis incana*) with *Stipa* tussock grassland.

Profile

- A₀ (L) 4 - 0cm thick layer of dry Quehuíña bark fragments, twigs and dead leaves; very dark reddish brown; pH 5.0
- A₁ 0 - 2cm silt loam; 10YR 4/1 - 4/2, dry; 10YR 3/1, moist; friable; strongly developed very fine granular and crumb structure; non-sticky and very slightly plastic when moist; pH 5.2; boundary distinct.

- A₃/B₁ 2 - 8 cm heavy siltclay loam to light silty clay; 10YR 6/3 dry; 10YR 4/3, moist; firm, slightly to moderately hard when dry; strongly developed medium-to-fine angular blocky structure breaking to very fine granules and crumbs; peds porous but only very weakly coated with clay skins; non-sticky and slightly plastic when moist; pH 4.8; boundary distinct.
- B_{2.1} 18 - 36 cm silty clay 10YR 5/1, dry; 10YR 5/6 moist; firm-to-friable hard when dry; very coarse angular blocky to prismatic structure, breaking to fine, very fine angular blocks, coarse granules and crumbs; peds moderately coated with clay skins; slightly sticky but moderately-to-strongly plastic when moist; pH 4.7; boundary distinct.
- B_{2.2} 36 - 80 cm. very heavy (silty) clay; 10YR 6/4, dry; 10YR 5/4, moist; firm; very hard when dry; very strongly developed fine angular blocky structure breaking to very fine angular blocks and coarse granules; clay skins abundant; slightly sticky but strongly plastic when moist; mottled strong brown (7.5YR 5/6) in lower part; pH 5.0; boundary merging.

from .. weathered silty micaceous shale.

This soil could be considered as a very strongly enleached, moderately melanised clay from pre-weathered illitic clay after micaceous shale. Associate soils are rather weakly weathered shallow acid Brown Forest Soil trending towards Red-Yellow Podzolic soils.

Each of the above three profiles was recorded from slightly undulating sites on the top of broad ridges. They are thus not typical of the region, which is almost entirely dominated by lithosols on steep slopes, but they do show well the effect of the environmental impress on soil formation. The associate soils from quartz-rich parent materials show, even better, the strength of the leaching process and the relatively weaker strength of the weathering process in the cool temperate subhumid environment. The position of these profiles is shown on the accompanying sketch map (Fig. 8) made during a rapid road traverse between Cochabamba and Santa Cruz.

The contrasting sets of soils from sandstones on the one hand, and shales, claystones, etc., on the other hand, occur in almost all sectors of the environmental region of the central and southern Sierra. The above profiles indicate some of the differences that can occur in the case of the soils formed from pre-weathered clays from the second type of rocks. In respect of the soils formed from sandstones and related rocks the following trends are visible:-

- (i) Under upper montane steppe and paramo vegetation (map unit 23) of the cool-to-cold moist subhumid environment between about 3950 m to 4300 m in a region of maximum cloudiness, the soils are shallow, dark in colour, with a slightly peaty topsoil and with subsoils of distinctly heavier texture than the topsoils - as is shown in the following profile:-

"Pirqui fine sandy loam"

113 km from Oruro on road to Cochabamba.
Altitude 4,300 m. Slight depression in saddle of broad ridge crest. Thin turfy mat. Stipa tussock grassland formerly.

Profile:

- A₁₁ 0 - 8 cm fine sandy loam; 10YR 4/2 dry; 10YR 3/2, moist, compact turfy; no visible structure in the mass but breaks further to very fine granules and crumbs; friable; non-sticky but slightly plastic when moist; boundary indistinct.
- A₁₂ 8 - 17 cm silt loam grading to fine sandy loam; 7.5YR 4/2 - 4/4, dry; 7.5YR 3/2, moist; friable-to-firm, weakly developed coarse angular blocky structure breaking to fine and very fine angular blocks and breaking further to granules and crumbs; non-sticky but slight-to-moderately plastic when moist; boundary distinct.
- A₃ 17 - 28 cm heavy sandy loam to sandy clay loam; very friable; 7.5YR 5/4, dry; 7.5YR 4/4, moist; no visible structure in the mass but breaking to irregular coarse angular blocky structure, further breaking very readily to crumbs and single grains; non-sticky but slightly plastic when moist; regular vertical fissures visible in the mass; boundary distinct.
- B 28 - 36 cm light clay; 7.5YR - 5YR 5/6, dry; 5YR 4/6, moist; friable; irregular very coarse blocky structure breaking to weakly developed fine angular blocks, breaking further to granules and crumbs; very porous; slightly hard when dry; very slightly sticky and moderately plastic when moist; boundary distinct.
- BC 36 - 40 cm very stony sandy clay loam and sandstone fragments.
from .. reddish sandstone.

This soil could be regarded as a very weakly weathered, moderately en-leached, clay eluviated, moderately-to-strongly melanised, soil from sandstone.

With decreasing altitude and increasing dryness of the environment, the soils become grayer in colour and the textural 'B' horizon becomes more prominent.

(ii) Under upper montane grassland with *Polylepis incana* forest (map unit 22) in the cool dry environment at between 3550 m and 3950 m, the soils show the general profile:

- A₁ 0 - 7 cm light brownish gray (10YR 6/2, dry; 10YR 4/2, moist) sandy loam.
- A₃ 7 - 21 cm pale brown (10YR 6/3, dry; 10YR 4/3, moist) sandy clay loam.
- B₂ 21 - 29 cm yellowish brown (10YR 5/4, dry; 10YR 4/4, moist) very heavy clay; dense and compact when dry but porous and friable when moist; with prominent vertical cracks and some weathering in the cracks.
- C 29 - 34 cm pale yellowish brown stony clay.
from .. sandstone.

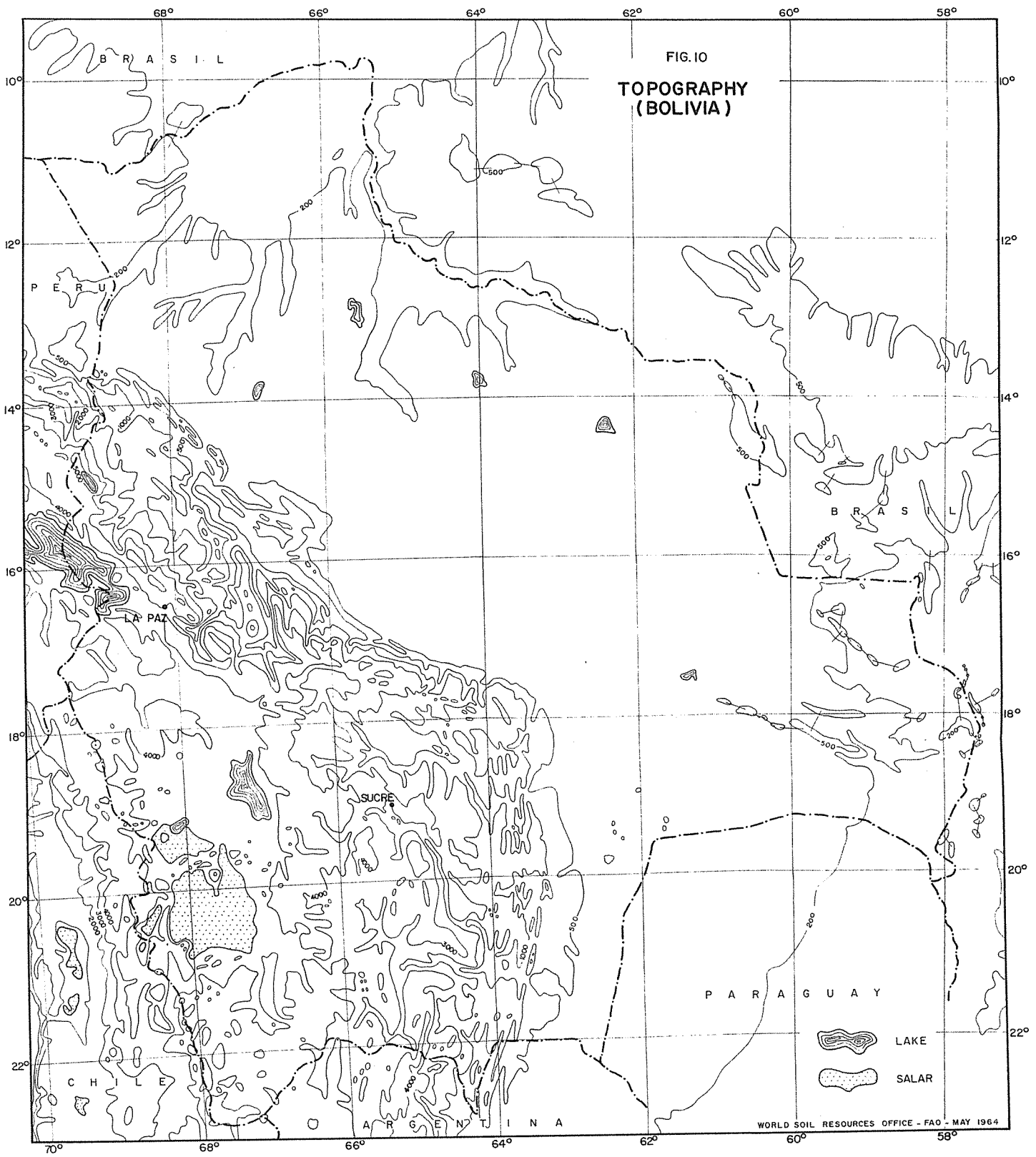
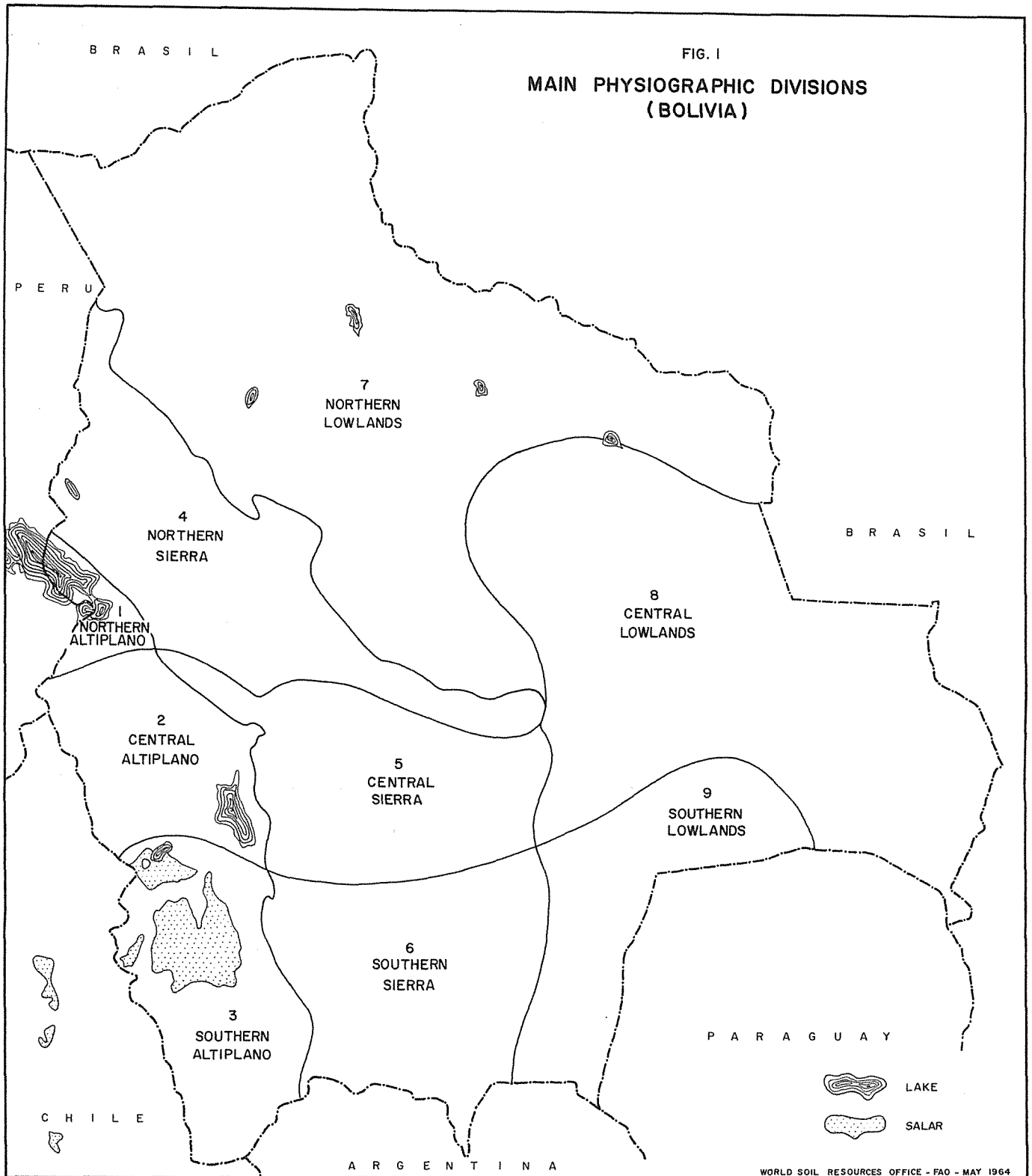


FIG. 1
MAIN PHYSIOGRAPHIC DIVISIONS
(BOLIVIA)



BRASIL

FIG.2

PROBABLE PATTERN OF CLIMATIC REGIMES (BOLIVIA)

PERU

BRASIL

PARAGUAY

CHILE

ARGENTINA

- 1 COLD, DESERTIC
- 2 COLD, DRY SUBHUMID
- 3 COLD, MOIST SUBHUMID
- 4 COLD, HUMID TO PERHUMID
- 5 COOL TEMPERATE, DRY SUBHUMID
- 6 COOL TEMPERATE, MOIST SUBHUMID
- 7 COOL TEMPERATE, HUMID TO PERHUMID
- 8 TEMPERATE, SEMI-ARID TO DRY SUBHUMID
- 9 TEMPERATE, DRY SUBHUMID

- 12 WARM TEMPERATE, SEMI-ARID
- 13 WARM TEMPERATE, DRY SUBHUMID
- 14 WARM TEMPERATE, MOIST SUBHUMID
- 15 WARM TEMPERATE, HUMID
- 16 SUBTROPICAL, SEMI-ARID
- 17 SUBTROPICAL, DRY SUBHUMID
 - a. WIDE TEMPERATURE FLUCTUATIONS
 - b. NARROWER TEMPERATURE FLUCTUATIONS
- 18 SUBTROPICAL, MOIST SUBHUMID
 - a. WINTER RAINFALL ONLY
 - b. WINTER SUMMER SPRING RAINFALL

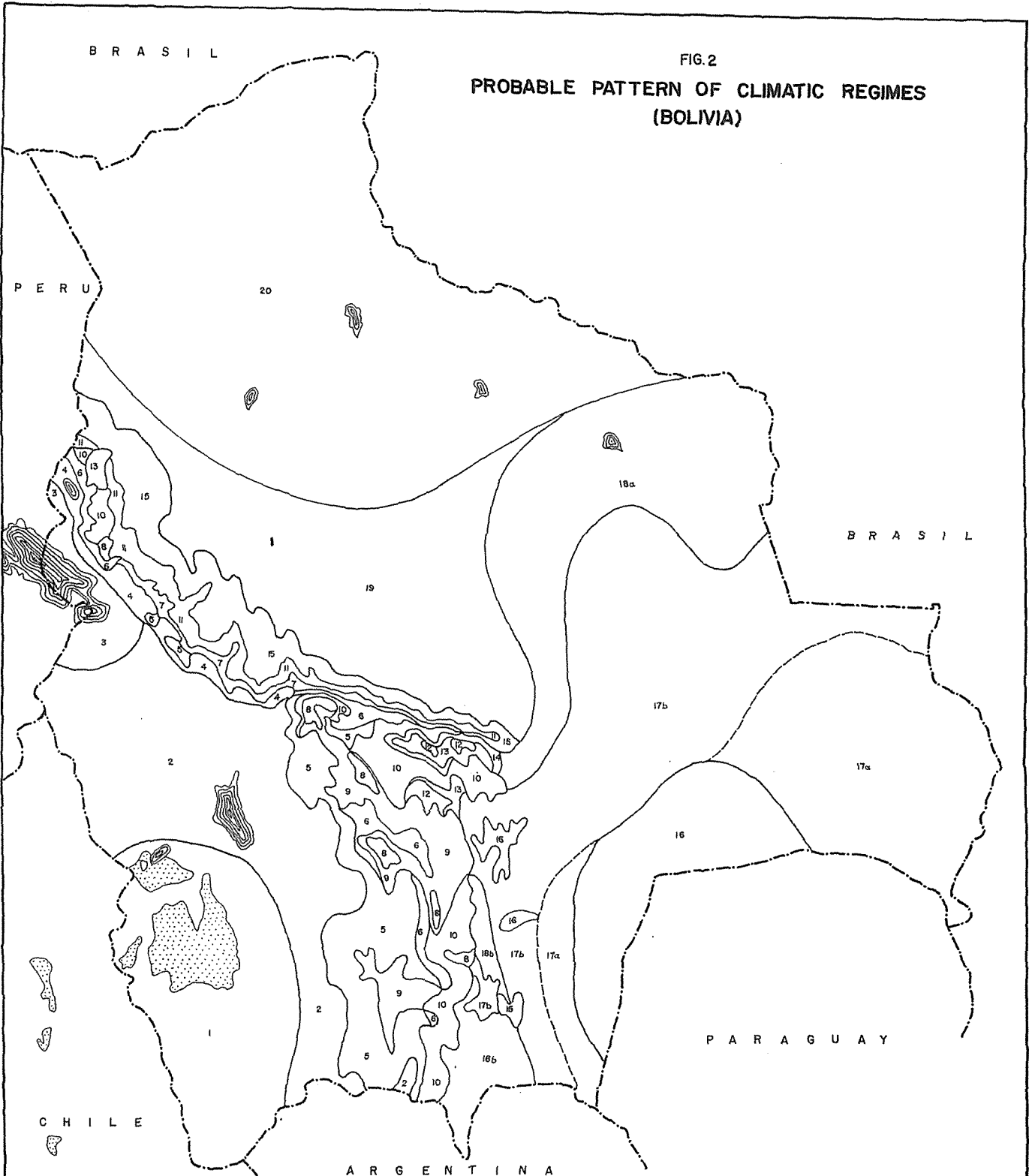
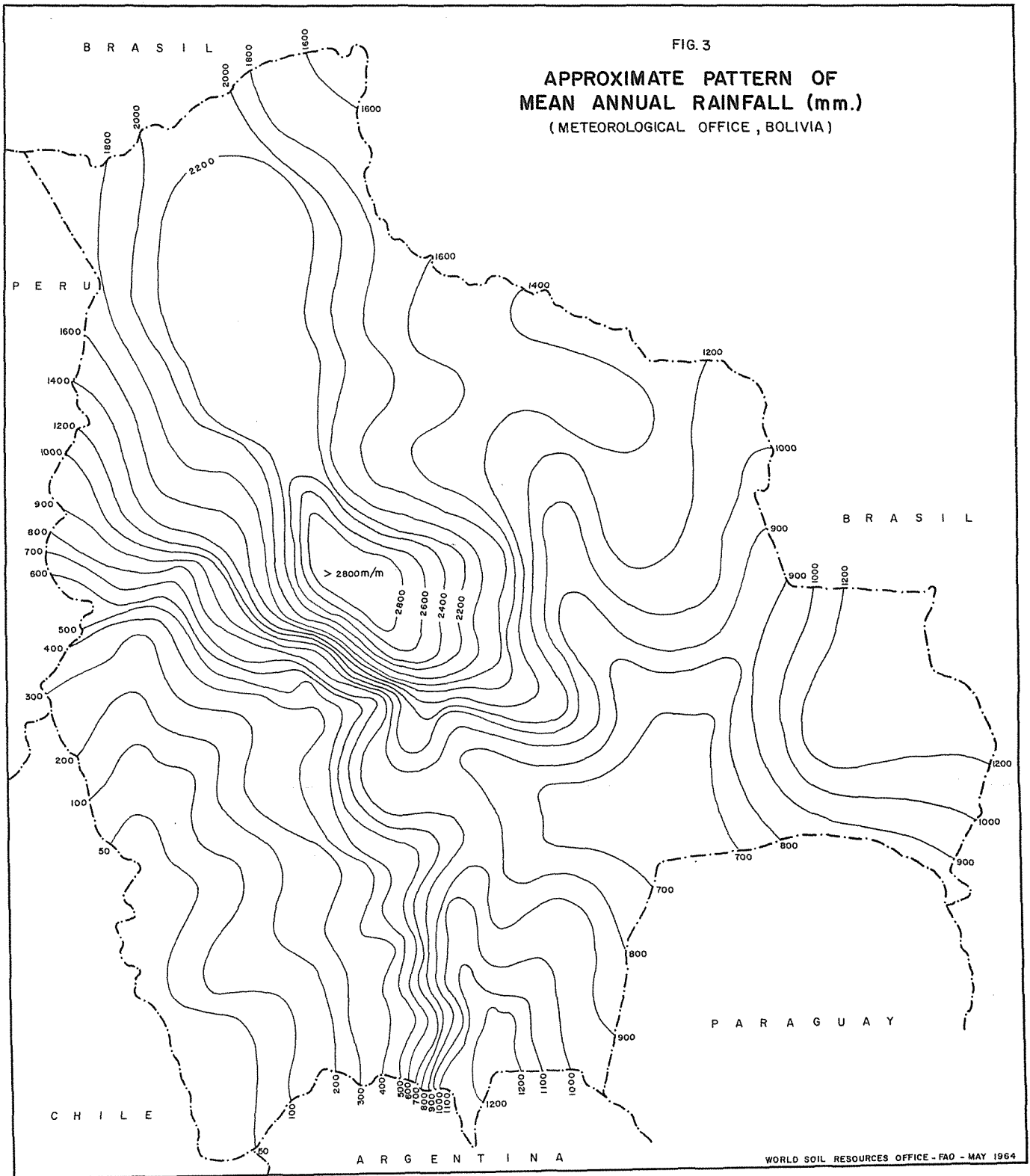
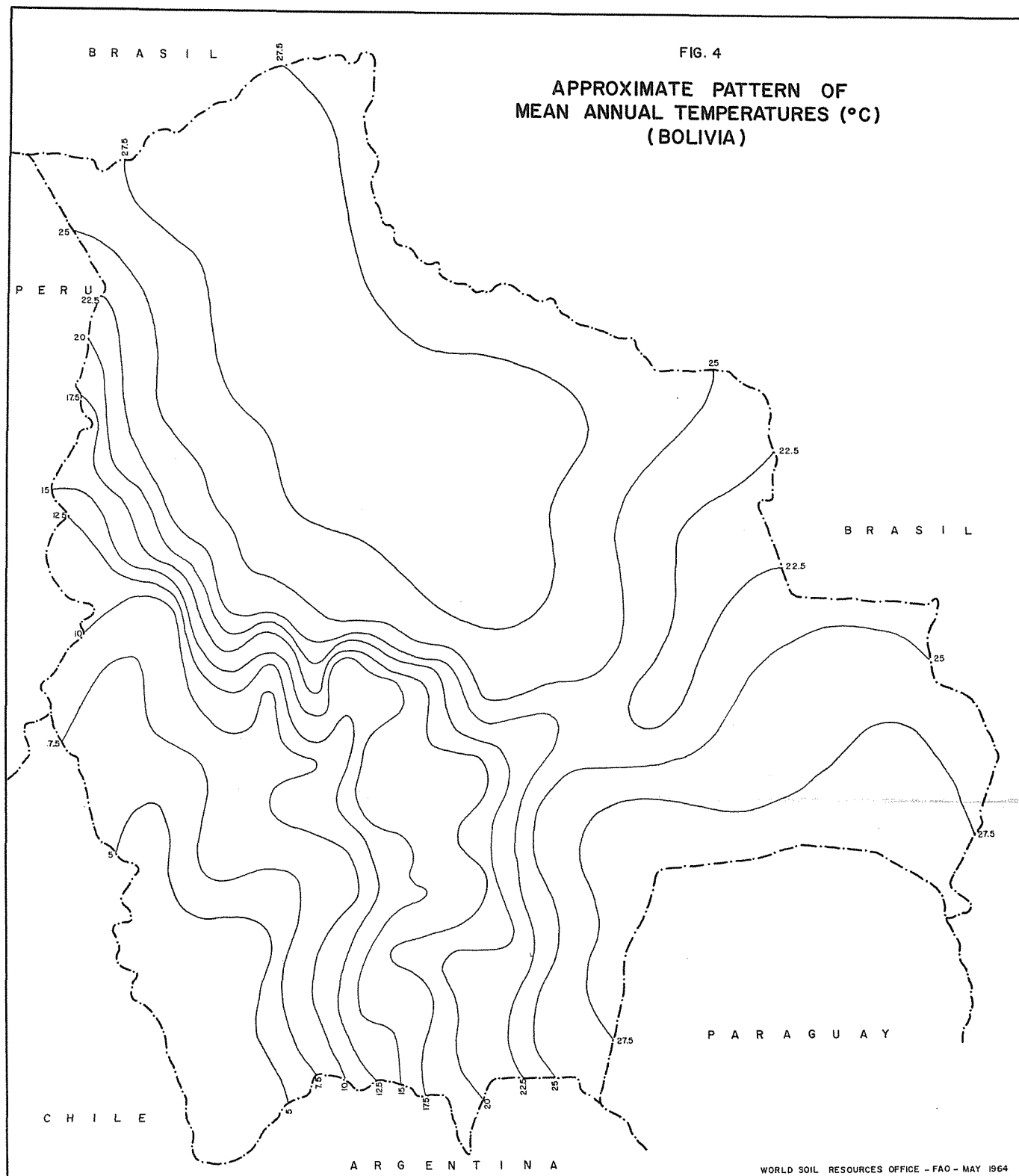


FIG. 3

**APPROXIMATE PATTERN OF
MEAN ANNUAL RAINFALL (mm.)**
(METEOROLOGICAL OFFICE, BOLIVIA)

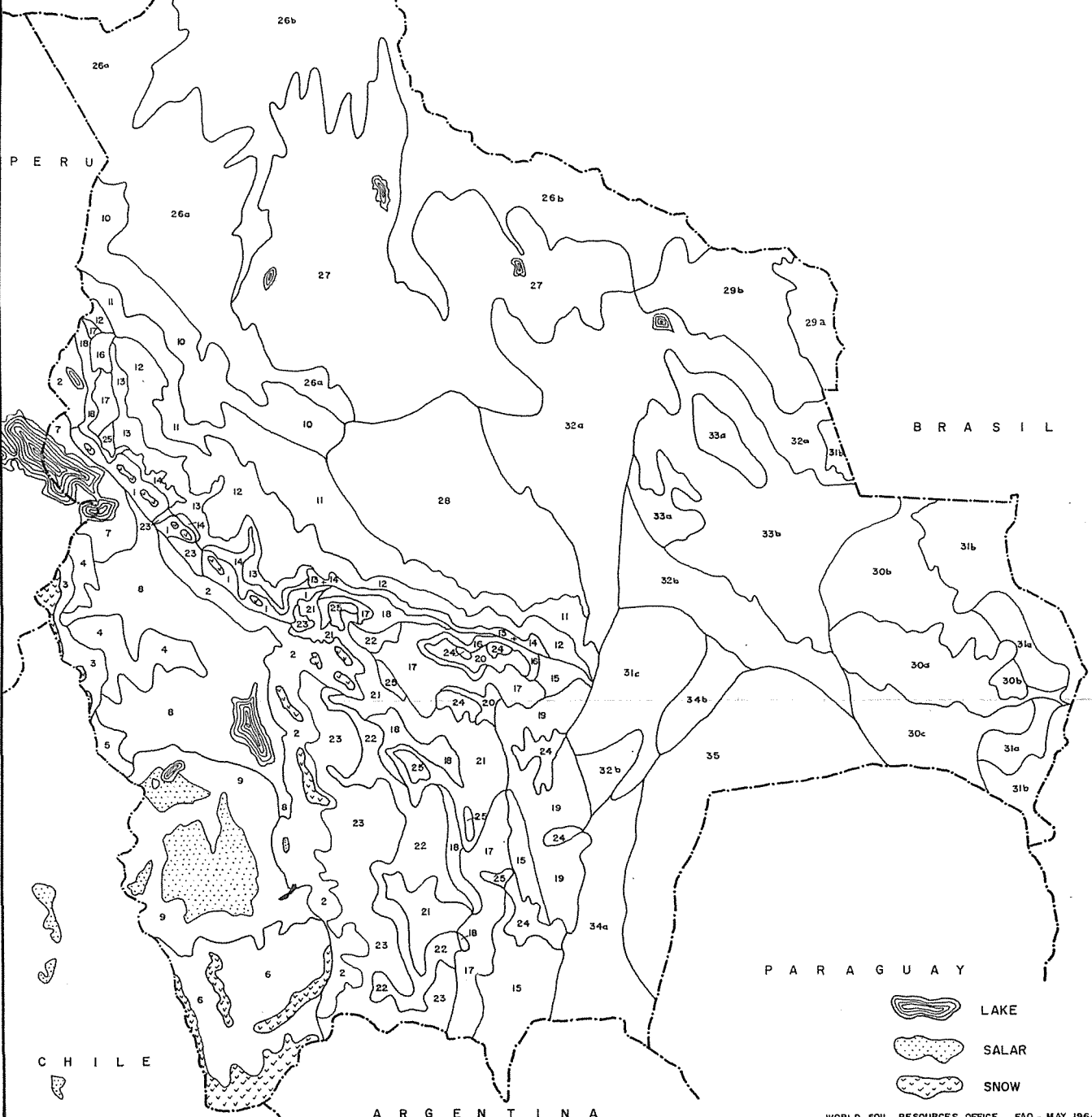




B R A S I L

FIG.5

PROBABLE PATTERN OF ENVIRONMENTAL UNITS
(BOLIVIA)



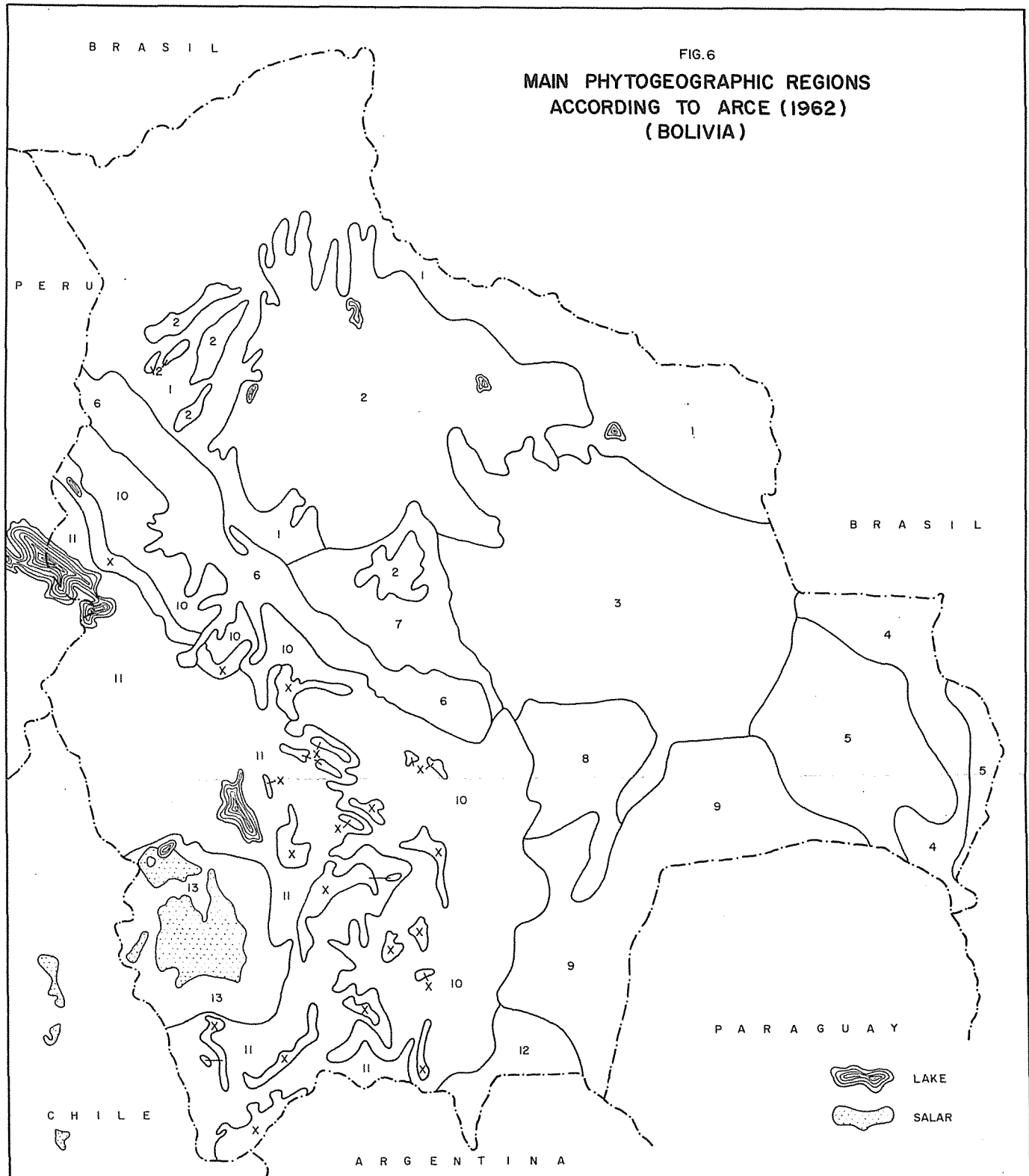
B R A S I L

FIG.6

MAIN PHYTOGEOGRAPHIC REGIONS
ACCORDING TO ARCE (1962)
(BOLIVIA)

P E R U



B R A S I L



C H I L E

A R G E N T I N A

P A R A G U A Y

 LAKE
 SALAR

- | | |
|--|---|
| 1 AMAZON HYLEA | 8 SANTA CRUZ SAVANNAS |
| 2 ALLUVIAL GRASSLANDS OF MOJOS | 9 CHAQUEÑA FORMATION |
| 3 ZONE OF GUARAYA AND CHIQUITANA | 10 MESOTHERMIC VALLEYS |
| 4 St. MATHIAS GRASSLAND ZONE | 11 ALTIPLANO |
| 5 UPPER PARAGUAY HYLEA | 12 TUCUMAN - BOLIVIAN FORMATION |
| 6 YUNGAS | 13 SALARS AND PAMPAS |
| 7 CHAPARÉ FORMATION | X MOUNTAIN SUMMITS |

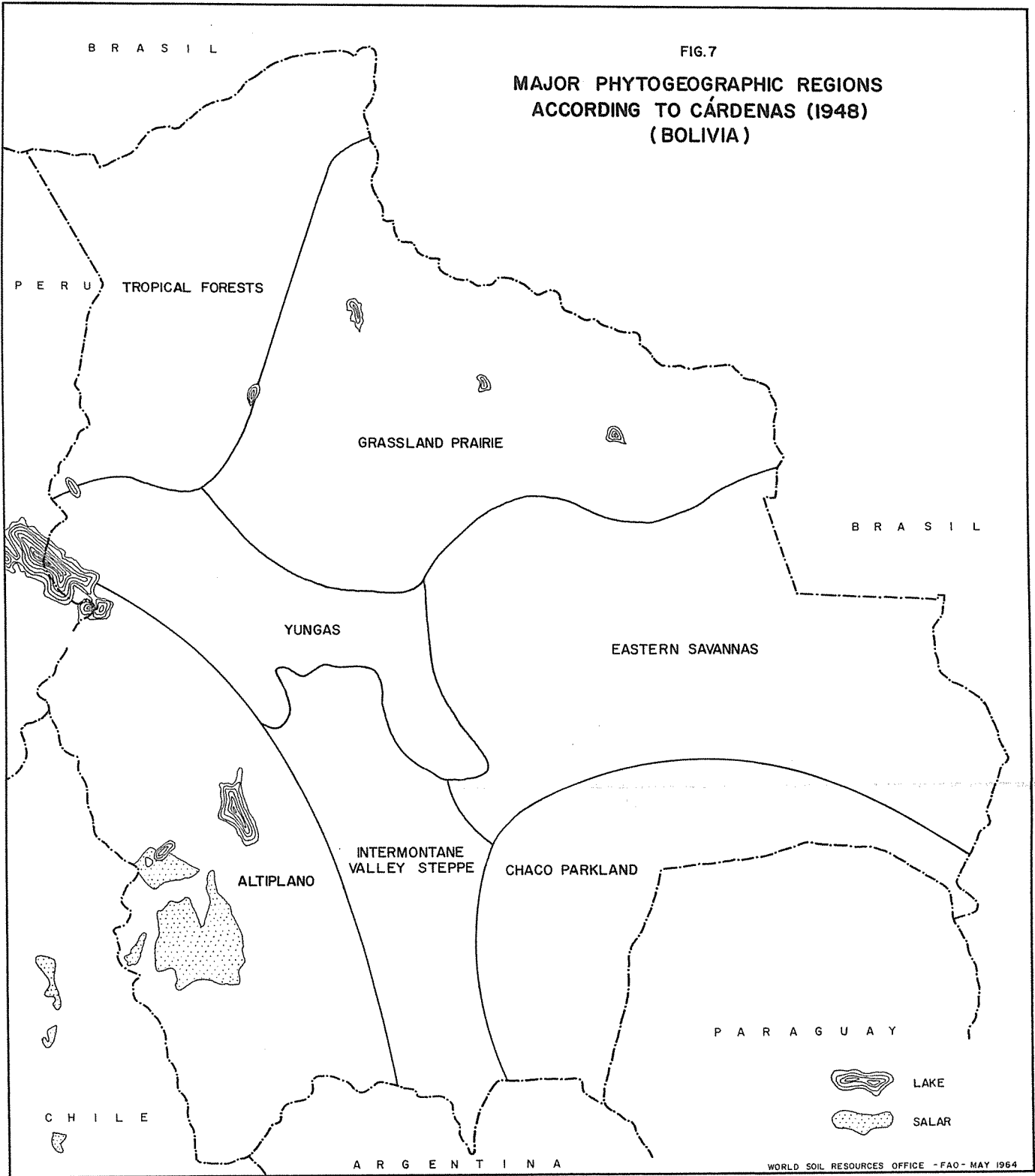
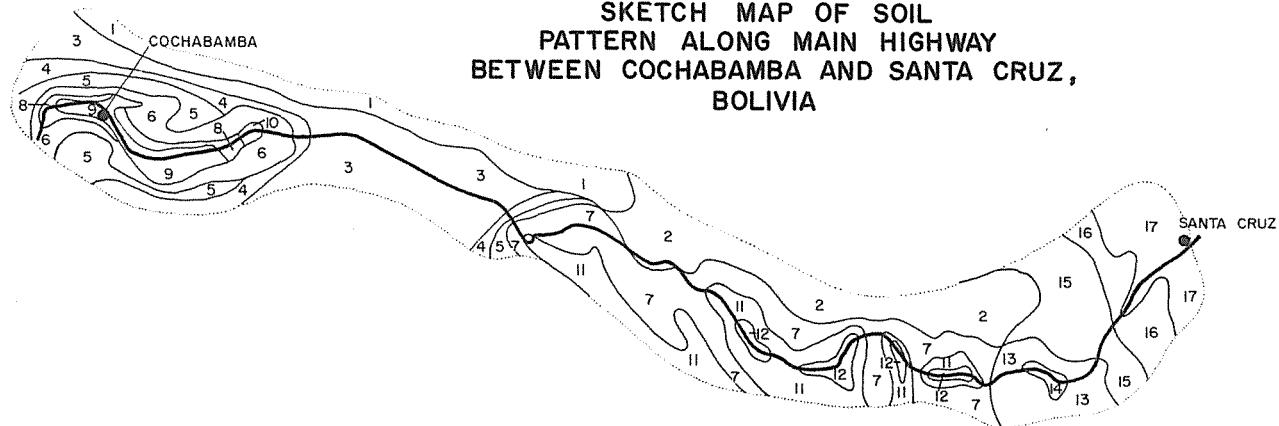


FIG. 8

SKETCH MAP OF SOIL
PATTERN ALONG MAIN HIGHWAY
BETWEEN COCHABAMBA AND SANTA CRUZ,
BOLIVIA



- 1 BROWN PODZOLIC SOILS , WITH GLEY PODZOLS AND LITHOSOLIC ACID BROWN FOREST SOILS
- 2 LITHOSOLIC ACID BROWN FOREST SOILS , WITH LITHOSOLIC BROWN FOREST SOILS , AND BROWN PODSOLIC SOILS
- 3 ANDEAN ACID BROWN SOILS INTERGRADING TO PARAMO SOILS , WITH ACID GREY CLAYS PODZOLS , AND RELATED LITHOSOLS
- 4 LITHOSOLIC GRAY-BROWN PODZOLIC SOILS , WITH ACID BROWN FOREST SOILS AND GREY MONTMORILLONITIC CLAYS
- 5 LITHOSOLIC GRAY-BROWN PODZOLIC SOILS , WITH BROWN FOREST SOILS AND DARK GREY MONTMORILLONITIC CLAYS
- 6 LITHOSOLIC BROWN MEDITERRANEAN SOILS , WITH CALCIC BROWN SOILS
- 7 LITHOSOLIC BROWN MEDITERRANEAN SOILS , WITH RED-YELLOW PODZOLIC SOILS , GREY-BROWN PODZOLIC SOILS AND DARK GREY MONTMORILLONITIC CLAYS
- 8 LITHOSOLIC CALCIC BROWN SOILS , WITH LITHOSOLIC BROWN MEDITERRANEAN SOILS AND CALCISOLS
- 9 CALCIC BROWN SOILS AND ALLUVIAL SOILS ,
- 10 CALCIC BROWN SOILS , WITH CALCISOLS
- 11 RED-YELLOW MEDITERRANEAN SOILS , INTERGRADING TO BROWN SEMI-ARID SOILS AND WITH GRUMUSOLS
- 12 BROWN AND REDDISH BROWN SEMI-ARID SOILS , WITH CALCISOLS
- 13 LITHOSOLIC GREY FOREST SOILS , (SUBTROPICAL GREY-BROWN PODZOLIC SOILS)
- 14 GREY FOREST SOILS AND RED-YELLOW MEDITERRANEAN SOILS
- 15 LITHOSOLIC RED-YELLOW PODZOLIC SOILS , OF MODERATE BASE STATUS , WITH FERRISOLS
- 16 RED-YELLOW PODZOLIC SOILS , OF LOW BASE STATUS
- 17 PLANOSOLS , ALLUVIAL SOILS AND RED-YELLOW PODZOLIC SOILS

This profile shows the development of a 'fragipan'; but is less leached than the foregoing profile, slightly less weathered and much less melanised.

(iii) Under upper montane forest of Polylepis incana (map unit 18) in the cool moist subhumid environment of about 3500 m the soils show more distinct signs of strong leaching, and the clay subsoil horizon loses its 'fragipan' characteristics owing to some cementation by iron oxides. The upper part of this horizon is often mottled, viz:-

A ₁	0 - 5 cm	very dark brown to black (7.5YR 2/1, moist) and sandy loam.
A ₂	5 - 7 cm	gray (10YR 5/1, moist) sandy loam.
A ₃	7 - 12 cm	slightly mottled gray brown and brown (10YR 5/2 and 3/3) sandy clay loam.
B ₂	12 - 18 cm	pale brown (10YR 6/3) diffusely mottled reddish brown (5YR 4/3) and yellowish red (5YR 5/6) compact, slightly cemented sandy clay.
C	18 - 26 cm	strong brown (7.5YR 5/6) stony sandy clay loam from .. sandstone.

This soil could be described as weakly weathered, weakly podzolised, clay eluviated, strongly melanised slightly-to-moderately gleyed soil from sandstone. Nearby colluvial soils are very strongly podzolised and appear to be typical weakly weathered podzols.

(iv) Under montane low chapparal, xerophytic forest and grassland (map unit 21) in the temperate dry subhumid environment between 2750 m and 3000 m, the soils develop a very prominent fragipan which probably owes its formation to the presence of minute traces of silica. This feature is a true fragipan being rich in silt and sand, and not excessively rich in clay (although some clay has accumulated in this horizon), extremely hard when dry and somewhat porous when broken. The fragipan forms a massive horizon, often resting directly on the weathering sandstone, but in places resting on porous sandy clay. Strong vertical fissures traverse the mass, and some mottling extends along the fissures. The soil is very similar to some of the Yellow-Gray Earths of New Zealand. A typical profile of this Bolivian soil shows:

"Sayari loamy sand"

Near Sayari oil pumping station, about 3250 m altitude. Formerly Quehuina forest (Polylepis incana).

Profile:

0 - 4 cm	loamy sand; 7.5 - 10YR 6/4, dry; 7.5YR 4/4, moist; friable, slightly hard when dry; weakly developed fine and very fine subangular blocky structure breaking to very fine granules and crumbs; non-sticky and non-plastic when moist; boundary distinct.
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- 4 - 18 cm sandy loam; 10YR 6/3 - 6/4, dry; 7.5YR - 10YR 4/4, moist; very friable, soft; very weakly developed subangular blocky structure, breaking easily to crumbs and single grains; non sticky and very slightly plastic when moist; boundary abrupt.
- 18 - 36 cm (cemented and extremely hard when dry; friable when thoroughly moist) silty clay loam to silty clay; 7.5YR - 10YR 6/4, dry; 7.5YR 4/4 - 5/6, moist; no visible structure in the mass, but breaks to fine and very fine blocks and coarse granules; slightly sticky and moderately plastic when moist; very porous. Large vertical fissures penetrate the mass, and from these horizontal cracks extend outwards. The colour of the centre of the fissures is pale gray (10YR 7.1) and the actual surface of the fissure is strong brown (7.5YR 5/6) or reddish-yellow (5YR 6/6).

resting on.. weathering sandstone.

This soil could be described as a weakly weathered weakly enleached, moderately clay illuvial, very weakly melanised soil with gammate fragipan, from silty sandstone.

(v) Under montane dry forest and tall chaparral (map unit 17) in the temperate moist subhumid environment at between 2500 and 2900 m, the soils have some of the characteristics of weakly weathered Brown Forest soils but with a more prominent textural 'B' horizon. A general profile shows:

- A_{1.1} 0 - 6 cm very dark brown (7.5YR 2/2, moist) heavy sandy loam.
- A_{1.2} 6 - 14 cm dark brown (10YR 3/3, moist) sandy clay loam
- A₃ 14 - 18 cm brown (7.5YR 5/4, moist) sandy clay loam with strongly developed medium blocky aggregates and faint reddish mottles.
- B₂ 18 - 26 cm light yellowish brown (10YR 6/4, moist) slightly sandy clay; very hard when dry, moderately friable when moist; with faint reticulate mottling along the fissure pattern
- C 26 - 30 cm strong brown (7.5YR 5/8) well-structured stony sandy clay loam.

from .. sandstone (micaceous)

This soil could be described as a weakly-to-moderately weathered, moderately enleached strongly clay illuvial, moderately melanised, very weakly gleyed soil from sandstone.

(vi) Under Montane dry woodland with thorny chaparral (map unit 25) in the temperate semi-arid to dry subhumid environment between 2400 m and 2700 m, the soils commonly have a very pronounced fragipan and are usually strongly calcareous, as is shown by the following profile:

"Puniata fine sandy loam"

Approximately 38 km from Cochabamba on road to Santa Cruz.
Altitude 3000 m. Low saddle opening on to rolling uplands. Under grassland

but formerly supporting thorny chaparral.

Profile:

- | | |
|------------|--|
| 0 - 1 cm | fine sandy loam sand; 1OYR 5/4, dry; 1OYR 4/4, moist; very friable; very fine subangular blocky to granular structure breaking to crumbs and single grains; non-sticky and non-plastic when moist; boundary indistinct. pH 7.0. |
| 1 - 20 cm | fine sandy loam; 1OYR 6/4, dry; 1OYR 5/4, moist; extremely friable, powdery; very fine angular blocky and granular structure, breaking to crumbs and single grains; non-sticky and non-plastic when moist; boundary sharp. pH 7.4. |
| 20 - 50 cm | fragipan, extremely hard when dry; strong vertical fissures in pan, filled with calcium carbonate in coarse crystalline form; upper 20 cm of fragipan has horizontal fissures also filled with carbonate, giving coarse laminate structure; texture sandy clay loam; 1OYR 6/2, 1OYR 5/3 and 7.5YR 5/4, dry; main colour 7.5YR 4/2, moist; fragipan friable when moist; non-sticky but moderately plastic when moist; pH 7.6; boundary sharp. |
| on .. | gravelly stony clay; very hard when dry, firm when moist. Indications of solifluction or glacial mixing of soil parent materials. |

This soil would appear to be very weakly weathered and very weakly leached, slightly clay illuvial, weakly melanised, and derived from sandstone materials considerably disturbed by mass movement. Associated soils under dry woodland have characteristics more typical of non-calcic Brown Soils. In slightly drier parts of the same region, areas occupied by cactus formations have typical calcisols with light reddish brown soils.

(vii) Under lower montane dry forest and thorny woodland (map unit 16) in the warm temperate moist subhumid environment between 1500 m and 1800 m the soils derived from sandstone are decidedly reminiscent of Red-Yellow Mediterranean Soils. With these are associated soils resembling non calcic Brown soils derived from non-calcareous mudstones and shales. Locally, the latter appear to intergrade with grey forest soils. The range of soil profiles is rather similar to that occurring near Salta in Argentina.

(viii) Under lower montane thorny woodland, chaparral and cactus (map unit 20) in the warm temperate dry subhumid environment at elevations between 1100 m and 1400 m, soils resembling minimal Red-Yellow Mediterranean soils appear on sandstones. These soils are very weakly weathered, weakly leached, slightly-to-moderately clay illuvial, and very weakly melanised, with carbonate concretions in the subsoil below the textural 'B' horizon, and occasionally the whole profile is very slightly calcareous. A general profile shows:

- | | | |
|----------------|------------|--|
| A | 0 - 20 cm | light (reddish) gray brown sandy loam. |
| B ₁ | 20 - 40 cm | pale reddish brown sandy clay loam with strong prismatic structure, slightly calcareous. |

B₂ 40 - 60 cm very compact and hard (dry) reddish brown sandy clay loam, calcareous.

on .. pale reddish brown sandy clay loam.

Associated soils from shales and mudstones appear to be calcisols.

- (ix) Under lower montane cactus formations (map unit 24) in the warm temperate semi-arid environment between 1100 m and 1300 m, the soils are definitely red-brown soils; whether the parent materials are sandstone or more fine-grained sediments. Many soils show a distinct horizon of calcium carbonate accumulation and all soils appear to be calcareous throughout the profile. Soils colours range from light reddish gray to reddish brown. There is a definite increase in heaviness of texture in the 'B' horizon, although less marked than in the equivalent soils of the dry subhumid regions. These soils could be described as very weakly weathered, very weakly en-leached, very weakly melanised, slightly clay eluviated and strongly carbonate accumulating.

Since the majority of soils in the central and southern Sierra physiographic division are lithosols, the chief farming problem is the control of erosion. The main cropping soils are usually located in the valley bottoms and on the accumulating colluvial soils along the foot of the slopes. However, so great is the population pressure in this area, that many families are forced to extend their crop farming operations for several hundred metres up the valley sides. In some cases this has caused erosion down to unweathered bed rock. The chief limiting factors restricting crop yields are probably lack of soil moisture, shallowness and instability of the soil. Inadequacy of plant nutrients plays little part in the problem, except at the highest altitudes, where frost and short growing seasons are often of more significance than soil fertility. So long as the present farm population pressure remains acute and every farmer continues to be compelled by circumstances to plant any usable soil in subsistence crops as an insurance against starvation, these soils must continue to be abused. There is nothing that the soil scientist can suggest to improve system of soil management, in the face of the desperate human problem. Under ideal conditions, most of the present agricultural land should be planted in forest trees.

Turning now to the northern sierra region, known as the "Yungas" region, the soil picture is a very different one. The forested yungas region begins abruptly in the very cool, very moist region, usually shrouded in clouds, where the warm moist air from the Amazon basin meets the downflow of cold air from the Andean highlands. The forest of the ridge tops is low and gnarled, with several species of Podocarpus, and all the trees festooned with mosses, lichens and great masses of epiphytes. In patches, the forest is thin and full of tall sedges, indicating areas of local peat accumulation. Practically all the soils, even those of the steep slopes, are covered with a mantle of forest peat; the surface of which is interlaced with twisted roots. Here the soils are Gley Podzols; on the ridge tops, many of these podzols are fairly deep and show the following general profile:

"Hichuloma peaty silt loam"

10 km northeast Unduavi village. Altitude 3250 m. Flattish saddle with cloud forest.

Profile:

O	6 - 0 cm	dusky red fibrous loamy peat
A ₁	0 - 25 cm	dark grayish brown peaty silt loam
A ₂	25 - 31 cm	pale gray fine sandy loam
B ₁	31 - 38 cm	pale yellowish brown sandy clay loam mottled strong brown and very dark brown
B ₂	38 - 39 cm	cemented iron pan
BC	39 - 45 cm	fragments of weathering micaschist and yellowish stony silty clay loam
	from ..	decomposing micaschist.

A similar sequence of soil horizons occurs in many of the steep slopes but the total depth of the profiles (including the peaty 'O' horizon) is usually less than 15 cm. With these soils are associated Lithosols related to weakly weathered Acid Brown Forest soils. Practically all the soils in this belt, irrespective of the angle of slope, are weakly weathered, very strongly leached, moderately-to-strongly gleyed, and strongly melanised. In most soils there is some development of a thin discontinuous cemented iron pan usually running along the face of the parent rock and penetrating along fissures in the rock. On slightly less steep slopes the soil has the following profile:

"Yerbani" fine sandy loam, hill soil

Near top of pass, about 16 km north-east of Unduavi village. Altitude 3200 m. Forest.

Profile:

0 - 15 cm	dark grayish brown "greasy" fine sandy loam with much amorphous organic matter.
15 - 30 cm	Pale yellowish "slippery" stony loam with very weak aggregation but with iron-oxide coating on rock fragments.
on ..	brownish yellow very stony silt loam with occasional ironstone "concretions" formed by iron impregnations of small fragments of rock. Mainly weathering rock fragments showing colluvial accumulation on slope.

(underlying rock is an indurated micaceous sandstone).

With decreasing altitude the soils pass into Lithosolic Acid Brown Forest soils, with occasional patches of deeper soil on the ledges of the mountain side having well-developed podzols. Weakly-to-moderately weathered Lithosolic Brown Forest soils appear at about 2800 m to 3500 m depending on the direction of the valley and the aspect of the slope. The degree of weathering in these soils increases with decreasing elevation until, in the humid temperate belt, the soils have approximately the same appearance as the typical Brown Forest

soils of the northern part of the west coast of the South Island of New Zealand. They are still predominantly lithosolic, but areas of deeper soil (called "Steepland" soils in New Zealand) are becoming more frequent. A typical profile of one of these Bolivian moderately weathered Brown Forest steepland soils shows:

"Chuspipata silt loam" steepland

Approximately 25 km south west from Coroico.
Altitude 2300 m. Slope 35"
Under regenerating forest.

Profile:

- A₀ (L) 5 - 0 cm somewhat decomposed, fibrous forest litter with strong aromatic smell, 5YR 2/2, moist.
- A₁ 0 - 15 cm silt loam; 7.5YR - 5YR 4/4, moist; 10YR 6/4, dry; friable; moderately developed medium subangular blocky structure breaking to granules and crumbs; non-sticky and slightly plastic when moist; boundary gradual.
- A₃ 15 - 30 cm heavy silt loam; 7.5YR 4/4, moist; 10YR 7/3, dry; friable; moderately developed medium to fine angular blocky structure breaking to coarse and medium granules; non-sticky and slight-to-moderately plastic when moist; boundary fairly distinct.
- B 30 - 70 cm silty clay loam; 10YR 5/6, moist; 7.5YR 5/6, dry; friable; weakly developed coarse angular blocky structure breaking to fine angular blocks and granules; non-sticky and moderately plastic when moist; occasional weak clay skins; boundary gradual.
- BC on.. very stony silt loam; 10YR 5/6, moist with many fragments of slightly decomposing micaceous sandstones.

At elevations below 2000 m, the climate becomes noticeably warmer and the soils are a brighter brown colour and more weathered. The mountain slopes are covered with an intricate soil pattern, in part lithosolic strongly weathered Brown Forest soils and in part with related steepland soils. These steepland soils are closely similar to the strongly-weathered Brown Forest soils of Northern New Zealand.

The change from these soils to distinctly reddish brown soils with an increasing proportion of kaolinitic clays is comparatively rapid. At about 1700 m, the soils are nearly all reddish-brown in colour, frequently quite deep (even on very steep slopes), and many begin to take on the first characteristics of Red-Yellow Podzolic soils. The first soils definitely belonging to the latter group always appear over sandstones relatively rich in quartz; while soils from shales and mudstones generally retain most of the features of very strongly weathered Brown Forest soils.

In this region, the general topography becomes somewhat less steep and many slopes of between 20° and 25° are present. On these typical hill soils related to very strongly weathered Brown Forest and Red-Yellow Podzolic soils are developed. Two profiles are described overleaf.

(i) From micaceous shale

"Coroico" clay loam, hill soil

Approximately 2 km east of Coroico town on 25° hill slope under second-growth shrubby vegetation. Hill soil, altitude about 1550 m.

Profile:

- | | |
|------------|--|
| 0 - 25 cm | clay loam; 7.5YR 5/3, dry; 7.5YR 3/3, moist; moderately developed coarse granular and fine subangular blocky structure firm-to-friable; fairly hard when dry. Moderately sticky and moderately-to-strongly plastic when moist. |
| 25 - 40 cm | clay; 5YR 5/4, dry; 2.5YR 3/6, moist, firm; very hard when dry; fine angular blocky and coarse granular structure; moderately-to-strongly sticky and strongly plastic when moist. |
| 40 - 60 cm | heavy clay; 2.5YR 6/4, dry; 2.5YR 3/3.5, moist; firm-to-very firm, very hard when dry; medium and fine angular blocky structure breaking to granules; slightly sticky and moderately-to-strongly plastic when moist. |

(ii) From micaceous sandstone

"Chiqueno" clay loam, hill soil

Approximately 32 km north-east from Coroico
Altitude 1200 m. Formerly forested, now farmed.

Profile:

- | | |
|------------|--|
| 0 - 25 cm | dark brown (silty) stony clay loam, friable-to-firm; strongly developed fine subangular blocky (nutty) structure breaking to coarse fine nuts, slightly sticky and moderately plastic when moist; boundary indistinct. |
| 25 - 65 cm | reddish yellow-brown clay; firm-to-friable; very strongly developed fine angular blocky structure breaking to fine granules; slightly-to-moderately sticky and strongly plastic when moist; moderate development of clayskins; boundary diffuse. |
| 65 -150 cm | yellowish-brown very stony clay; firm; moderately developed medium and fine angular blocky structure breaking to very fine angular blocks and granules; slightly sticky but very plastic when moist; abundant clayskins. |

Below 1000 m, where a humid subtropical climate prevails, the majority of the soils are typically Red-Yellow Podzolic and are mainly hill soils.

The natural soil fertility of the "Yungas" region is relatively high: the soils are well-provided with nutrient reserves and weathering releases these nutrients at a rate adequate to supply all but the most demanding plants. The soils are "fertile" in the chemical sense, the temperature regimes are suitable for a wide range of crops, and moisture is available in abundance. These are undoubtedly factors that originally encouraged farmers to begin operations in this region. However, only a very small proportion of the region is suited to permanent agriculture, in the modern sense.

The first farmers undoubtedly practised normal shifting cultivation and no great harm was done so long as the agricultural population was not too numerous. In many areas, in recent years, the number of farmers has increased to an excessive level and this, combined with steadily improving access to markets, has brought about very severe acceleration of erosion. Under shifting cultivation the land was used rationally, allowed an adequate length of time to recuperate between cropping activities, and there was no strong incentive for the farmer to plant more than his immediate family requirements. Today, much of the land near the roads is under almost continuous cultivation (until it erodes to bed rock) and every farmer hopes to plant up to the limit of his resources. As a result, about 60% of the accessible areas are severely eroding at the present time.

What can the soil scientist recommend in the face of this situation. He can suggest little for the areas where the fundamental problem is a social one, but for the new areas of land which will become accessible when future trans-Andean roads are built, he can recommend much stricter control of soil management. Some of the most popular areas (with warm temperate and subtropical climatic conditions) are highly suitable for tree crops such as cocoa, coffee, avocado pear, papaya, and even tea (on the Red Yellow Podzolic hill soils). These should be planted on land directly cleared from forest, and the land should then be maintained permanently under these tree crops. Row-crops, needed for the farmer's subsistence, should be planted only on or near the valley bottoms and never on the steep slopes. Row crops grown for sale in the markets should be totally prohibited. Specific row crops, where some permanent land-scaping and erosion control practices are mandatory (terracing for cocoa production) could be permitted where the slopes and soils are suitable, but under no circumstances should the farmer be allowed to introduce his present habit of planting low-value food crops (such as manioc) in rows aligned up and down the steepest slopes. This implies the introduction of a much more serious land use policy, backed by a means to control, and to punish for infringements. To some extent, this could be achieved simply by restriction on the products permitted to be sold from a particular valley: the natural topography virtually canalises out-going produce along a very limited number of transport routes; and these are, in any case, under the control of the police and army. This would serve as notice to the farmers that the Government was seriously concerned about the land use problem in the Yungas region. It would need to be backed up by a comprehensive attempt to educate the farmer how to get the best from his land, without destroying further the National heritage.

The third major physiographic unit of Bolivia is the highlands, comprising the altiplano proper and the surrounding fringe of mountains. Here the soil pattern is less complex, although the agro-sociological problem is the very reverse.

The soils of the Bolivian highlands have developed under a unique climatic regime; the total environmental conditions under which these soils are developing are quite exceptional. The soils are subject to intense insolation and radiation; subject to very wide and rapid temperature variations; subject to rather low annual moisture regimes, compounded by extremely high evaporation rates and frequent exceptionally strong winds. The plant cover is restricted to rather sparse steppe grassland, low xerophytic scrub, cushion-mound plants and sub-alpine ephemeral species. Normally dry westerly winds prevail over the Bolivian highlands but from December to March the region comes somewhat under the influence of the moist air mass moving south-westward from the Amazon basin. During this period, there is a marked increase in humidity, frequent cloudiness, and occasional rain or snow. During the rest of the year, the sky is notably clear and there is a much wider ranges from less than 100mm to about 700 mm) falls during the four summer months. The mean diurnal fluctuation in temperature is about 10°C from December to March; but is greater than 24°C during the rest of the year. Severe night frosts are common, especially over the central and southern altiplano regions; - the frost hazard, however, diminishes appreciably in the vicinity of Lake Titicaca where the diurnal temperature range is also less wide. All this adds up to a most unusual climatic regime from the point of view of soil formation, and it is also one that embraces extremes of temperature and moisture far beyond that which can be tolerated by the majority of agricultural crops.

The soil weathering environment is weak, the state of leaching ranges from weak to strong, and it could be expected that the soils would possess too little clay for clay eluviation to be a major process. Soil melanisation processes, on the contrary, are very strong in all but the most desertic parts of the highlands. Gleying processes are virtually non-existent except where the ground-water level is shallow or where spring-waters emerge at the surface. The zonal soils of the Bolivian highlands are, however, not to be found on the Altiplano. The Altiplano is a relic of a former landscape existing before the Andean orogeny that has, since its elevation, become infilled by lacustrine sediments, glacial debris, and, in some areas, accumulations of volcanic ash. Much of the Altiplano is covered with pre-weathered clayey material. There is also a surprising amount of clay on the slopes of the hills surrounding the Altiplano which may be of glacial or inter-glacial origin, or which may date back to an ancient weathering mantle present on the landscape before its uplift in Tertiary times.

If we exclude these conspicuously clayey soils as being not typical of the zonal processes, then we find that the dominant soil of the highlands of Bolivia is a shallow form of the "Paramo" soils so common on the highlands of Peru and Ecuador. The Paramo soils of the latter countries are conspicuous for the great depth and blackness of the topsoils and they usually support a characteristic grassland or dwarf scrubland plant cover. In Bolivia, the plant cover is of the same order (but different species and genera are present), and the topsoils are also conspicuously dark, but much shallower than the northern Paramo Soils.

The Paramo soils of Bolivia change slightly in character from east to west and from north to south. Those of the northeast have formed under cold, humid environmental conditions (map unit 1), whereas most of the Paramo soils in the eastern highlands have formed under a cold and moist subhumid environment

(map unit 2) or cold-to-cool temperate dry subhumid environment (map unit 23) On the western mountains, they have probably formed under cold semi-arid and cold desertic environments, although no meteorological data are available and, in truth, in these regions the soils begin to lose many of their 'Paramo' characteristics.

The following three profile descriptions indicate, in a general way, the range of variation occurring over the eastern highlands:

(i) Minimum Paramo soil of the cold humid environment

"Chacaltaya heavy sandy loam"

Approximately 8 km southwest from Unduavi on road to La Paz. Altitude about 3550 m. Slope 12°. Stipa grassland with small bushes.

Profile:

A ₁₁	0 - 75 cm	matted with fine grass roots, almost peaty (heavy) sandy loam; 1OYR 3/2, moist; very friable; fine crumbs structure; somewhat fibrous due to living grass roots; non-sticky and non-plastic when moist. Boundary distinct.
A ₁₂	12 - 30 cm	sandy loam; 1OYR 2/2, moist; 1OYR 6/1, dry; friable; weakly developed coarse and medium angular blocky structure breaking very readily to very fine angular blocks, granules and crumbs; very slightly sticky but only slightly plastic when moist. Boundary diffuse.
A ₃₁	30 - 50 cm	sandy loam to loamy sand; 1OYR 2/2 - 2/1, moist; 1OYR 6/1 dry; friable; moderate to strong coarse angular blocky structure breaking to very fine angular blocks, granules and crumbs; very slightly sticky and very slightly plastic when moist. Boundary gradual.
A ₃₂	50 - 70 cm	loam; 1OYR 2/2, moist; 1OYR 6/1, dry; very friable; strongly developed medium angular blocky structure powdering readily to very fine granules and crumbs; very slightly sticky but subject to moderately plastic when moist. Boundary distinct, almost abrupt.
BC	70 - 75 cm	very stony sandy clay loam; 1OYR 3/2, moist; 1OYR 4/2 - 5/6, dry; friable; very strongly developed very fine sub-angular blocky structure breaking to granules and crumbs; slightly sticky and moderately plastic when moist. Boundary distinct.
C	on ..	gravelly and stony coarse sand, 1OYR 4/2, moist.

(ii) Minimal Paramo soil of the very cold (subalpine) humid environment

"Incacha peaty sandy loam"

About 18 km southwest of Unduavi village, at an altitude of 4150 m. below last study slope to summit of road between Unduavi and La Paz. Grassland slope - very gently undulating, about 5°.

Profile:

- 0 - 18 cm very dark (reddish) brown peaty sandy loam; extremely friable, powdery when dry; very fine granular and crumb structure; non-sticky and non-plastic when moist. 10YR 5YR 2/1, moist; 10YR 5/1, dry. Boundary sharp.
- 18 - 28 cm very dark brown to black silt loam; firm-to-friable; distinct short prismatic structure breaking readily to coarse angular blocks and breaking further to very fine granules and crumbs; non-sticky and non-plastic when moist; boundary distinct.
- 28 - 31 cm dark brown heavy silt loam; 10YR - 5YR 2/2, moist; 10YR 5/1, dry; firm-to-friable; no visible structure in the mass but breaks to irregular coarse blocks, which break further to fine angular blocks, granules and crumbs; non-sticky and very slightly plastic when moist. Boundary distinct.
- 31 - 32 cm silty clay loam; 7.5YR 3/2, moist; 10YR 5/4, dry; mottled slightly, pale yellow and strong brown; no visible structure in the mass but breaks to coarse and fine granules, very slightly sticky and slight-to-moderately plastic when moist.
- on .. greenish-gray gravelly clay loam mixed with fragments of micaceous sandstone. Most fragments show some coating of iron-oxide.

(iii) Minimal Paramo soil of the cold, moist subhumid environment

"Lequepalca loamy sand"

Approximately 52 km from Oruro on road to Cochabamba.
Altitude 4400 m. Stipa tussock grassland. Saddle.

Profile:

- A₁₁ 0 - 2.5 cm dark grayish brown loamy sand to sandy loam; friable to very friable; subangular blocky structure breaking to very fine granules and single grains; non-sticky and non-plastic when moist.
- A₁₂ 2.5 - 14 cm very stony very dark gray-brown heavy sandy loam, friable; strongly developed very fine angular blocky structure; very slightly sticky and slightly plastic when moist; many roots.
- C 14 - 18 cm pale reddish brown very stony silty clay loam; firm; no visible structure in the mass but breaks to very strongly developed medium-to-fine angular blocky structure; slightly sticky and slightly-to-moderately plastic when moist.
- on.. reddish micaceous sandstones, only slightly weathered.

The minimal Paramo soil of the cold-to-cool, dry subhumid environment is similar to the last profile but has, in addition, a distinct textural 'B' horizon ranging from 10 cm to 25 cm in thickness, between the A₁₂ and the C horizons.

The Paramo soils as a group have been far from adequately studied. Little, for example, is known about the very striking soil melanisation processes. It appears to be similar to that occurring in certain volcanic ash soils where the intense and persistent black colour is thought to be due to interaction between certain humus compounds and allophanic clays derived from the weathering of volcanic glass. Allophane has not yet been shown to be present in all kinds of Paramo soils, yet the presence of small amounts of volcanic glass in almost any of the Andean highland soils would not be so unlikely, considering the enormous number of volcanoes existing along the Andean chain. Apart from uniformly strong melanisation, the three profiles listed above all show characteristics of very weak weathering; whereas the state of onleaching ranges from moderate to strong. In the drier highland environment of the south and west the soils are less strongly melanised, are very weakly weathered and very weakly enleached. These latter soils grade into the highland desert soils of Chile and Argentina.

With regard to plant nutrient status, all but the most humid Paramo soils have a high reserve of nutrients and a slow rate of release of nutrients, except during the wet summer season when the rate of release is more rapid. They are, however, all rather deficient in nitrogen. The soils of the Altiplano proper, (which are for the most part not Paramo soils), are also deficient in nitrogen but are otherwise quite well supplied with plant nutrients, both 'reserve' and 'available'. The Altiplano soils range from reddish-brown and brownish-gray clays in the central and northern sectors.

The main factors restricting agricultural development of Bolivian highland soils are climatic, and the next most important group of factors are agrosociological. The range of crops and pastures that can be successfully grown on the highlands will always be limited and this alone sets severe limits for economic development. With regard to the agrosociological factors, the problem is like the problem of the central and southern sierra regions, and is basically due to an excessively numerous agricultural population. Despite the limitations of climate, and the inherently high natural fertility of the soils, the land is being systematically over-cropped and over-grazed; bringing in train the inevitable problems of erosion and soil depletion.

VI. PROBABLE NATURE AND CLASSIFICATION: A TENTATIVE SOIL MAP SHOWING THE SOILS OF BOLIVIA CLASSIFIED ACCORDING TO THE WORLD SOIL RESOURCES OFFICE SCHEME PREPARED FOR THE THIRD DRAFT OF THE SOIL MAP OF SOUTH AMERICA

Based largely upon the data presented in the foregoing sections, a very tentative attempt has been made to prepare a generalised soil map (Fig.9) for Bolivia on a scale of 1:5,000,000. This map has been prepared in collaboration with Ing. Lucio Arce of the Bolivian Government Service and it is intended to serve as a guide for thinking about Bolivian soil problems and as a target to be modified by the soil surveyors who will unearth more precise information about the soils of Bolivia in the future. Even in this primitive stage, this soil map can be helpful to agronomists and foresters working in Bolivia, if it is used in conjunction with this explanatory report.

The provisional legend for this map (Fig. 9) is given in full below. The classification used is that provisionally decided upon by the World Soil Resources Working Party for Latin America, at the Rio de Janeiro Meeting in 1962 (18). The technical data on which the various soils have been assigned to various positions in this classification has been provided by Arce (personal communications, 1962 and 1963), Coulter (personal communications, 1962), Arens (personal communications, 1962 and 1963), Storie, 1955 (16), Arce, Fernández, Hinojosa, and de Hansen, 1963 (5), the British Mission, 1962 (12) and the FAO Mission for Soil Studies which visited Bolivia in 1963 (19). Much of the territory has not been visited personally by the author of this report.

The legend to accompany this soil map is set out below:-

LEGEND TO ACCOMPANY SKETCH MAP OF BOLIVIAN SOIL PATTERN

RECENT ALLUVIAL SOILS

- 1.1 Recent Alluvial soils of humid tropics (with weak dry season): soils of medium to heavy texture.
- 1.2 Recent Alluvial soils of humid tropics (with weak dry season): soils of medium, light and heavy texture.
- 1.3 Recent Alluvial soils of humid sub-tropical region (with weak dry season): soils of medium to light texture.
- 1.4 Recent Alluvial soils and related halomorphic and calcimorphic soils of the dry sub-humid sub-tropical regions with a strong dry season.
- 1.5 Recent Alluvial soils of moist sub-humid sub-tropical regions with a strong dry season: soils of medium to light texture.

HYDROMORPHIC SOILS

- 2.1 Hydromorphic soils of humid tropics (with weak dry season): Mainly Humic Gleys and Groundwater Latosols.
- 2.2 Hydromorphic soils of dry sub-humid sub-tropical regions (with moderately strong dry season): mainly Humic Gleys and Pseudogleys.

HYDROMORPHIC SOILS (Continued)

- 2.3 Hydromorphic soils of moist subhumid sub-tropical regions (with moderate dry season): Humid Gleys and Pseudogleys.

LITHOSOLS AND MOUNTAIN SOILS

- 3.1 Lithosolic Brown Forest soils and associated steepland Brown Forest soils of the humid cool temperate regions.
- 3.2 Lithosolic Acid Brown Forest soils, with related steepland soils and local Gley Podzols, of the superhumid cool temperate regions.
- 3.3 Lithosolic Non-Calcic Brown soils in association with lithosolic Red-Yellow Mediterranean-like soils and grey calcareous clays, of the cool temperate regions.
- 3.4 Lithosolic Non-Calcic Brown soils in association with intergrades between Red-Yellow Mediterranean soils and Red-Yellow Podzolic soils, and with brown-grey calcareous clays, of the warm temperate regions.
- 3.5 Lithosolic Grey Forest soils in association with Red-Yellow Mediterranean soils, Brown Calcic soils and Calcisols, of the dry sub-humid sub-tropical regions.
- 3.6 Lithosolic Non-Calcic Brown soils and related lithosolic Red-Yellow Podzolic soils intergrading to Grey Forest soils, of the temperate sub-humid regions.
- 3.7 Lithosolic Grey Wooded soils of the cool temperate moist sub-humid regions.
- 3.8 Leached lithosolic Grey Wooded soils of the cool temperate dry sub-humid regions, intergrading to Gray-Brown Podzolic soils
- 3.9 Lithosolic minimal Paramo soils and shallow Podzols of the cold temperate moist sub-humid regions.

REGOSOLS

- 4.1 Complex of sand Regosols with solonetzoid Reddish Chestnut soils, of dry sub-humid sub-tropical regions with a strong dry season.

ALTIPLANO SOILS

- 5.1 Grey Desert soils and associated sand regosols and with Solonchaks of the cold arid Altiplano regions.
- 5.2 Brown and Reddish-Brown desertic soils, with associated Halomorphic soils, peaty hydromorphic soils and Regosols, of the cold semi-arid Altiplano regions.
- 5.2a Brown and Reddish-Brown desertic soils, with associated halomorphic soils, peaty hydromorphic soils and Regosols, of the cold semi-arid Altiplano regions with pumiceous volcanic ash.
- 5.2b Brown and Reddish-Brown desertic soils, with associated halomorphic soils, peaty hydromorphic soils and Regosols, of the cold semi-arid Altiplano regions with fine ash and regosolic dune sands.

ALTIPLANO SOILS (Continued)

- 5.3 Dark Brown and Grey (Altiplano) Prairie soils, in association with Humic Gley and Calcic Humic Gley soils, of the cold dry-to-moist sub-humid Altiplano.
- 5.4 Highland soils and Lithosols related to minimal Paramo soils of the cold dry sub-humid and cold semi-arid regions.
- 5.5 Highland soils and Lithosols related to shallow peaty Paramo soils of cold humid regions.
- 5.6 Highland soils and Lithosols of dry sub-alpine regions.
- 5.7 Highland soils and Lithosols of semi-arid sub-alpine regions.

CALCISOLS

- 6.1 Calcisols in association with Sierozem-like soils of semi-arid warm temperate regions.
- 6.2 Calcisols in association with Reddish-Chestnut soils of the semi-arid sub-tropical regions.

BROWN SOILS

- 7.1 Solonetzoid Reddish-Brown soils in association with Solonetz, Solonchak, Takyr-like soils and related halomorphic soils, Regosols and salares of the semi-arid sub-tropical regions with a very strong dry season.

CHESTNUT SOILS

- 8.1 Reddish-Chestnut soils, in part solonetzoid, in association with Solonetz, Soloth, Pseudo-Solonchak, and related halomorphic soils, of the dry sub-humid sub-tropical regions with a very strong dry season: Chaco xerophytic woodland phase.
- 8.1a Reddish-Chestnut soils, in part solonetzoid, in association with Solonetz, Soloth, Pseudo-Solonchak, and related halomorphic soils, of the dry sub-humid sub-tropical regions with a very strong dry season: Chaco xerophytic woodland phase with many areas of regosolic dune sands.
- 8.2 Solonetzoid Reddish-Chestnut soils in association with Solonchaks, Solonetz, Salares, and Regosols (forming a terrace edge) of dry sub-humid sub-tropical regions.
- 8.3 Chestnut soils and related hydromorphic soils (mainly "Pseudogleys" and Saline Gleys, etc.,) of dry subhumid sub-tropical regions.
- 8.4 Reddish-Chestnut soils in association with hydromorphic soils (both "Pseudogley" and Gley), Regosols, and leached Planosols, of the dry sub-humid sub-tropical regions with a strong dry season: "Chiquitana" deciduous woodland and savanna phases.

NON-CALCIC BROWN AND RELATED SOILS

- 9.1 Non-Calcic Brown soils in association with Red-Yellow Mediterranean soils and with dark grey calcareous soils, of the temperate sub-humid regions with a moderate dry season.
- 9.2 Non-Calcic Brown soils and Calcic-Brown soils in association with Calcisols and dark grey calcareous clays, of the warm temperate to sub-tropical dry sub-humid regions with a strong dry season.
- 9.3 Grey Forest soils of the moist-to-dry sub-humid sub-tropical regions with a moderate dry season.

RED-YELLOW PODZOLIC AND REDDISH-BROWN LATERITIC SOILS INTERGRADING TO RED AND YELLOW MEDITERRANEAN SOILS

- 10.1 - in association with "Pseudogleys" (Planosols) and humic gley soils, of the very warm sub-tropical dry sub-humid regions with a very strong dry season and on undulating to flattish relief.
- 10.2 - in association with "Pseudogleys" (Planosols) and humic gley soils, of the very warm sub-tropical dry sub-humid regions with a very strong dry season but on strongly rolling to hilly relief.
- 10.3 - in association with "Pseudogleys" (Planosols) and Dark Humic Gley soils, of the slightly cooler dry subhumid sub-tropical regions with a strong dry season, and on undulating to flattish relief: locally intergrading to latosols on some flat-topped hills.
- 10.4 - in association with "Pseudogleys" (Planosols) and Dark Humic Gley soils, of the slightly cooler dry sub-humid sub-tropical regions with a strong dry season, and on undulating to flattish relief: locally intergrading to latosols on some flat-topped hills but on strongly rolling to hilly relief.
- 10.5 - complexly associated with Planosols and Dark Humic Gley soils, and Groundwater Latosols, of the moist sub-humid sub-tropical regions with a strong dry season.
- 10.6 - complexly associated with Planosols and Humic Gley soils, of the very warm dry sub-humid sub-tropical regions: forested phase.
- 10.7 - complexly associated with Planosols and Humic Gley soils, of the very warm dry sub-humid sub-tropical regions: savanna phase.
- 10.8 - intergrading to slightly leached Reddish-Chestnut soils, and in association with solonetzoid soils, of the very warm sub-tropical dry sub-humid regions.

RED-YELLOW PODZOLIC AND REDDISH-BROWN LATERITIC SOILS INTERGRADING TO LATOSOLS

- 11.1 - in association with Groundwater Latosols and with related hydromorphic soils, of the humid tropical regions with a weak dry season, and on gently undulating to rolling relief.

RED-YELLOW PODZOLIC AND REDDISH-BROWN LATERITIC SOILS INTERGRADING TO
LATOSOLS (Continued)

- 11.2 - in association with Groundwater Latosols and with related hydromorphic soils, of the humid tropical regions with a weak dry season, but on strongly rolling to hilly relief.
- 11.3 - intergrading strongly to Latosols, and with associated hydromorphic soils (including Groundwater Latosols, Humic Gleys, etc.) and with Podzols, of the moist sub-humid tropical regions with a moderate-to-strong dry season, and on undulating to rolling relief.
- 11.4 - intergrading strongly to Latosols, and with associated hydromorphic soils (including Groundwater Latosols, Humic Gleys, etc.) and with Podzols, of the moist sub-humid tropical regions with a moderate-to-strong dry season, but on mainly hilly to steep relief.
- 11.5 - complexly associated with Young Alluvial soils with well-developed argillic horizons, and with Recent Alluvial soils, hydromorphic soils (including Dark Grey Humic Gleys, Humic Gleys and Calcic Humic Gleys), of the humid sub-tropical regions with a moderate dry season.
- 11.6 - mainly Red-Yellow Podzolic soils of medium to low base status, of the humid sub-tropical to warm temperate regions, and on hilly relief.
- 11.7 - mainly Red-Yellow Podzolic soils of medium to low base status, of the humid sub-tropical to warm temperate regions, but mainly hilly to steep relief, and with related Lithosols.
- 11.8 - complexly associated with leached Planosols, Dark Grey Humic Gleys, and with local intergrades to Red-Yellow Mediterranean-like soils, of the humid sub-tropics with a moderate-to-strong dry season.
- 11.9 - steepland Red-Yellow Podzolic soils, and strongly weathered Brown Forest soils and related Lithosols, of the humid temperate regions with a weak dry season.

LATOSOLS

- 12.1 Complex association of heavy and light-textured Yellow Latosols, Red-Yellow Podzolic soils, Red-Yellow Latosols, with related hydromorphic soils including Groundwater Latosols, of the humid tropical regions with a weak dry season.
- 12.2 Forested phase of medium to light-textured Red-Yellow Latosols and related hydromorphic soils, of the humid tropical regions with a weak dry season.
- 12.3 Savanna phase of light and heavy-textured Latosols, with intergrades to Red-Yellow Podzolic soils and with related hydromorphic soils, of the humid tropical regions with a moderate dry season.

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VII. LIST OF TEXT FIGURES

- Fig. 1. Main Physiographic Divisions and Sub-Regions.
- Fig. 2. Probable Pattern of Climatic Regimes.
- Fig. 3. Approximate Pattern of Mean Annual Rainfall.
- Fig. 4. Approximate Pattern of Mean Annual Temperatures.
- Fig. 5. Probable Pattern of Ecological Regions.
- Fig. 6. Phytogeographic Regions according to Arce.
- Fig. 7. Phytogeographic Regions according to Cárdenas.
- Fig. 8. Sketch Map of Soils along main highway between Cochabamba and Santa Cruz.
- Fig. 9. Probable Pattern and Classification of Major Bolivian Soils.