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TAXONOMIC CONSIDERATIONS OF SOME CLAYEY SOILS OF VENEZUELA

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University for the Degree of

Master of Science

by

Deud A Dumith M

August 1973

BIOGRAPHICAL SKETCH

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INTRODUCTION

During the last decade, a great deal of attention has been given to the clayey soils in Venezuela. Many soil surveys conducted as part of feasibility studies for construction of irrigation and drainage projects demonstrate that these soils are extensive, and of importance not only for the objective of agricultural development with and without irrigation, but also for non-agricultural uses.

These soils occupied more than 50 percent of the total area under irrigation in 1967, even though in the process of selecting the areas for development, the best soils always received high priority (Dumith, 1967).

The total estimated area of these soils in the country is about 5,256,000 ha (CIDIAT and SVCS, 1971), which represents nearly 25 percent of the total agricultural land in the nation. In the future, as new areas are developed, the perspective is to have an increasing proportion of these soils under agricultural production and other kinds of uses.

Clayey soils are also extensive in the warm temperate and tropical regions of the world. According to preliminary data gathered by the President's Science Advisory Committee (1967), the total approximate extent of these soils is about 690 million hectares, of which 132 million hectares are considered arable land. Dudal (1965) indicated that Dark clay soils in the tropical and subtropical regions of the world amount to 257 million hectares, and are particularly extensive in Australia, India and Sudan.

From the agricultural view point, these soils have considerable

problems. Many of the physical soil properties impose severe limitations on the use and management of these soils. Because of the fine texture and extremes of consistence at different moisture contents, current agricultural practices such as tillage, cultivation and harvesting are difficult to be conducted effectively. The optimum range of moisture for tillage is very narrow, and soils remain in that condition for a relatively short period, so that high power implements are required. Mechanization with heavy machinery, although essential for the development of a modern agriculture in these soils commonly brings about degradation of the structure, and compaction to the extent that favorable conditions for plant growth are severely damaged.

Timeliness of tillage is a continuing problem because not only the plow layer should have adequate moisture, but also in the underlying layer the soil moisture should be appropriate to insure maximum resistance to compaction. Other physical properties, such as slow permeability and infiltration, limit water movement throughout the soil creating poor drainage and unsatisfactory conditions for plant growth. These characteristics also interfere with irrigation practices, and are conducive to salinity build-up because leaching of salts added by the irrigation water is virtually impossible. On the other hand, under conditions of excess water in the rainy season, rain-fed agriculture is uncertain unless artificial drainage and special practices for land preparation are utilized.

These soils have many limitations for non-agricultural purposes. They have high plasticity and liquid limits, and low load bearing strength when wet. Most are expansible soils that experience marked volume changes as moisture changes. Because of these properties, building foundations, roads, underground utilities, and other engineering structures may be severely

damaged, unless such structures are specially designed to overcome the limitations. Corrosivity of uncoated metal and concrete underground utilities is always a potential problem because of the poor soil drainage (reducing conditions) or the high electrical conductivity in some of the saline fine-textured soils.

Because the clayey soils are extensive and have properties that impose limitations on their use and management, it is considered important to evaluate more fully the similarities and differences among these soils. Major items of concern are: (1) the physical, chemical, and mineralogical characterization of the soils to better predict their behavior for different kinds of use and to better understand their genesis; (2) the consistent recognition, classification, and correlation of these soils to better evaluate the kinds and qualities of such soils as an aid in transferring experiences; and (3) a sound program of soil survey to assist in developing research programs to deal with the actual problems of use and management and to know where such results can be applied.

This study is intended as a contribution to the knowledge about clay mineralogy and taxonomic classification of six clayey soils developed under different sets of soil-forming conditions in Venezuela.

GENERAL CHARACTERISTICS OF CLAYEY SOILS

Nomenclature and Properties of Clayey Soils

Many names have been used to refer to clayey soils all over the world, including Black Cotton, Black Earth, Smonitza, Rendzinas, Regurs, Tirs, Grumosols, Dark Clay Soils and Vertisols.

Hilgard (1921) pointed out that many of these soils were similar to the Black Adobe from California, and to the Prairie soils from the cotton states in the U.S.A., such as the Houston Black Clay.

Black Cotton soils of the Central Province of India developed on Deccan trap (basalt), sandstone, and gneiss rocks were described by Bal (1935). His report indicated that those soils have 40 to 50 percent clay, a lime content that varies inversely with the rainfall, no marked soil horizonation, although a slightly higher clay content may be noted in the sub-soil; some leaching of calcium and silica from the surface; a low organic matter content and very often, they occur in the lowest position in the landscape.

Regurs soils from India were studied by Simonson (1954) who also noted the similarity with the Houston Black Clay in the U.S.A. The Regur soils occur in the Deccan Plateau, between 15° and 25° north latitude, having a semi-arid climate with rainfall varying from 20 to 40 inches a year. The rainfall distribution is markedly seasonal, mostly falling from June to September. Average annual temperature is about 75°F. The main parent rock is augite-basalt (Deccan trap). It was pointed out that the soils exhibit a low degree of horizonation and a high degree of uniformity, particularly in color, texture, consistence and structure, which is thought

to reflect the low intensity with which the soil-forming factors have modified the initial fine-textured parent material. The lack of horizon differentiation was also attributed to the mixing effect which often accompanies the alternating volume change produced by variation fo soil moisture over time.

These soils have pH values that are consistently alkaline, calcium carbonate content for the most part is between 0.5 and 8.0 percent and may occur as concretions distributed throughout the soil profile. The soils with least alkaline reactions contain iron-manganese concretions which would indicate a more intense degree of weathering. These soils have a mean clay content of 50 percent, that slightly increases with depth. The cation exchange capacity ranges between 40 and 60 meg/100 g, which is thought to be consistent with a relatively high proportion of montmorillonite in the fine clay fraction.

According to Roy and Barde (1962), the Black Cotton soils in India occur in regions having a summer mean maximum temperature about 42°C. and winter mean minimum temperature greater than 7°C. There is a marked seasonality of rainfall varying between 50 and 100 cm annually, with 75 percent of the total concentrated from June to September. The alternate wet and dry conditions are commonly associated with a dry deciduous or tropical thorn forest and coarse grasses.

Villar (1944) classified the Tirs of Morocco into several types of which the Glei Tirs bear some similarities with other clayey soils. The subclasses of Black Tirs occupy microdepressions, and the Gray Tirs occur on slightly higher sites within large depressional areas. Both types of soils are calcareous, the surface layer contains about 70 percent clay and is low in organic matter. On drying they crack to several feet and

the surface is marked by polygonal networks. These soils are almost impervious, poorly drained, flooded during the rainy season, very difficult to till and unsuitable for agriculture unless drained.

The Black Earth of Australia has been correlated with the Regur of India and Tirs of Morocco (Prescott, 1931). These soils are formed on heavy textured sediments, mainly of basaltic origin, and have mostly neutral to alkaline subsoils. They lack eluvial and illuvial horizons. Calcium carbonate is observed as streaks and small concretions. The organic matter is low and decrease regularly with depth.

The Houston Black Clay from the U.S.A. was studied by Templin et al (1956) as a type of Grumosol, which formed on marine argillaceous limey material under prairie vegetation in the moist-subhumid part of the Gulf Coastal plain in Texas, where the annual rainfall amounts to about 40 inches and exhibits marked seasonality.

This soil has a narrow range of clay content (57 to 61 percent), of which the fine clay makes up as much as 84 percent of the total fraction. Montmorillonite strongly dominates the fine clay fraction, however kaolinite may be present up to a maximum of 20 percent and is generally constant throughout any individual profile. The calcium carbonate content varies widely and no secondary enrichment is observed. The mean cation exchange capacity in the surface horizon is 64 meg/100 g whereas in the C horizon is about 40 meg/100 g. The Brown grumosols in Arizona (Johnson et al, 1962) are derived from ultrabasic volcanic rocks under grass vegetation and a semi-arid climate. The soil pH values ranges from 5.2 to 7.8, bulk density varies between 1.74 and 1.98, and the organic matter content is less than 2.1 percent decreasing with depth. The cation exchange capacity is between 31 and 62 meg/100 g with calcium the dominant cation. The clay

fraction is predominantly well crystallized montmorillonite, with minor amounts of mica and kaolinite. Over a wide range of climatic conditions, all the profiles studied appear to be rather homogeneous in mineralogy and other differentiating properties except for the tendency of clay content to increase along with the average rainfall.

Oakes and Thorp (1950) attempted to group clayey soils together according to the following set of properties: (a) clay texture, (b) absence of eluvial and illuvial horizons, (c) moderate to strong granular structure in the top horizon, being blocky or massive below, (d) calcareous reaction, with acid to neutral intergrades to other groups, (e) high coefficient of expansion and contraction upon wetting and drying, (f) gilgai microrelief, (g) extremely plastic consistence, (h) exchange complex nearly saturated by calcium or calcium and magnesium, (i) clay minerals dominated by montmorillonite, (j) parent materials mostly calcareous, high in clay, and nearly impervious, (k) deep sola, (l) dark color of low chroma, (m) medium to low organic matter content, usually 1-3 percent in the surface but decreasing with depth, (n) stage of weathering relatively unadvanced or minimal, and (o) tall grass or savanna vegetation.

Finally, the term Grumosol was proposed for these dark clay soils developed under variable climatic conditions, but usually with alternating wet and dry seasons.

Clay Mineralogy

Ahmad (1969) made a comparative study of Grumosols of the Caribbean Archipelago. Despite the wide distribution and development on different kinds of parent material, these soils are fine-textured with a tendency for clay content to increase with depth. The clay mineralogy is remarkably homogeneous throughout the profile. Montmorillonite predominates with

accessory amounts of kaolinite, amorphous material, calcite and quartz.

Hallsworth and Beckman (1969) pointed out that many gilgai soils do have montmorillonite as a major constituent particularly in the subsoil, but there are others, in which montmorillonite is present in small amounts or is present only interstratified with illite. In a red clay gilgai soil from Oadnadatta, Southern Australia, kaolinite content ranges from 40 to 50 percent, with 10 to 20 percent randomly intestratified material, and 20 to 30 percent illite. In other cases kaolinite contents of 50 to 60 percent had already been reported.

Singer (1966) studied the mineralogy of the clay fraction from basaltic soils in Israel. He found decreasing amounts of montmorillonite as the rainfall increased, but the reverse effect was observed for the amorphous material. No correlation was noticed between rainfall and kaolinite content which would likely suggest that kaolinite formation was more dependent upon the type of rock structure. The increase in amorphous material was explained by a higher rate of montmorillonite breakdown as rainfall increases, as compared to a much lower rate of kaolinite formation.

Although mica and montmorillonite are present in equal proportions, no single clay mineral was found predominant in the gilgaied and bad-structured soil from Central Iraq (Harris, 1958).

It seems that the clay mineralogy is relatively constant despite the different sources of parent material and localities in which the soils were studied.

Gilgai Formation

The gilgai soils in Australia have also been widely studied. Several names have been used to refer to the small-scale undulations in the form of alternate hummocks and hollows showing some degree of regularity. This

kind of microrelief was first described by Prescott (1931) and subsequently by many others. There are considerable differences in magnitude and form of the undulations, and since the names were not used consistently to identify any one form, the term gilgai was proposed (Hallsworth et al, 1955) to include collectively the different manifestations of what appears to be primarily the same process. Six types of gilgai micro relief are recognized although intermediate forms exist. They are called normal or round gilgai, lattice gilgai, wavy gilgai, tank gilgai, stony gilgai, and melon-hole gilgai.

The puff consists mainly of subsoil pushed up to the surface due to uneven swelling of the clays which rewets along the open cracks at the end of the dry season. The significance of montmorillonite and exchangeable Na has also been noted in the process of gilgai formation. The cracks are suggested to play an important role in the uneven distribution of pressures upon rewetting.

Of the internal causes suggested for gilgai formation, namely, the increase with depth of clay content, exchangeable Na, exchange capacity, volume change and the ability to transmit thrust, only the last one is considered valid for the gilgai formation in alluvial soils in Iraq (Harris, 1958). According to Harris (1958) the fundamental cause for gilgai formation is the compaction taking place under the effect of the weathering agents. The physical effect of the alternating wetting and drying cycles, aided by the dispersion of the clay minerals, is thought to be responsible for the downpacking. Hydration and subsequent swelling of the clay flakes lead to the reorientation of the particles in the direction of least resistence. Upon drying, the flakes shrink and the other grains would be closely packed to them allowing the transfer of internal forces through

the soil, and further development of cracking during dry weather.

A different hypothesis was proposed by Edelman and Brinkman (1962) to explain gilgai microrelief developed on several geomorphic surfaces such as former lakes, sea or swamp bottom deposits. The sequence of events is: (1) soft mud is deposited in a lake, (2) dark-colored top soil develops by swamp vegetation once the lake has been filled with mud and the water level lowered, (3) evapotranspiration lowers the water table farther and large cracks appear, thereby drying the soil to a greater depth, (4) top soil fills the cracks in a dry season, (5) upon rewetting, soil swells and bulges upward through the weakest places where the depth of ripening is least, that is between the cracks, and (6) top soil is eroded from the microelevations and accumulated in depressions along with the alternating wetting and drying cycles.

Later, Hallsworth and Beckman (1969) with more recent data concluded that the magnitude and patten of gilgai vary in relation to: (a) the degree of swelling; (b) the size of soil aggregates in each horizon; (c) wetting cycles; (d) hydraulic conductivity; and (e) plasticity. They stressed the idea of maximum development of gilgai under wet and dry conditions in which the rainfall shows a marked seasonality.

Effect of Cation Saturation Upon Some Physical Properties

Ahmad et al (1969) studied the effect of different cations upon plastic limits, stability of aggregates, and hydraulic conductivity in a Tropical Black Earth considered as a type of Grumosol. The plastic limits were independent of saturating cation, but varied with the clay type. A linear regression was obtained for hydraulic conductivity and percentage of stable aggregates. Both properties showed strong dependence upon cation saturation. Potassium and sodium had a deleterious effect on aggregate

stability and hydraulic conductivity. Therefore, emphasis was placed on the possible deterioration of soil structure caused by addition of potassium fertilizer without adequate lime application.

El Swaify et al (1970) have found a large effect of saturating cations on the liquid limit, degree of dispersion and moisture retention in a Tropical Black Earth. Linear regression equations were derived as functions of relative proportions of saturating cations. All the regressions were highly significant:

Liquid limit = 1814 - 17.4(%Ca) - 17.2(%Mg) - 15.9(%Na) - 17.3(%K);

Degree of dispersion = 1229 - 11.9(%Ca) - 11.8(%Mg) - 11.5(%Na) - 12.0(%K);

Moisture retention (1/3atm) = 2092 - 20.4(%Ca) - 20.7(%Mg) - 19.5(%Na) - 20.5(%K).

Cracking and Development of Structure

Leyton and Yadav (1960) studied the effect of drainage on certain physical properties of a heavy clay soil. The proportion of water-stable aggregates, pore space and hydraulic conductivity improved upon drainage down to a depth of 15 inches. The improvement of aeration favored the microbial activity and plant rooting.

The importance of cracking in connection with irrigation has been emphasized by Stirk (1954) and Sleeman (1963). The intensity of cracking will depend on rainfall distribution, rate of drying, vegetation and the extent of swelling. The pattern is also dependent upon proportion and hydration of the clay minerals, and the nature of adsorbed cation. Ca-dominated montmorillonite, with free lime, will tend to form scattered wide cracks (Smith, 1959; Sleeman, 1963), which are more desirable for irrigation than high intensity fine cracks developed on lime-free, Na-saturated clay.

Smith (1959) and Fox (1964) observed a tendency for surface cracking to be parallel to, and between the crop rows, and than plant roots effectively hold the soil together preventing the formation of cracks in the row.

De Vos and Virgo (1969) found that the crack pattern of a Sudan Grumosol was less related to the soil chemistry than to external factors influencing the drying and rewetting of the soil. Typically the soil has large prismatic blocks subdivided by cracks into moderate, medium-to-coarse subangular blocky components in the surface horizon. At the base of this horizon, between 20 and 60 cm., platy and/or wedge-like structure is often present. The platy structure was considered to be of depositional origin. The wedge-like aggregates faces defined by polished and smooth slickensides, tend to predominate with depth particularly in the second and third horizons. The peds are often more prominent in dry soils and become weaker in moist sites, or in areas under continuous irrigation.

The deepest horizon below 175 cm is permanently moist and has mottles. Blocky structure and large slickensides constitute the most distinctive features at this depth. They concluded that the structural development in the upper profile is the result of contemporary pedogenesis whereas the large slickensides of the subtratum are probably relics of pedogenetic processes experienced in the past.

Two different phases of shrinking and swelling, termed unidimensional and threedimensional volume change (Fox, 1964), have been used to explain the formation of cracks, slickensides and wedge-like structure. The unidimensional loss of soil volume occurs vertically during the initial stages of drying. Below a critical moisture tension, horizontal contraction proceeds causing threedimensional shrinkage which is accompanied by the opening of vertical cracks. During the initial rewetting stage vertical and

horizontal pressures arise. The vertical component is partially relieved by upward movement of the overlying horizon and the horizontal component is absorbed by the crack width, but as the cracks are normally infilled by surface material, the horizontal forces are resolved at an obligue angle. The expansion and contraction forces are relieved by displacement of peds along the slickensides faces which have been developed during the initial stages of the threedimensional volume change phase.

Classification of Clayey Soils

Most of the clayey soils, namely, Regur, Tirs, Black Cotton, Tropical Black Clay, Gray and Brown Soils of heavy texture, and Smonitza were grouped together at a high categorical level in a great soil group designated Grumosol (Oakes and Thorp, 1950). However, a single categorical class at the subgroup level does not appear sufficient to embrace consistently the whole population of clayey soils as a group because of their variable characteristics, the diverse environmental conditions under which they have been formed, and the different parent materials upon which they have been developed.

In the 7th Aproximation (Soil Survey Staff, 1960) these soils were grouped in the Vertisol order, which include soils having 35 percent or more clay content, more than 30 meg/100 g of exchange capacity in all horizon below 5 cm. from the surface, cracks, intersecting slickensides and/or gilgai microrelief.

Further subdivision at the suborder level considered only two soil moisture regimes (aquic and ustic), defined by the chromas of the upper 30 cm. or the presence of distinct mottling. At the great group level two classes were separated considering the surface soil structure (surface mulching, and platy or massive structure).

Intergrades to other taxa were included at the subgroup level, although within the other soil orders no taxa were defined to include those soils that share partially some characteristics of Vertisols.

The 1967 supplement to U.S. Soil Classification System (Soil Survey Staff, 1967) introduced few modifications in regard to definition of the Vertisol order. Thirty percent or more clay in all horizons was adopted as a breaking point, instead of 35 percent clay as was stated before.

The main criterion used to separate classes of soils at the suborder level was changed to the soil moisture regimes which were defined in term of the length of time that the cracks remain open throughout the year. It was believed that Vertisols could not develop with an aquic moisture regime, and so, that suborder was eliminated. Another significant change was introduced by defining vertic intergrades in the subgroup category to include kinds of soils whose properties depart from the central concept of any taxon by significant cracking and shrink-swell potential which are characteristics exhibited by Vertisols (Soil Survey Staff, 1967; Dement and Bartelli, 1969). All the criteria proposed in the 1967 supplement have been retained in the U.S. Soil Taxonomy (Soil Survey Staff, 1970).

Most of the fine textured soils of Venezuela can be classified as Chromic Vertisols and Ochric Gleysols according to the definitions of soil units for the Soil Map of the World (Dudal, 1968). Chromic Vertisols are those soils with 30 percent or more clay in all horizons to a depth of at least 50 cm, which also have deep cracks, moist chromas of 1.5 or more throughout the upper 30 cm of the soil, and gilgai microrelief or, intersecting slickensides at some depth between 25 and 100 cm or, parallelepiped aggregates. Other soils of fine texture having a cambic horizon and cracks to depth of less than 50 cm are included as Vertic Cambisols.

Ochric Gleysols are soils developed from unconsolidated deposits, exclusive of recent alluvial deposits, having no diagnostic horizons other than a gleyic horizons and possibly a pallid A horizon or a cambic B horizon (Dudal, 1968).

GEOGRAP Y OF CLAYEY SOILS OF VENEZUELA

Regional Distribution of Clayey Soils

The total area occupied by clayey soils in Venezuela has been estimated at 5,256,200 ha. (CIDIAT and SVCS, 1971.) Their regional distribution is illustrated by figure 1, and Tables 1 and 2.

Table 1. Regional distribution of clayey soils in Venezuela (after CIDIAT and SVCS, 1971)

Region	Area (ha)	Percentage
1. Maracaibo Basin	390,000	7.4
2. Western-Central	268,700	5.1
3. Llanos:		
Western Llanos	1,650,750	30.3
Lower Llanos	2,165,500	41.2
Central Llanos	315,550	6.0
Eastern Llanos	296,900	5.7
Total for Llanos	4,428,650	83.2
4. Delta-San Juan River	226,750	4.3
Total for the country	5,256,200	100.0

The most extensive areas of clayey soils occur in the Llanos. They are particularly predominant in the Western and Lower Llanos amounting to 3,816,250 ha, or 71.5 percent of the total area of these soils in the country.

The intraregional distribution and the environmental conditions under which these soils could have been developed can be used as a framework within which the soil-forming factors and soil properties may be studied. For this purpose Table 2 has been included as to show the occurrence of

clayey soils within regions.

Table 2. Intraregional distribution of clayey soils in Venezuela. Major areas. (CIDIAT and SVCS, 1971)

Region	Sector	Area (ha)
1. Maracaibo Basin		
	Palmar River Valley	55,300
	Zulia-Tarra River Valley	190,000
	Catatumbo River Basin	52,000
2. Western-Central		
	Hueque-River Valley	96,000
	Lower Tocuyo-Aroa River Valley	86,200
	Carora	57,750
3. Llanos		
3.1 Western Llanos		
	Guanare	32,450
	Libertad	60,500
	Barinas	38,500
	Canagua	75,900
	Ciudad Bolivia	77,000
	Caparo	108,350
3.2 Lower Llanos		
	Arismendi	583,000
	San Fernando	472,500
	Payara	495,000
	Guasdualito	93,000
	Mantecal-Elorza	522,000
3.3 Central Llanos		
	Tiznados	173,800
	Calabozo	141,750
3.4 Eastern Llanos		
	Unare River Basin	261,000
	Barcelona	21,600
4. Delta-San Juan River		
	San Juan River Valley	133,600
	Orinoco Delta	87,750

The Soil-Forming Factors on a Regional Scale

The soil properties are products of pedogenetic processes that give

rise to horizon differentiation acting under the control of soil-forming factors. Some of these soil-forming factors such as climate are relatively homogeneous over large areas, to the extent that their effect on soil differentiation may be observed on a broader scale. Vegetation in a gross sense is closely correlated with climate, therefore its major effect is likely to be observed over large areas, as well. Local variations of vegetation are usually associated with variations of topography, parent materials and time.

If climate and vegetation are relatively uniform at a regional scale, time as a single factor would still serve to differentiate kinds of soils within a region, provided that groundsurfaces of different ages could be consistently recognized. The degree of expression of the soil properties derived from the pedogenic processes will show a marked contrast due to the different time elapsed in the course of soil formation. Finally, parent material and relief are commonly the greatest source of variation expected within a single landscape in many parts of the world. Although the scale of observation influences the significance attributed to topography, relatively small differences of topography may greatly modify the effect of climate upon vegetation and soil properties at a local scale.

The preceeding discussion leads us to realize that the properties of the soils under study can be better understood if they are considered under the general framework provided by the soil-forming factors.

Climate

The clayey soils of Venezuela occur within two major climatic types: the tropical savanna (Aw), and tropical steppe (BSh), which will be described below. The distribution of these climates throughout the country is showed in figure 2.

Tropical Savanna (Aw):

The prevailing climate in the Llanos is characterized by marked wet and dry seasons. Over most of the area the average annual rainfall (R) ranges from 1000 to 1800 mm. being greatly concentrated from April or May to November. The potential annual evapotranspiration (PET) exceeds the annual rainfall to the extent that the PET/R ratio is commonly between 1 and 2. The rainfall distribution is markedly seasonal. The dry period lasts for 4 to 6 months. The concentrated rainy period often causes a great excess of water which usually accumulates in the lower depressions in the landscape.

In contrast, the temperature is rather uniform throughout the year. The mean annual temperature is about 27° C. Although the seasonal variations recorded are consistently less than 3° C, the diurnal amplitude (difference between maximum and minimum daily temperature) may be as much as 10° C.

Figure 3 illustrates the main characteristics of the climate of four localities within the tropical savanna climatic region.

Tropical Steppe (BSh)

This climate is usually known as semi-arid. It is characterized by a marked water deficit. The mean annual rainfall (R) varies between 500 and 1000 mm. Its distribution is irregular or erratic throughout the year. The dry period commonly extends for 7 months. The potential evapotranspiration (PET) largely exceeds the annual rainfall to the extent that a marked aridity is observed in the landscape. The PET/R ratio ranges between 2 and 4. The rains come as short, intense showers which greatly contribute to the erosion of the landscape; rivers are intermittent in regard to their flow regime.

The mean annual temperature is about 29° C and the seasonal variation is rather negligible. Figure 4 illustrates the most important characteristics of this climate.

Vegetation

On a regional scale, the clayey soils appear to be developed under tropical dry forest and tropical very dry forest, whose flora composition is described below, and their distribution in the country is illustrated in figure 5.

Tropical Dry Forest

Three types of associations are usually recognized within this type of forest, namely: climax forest, secondary forest and tropical savanna (Ewel and Madriz, 1968).

Climax forest. It characteristically contains the following species: caoba, Swietenia macrophylla; cedro, Cedrella mexicana; apamate, Tabebuia, pentaphylla; gateado, Astronium graveolens; trompillo, Guarea trichilioides; palo de mora, Chlorophora tinctorea, and other palm genera such as Copernicea, Attalea and Acrocomia.

Secondary forest. It is widely spread throughout the country. It has grown where the native forest vegetation has been cleared for agricultural purposes or for timber, and then abandoned after several years of production. Among the species characterizing this type of forest are: saman, Phitecolobium saman; copaiba, Copaifera officinalis; caro, Enterolobium cyclocarpum; yagrumo, Cecropia peltata; jobo, Spondias mombin; ceiba, Ceiba pentandra; and guacimo, Guazuma ulmifolia. Transitional areas to the tropical very dry forest may contain other species, such as: cuji, Prosopis juliflora; roble, Platimiscum polystachyum; drago, Pterocarpus podocarpus; and indio

desnudo, Bursera simaruba.

Savanna. It appears usually associated with the tropical dry forest. In a gross sense, three kinds of savannas have been recognized in Venezuela; two of them are defined by the floral composition, and the other by landscape configuration. The latter is characterized by narrow winding banks, and intervening depressions consisting of a narrow overflow areas and decantational basins which form a distinctive intricate pattern. The overflow areas and decantational basins are subject to prolonged flooding and remain under water throughout the rainy season and partly during the dry season. The soils in depressional areas are moist well into February. Consequently, the landscape configuration, the relative position of the topographic forms, and flooding are conducive to a generalized poorly drained condition, and to the predominance of grassland type vegetation. Most of the clayey soils of the Llanos occur under this kind of savanna.

Tropical Very Dry Forest

This vegetation formation is made up by small, deciduous, fine-leaved and thorny trees. Typically, it has a two tree stories. The upper one, which may be as high as 18 m., is usually discontinuous and deciduous. The lower story is dominated by thorny shrubs and bushes.

The typical plant association is characterized by an upper story with dominant species, such as: gatillo, Capparis linearis; vera, Bulnesia arborea; guamacho, Pereskia guamacho; curavi, Tabebuia serratifolia; and roble, Platymiscium polystachium. The lower story is made up mostly by shrubs whose dominant species are: pinon, Jathropa urens; cuji Aromo, Poponax farnesiana; and maya, Bromelia

humilis.

Parent Material.

The parent materials of the soils of the Llanos are variable. Their composition is dependent upon the geologic formations present in the watersheds of the different rivers. However, as different geologic formations are eroded at different times, changes in composition and mineralogy of the parent material can also be expected as a function of the geologic time during which the sediments were deposited. Zinck and Stango (1966) pointed out that the t_{IV} accumulation of the Santo Domingo River originated mainly from the sedimentary rocks of The Andes, and the more recent accumulations were derived from the crystalline rocks underlying the sedimentary rocks. Also, the headwater of large rivers only reach the crystalline rocks, while the small river headwaters are confined to the sedimentary formations.

The parent materials in which the soils of the Llanos have developed come from the southeast flank of The Andes Mountains, and from the southern slope of the Coastal Range. The Andes are composed of igneous and metamorphic rocks, mainly granite, gneiss and micaschist, partially overlain by interbedded sedimentary rocks, among which sandstone and shale are predominant.

The Coastal Range, particularly the "Cordillera del Interior," where most of the rivers flowing southward to the Central Llanos have their headwaters, is primarily made up of strongly deformed and metamorphosed rocks of Cretaceous age, overlying a granite nucleus of undetermined age (Liddle, 1946). Conglomerates, limestone, schists, micaschists, gneiss and granite are major rock types that make up the "Cordillera del Interior" of the Coastal Range.

The soils of the Llanos have developed in alluvial sediments of mixed

mineralogy deposited during the late Quaternary periods.

Age.

Zinck and Stagno (1966) recognized four groundsurfaces of different ages in the piedmont and Western Llanos. These surfaces could have resulted from successive periods of deposition during the Pleistocene era which have been subdivided in four periods, termed t_{IV}, t_{III}, t_{II}, t_I, from the oldest to the most recent. The cyclic nature of these accumulations has been attributed to paleoclimatic oscillations in the Pleistocene (Tricart, 1965 and Zinck, 1966). The erosion of the mountains and subsequent deposition in the lowland took place during unstable periods characterized by a rainfall of high intensity and concentrated in relatively short periods (K unstable, Butler, 1959). The unstable periods have been alternating with periods of stability (K stable, Butler, 1959) where the rainfall is better distributed, to the extent, that erosion is reduced to a minimum, and the work of the rivers is concentrated in downcutting their previously deposited sediments. Pedogenesis takes place during the stable periods.

In the Piedmont and valleys of the Andes, the Pleistocene depositions occur as four terraces with considerable differences in elevation among them. On the contrary, due to the subsidence of the western plains the more recent accumulations covered up the preceeding ones. The last two Pleistocene accumulations are observed in the area (t_{II} and t_I), although the older surface has been buried to a large extent.

Topography.

Based on several soil surveys made in different parts of the country, the clayey soils occur in four major landscapes, namely: flood plains, entrenched valleys, internal fluviodeltaic and littoral fluviodeltaic

depositional systems (Zinck, 1970), which are described below.

Flood plains: A hypothetical landscape model depicting this landform is represented in figure 6. Four major landscape segments are often recognized, namely: natural levees, splay-like deposits, cover plain and slackwater deposits. The natural levees are channeled deposits found at both sides of the streambed. They are long, coarse-textured, narrow strips usually less than 50 m. wide, occupying the highest position in the landscape.

When the river bank breaks at localized points during the bank-full stage, coarse-textured sediments from the channel are spread over a limited area of the cover plain adjacent to the natural levee. This localized landscape segment, termed splay-like deposit, is recognized in the airphotos by a multitude of current scars, usually of light tone.

Adjacent to the natural levee a uniform strip 300 to 500 m. wide slopes down to the depressional areas. This strip of medium-textured sediments is the cover plain.

Farther from the streambeds, large decantational basins or depressions in which water accumulates are also found. These depressions consist primarily of clay-sized particles deposited under conditions of still water (slackwater deposits). The soils of the depressions are therefore clayey and poorly drained.

Internal fluviodeltaic depositional system. This depositional system is mostly found in continental areas that have been subject to subsidence related to tectonics. Huge depressional areas are then filled in by alluvial sediments brought by tributaries of large rivers, which in time of high water level, cause a damming effect on the tributaries. Typically, the landscape is characterized by an intricate pattern of very

narrow and winding banks, and closed intervening depressions. Within the depressional areas, three kinds of landscape segments are easily identifiable, which are termed low natural bank, wet depression and very wet depression (figure 7). In general the landscape is very flat over large distances, and during the wet season flooding is very frequent.

The sediments are subject to sorting before being deposited, by an intricate network of distributaries, that often shift from place to place during flooding stage. Adjacent to the distributaries the coarser fraction is deposited to form a high bank (deltaic bank), and then, as the velocity of flooding water usually decreases progressively with the distance from the tributaries, the energy available for transporting is considerably reduced, to the extent that only the finer fraction can be carried away in suspension.

The state of decreasing level of energy for transportation is responsible for the sorting of sediments in the process of deposition, in such a way, that a textural sequence of the deposits can be correlated with the different observed landscape segments. The coarser textures are associated with the bank and the finer textures with the wet and very wet depressions.

Littoral fluviodeltaic depositional system. Within this depositional system, the same geomorphic positions as those of the internal fluviodeltaic depositional system are recognized in the landscape, but affected by floodings to a lesser extent (figure 8) (Zinck, 1970). It is a system found in the flat coastal areas where the vertical range of tides is almost imperceptible, and as the transport energy of the flowing water has become zero, rivers drop their suspended bed loads.

The fluvial sediments are deposited in the coastal depressions filled by sea water, until the land area emerges and increases at the expense of

the sea. This process is usually referred to as "Progradation of Coast" and to be effective requires an abundant supply of sediments at the river mouth.

The process by which the sediments are sorted and deposited, and the landscape configuration are similar to those referred to in the former case. However, the presence of sea water is reflected in the ion composition of the parent materials and soil derived from them.

Entrenched valley depositional system. This landscape is characterized by distinctive sloping valley walls, largely shaped by mass-wasting, and a sequence of terraces at different elevations resulting from climatic fluctuations throughout the Pleistocene Epoch.

In addition to the valley walls, a sequence of four landscape segments can be recognized within a single terrace position. They are called riverbank (usually absent), overflow layer deposits (silty sediments), lateral depressions (silty clay and clay) and marginal depressions (fine clay sediments). The assemblage of these geomorphic positions is sketched in figure 9.

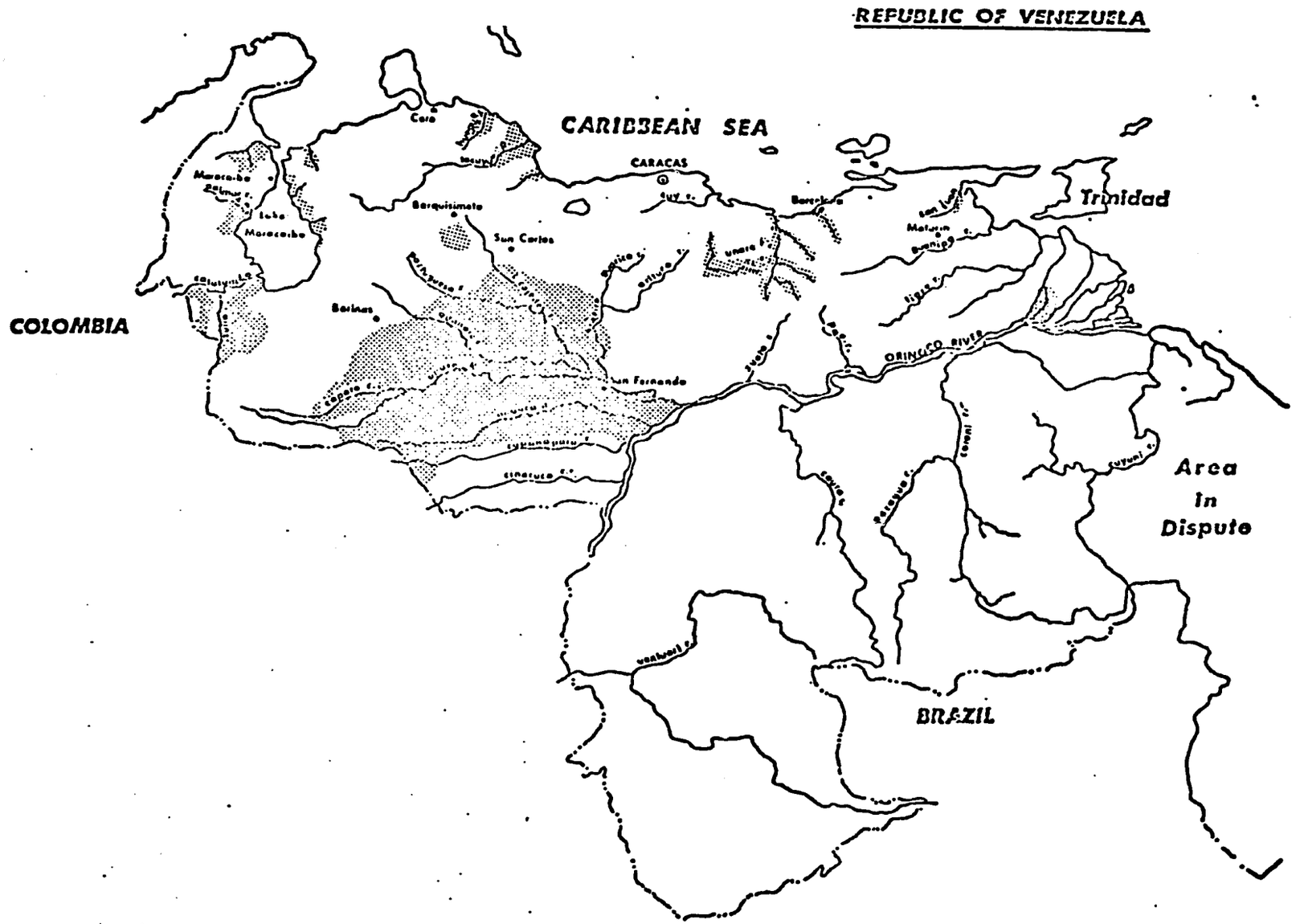


Figure 1. Distribution of clayey soils in Venezuela. (after CIDIAT and SVCS,1971).

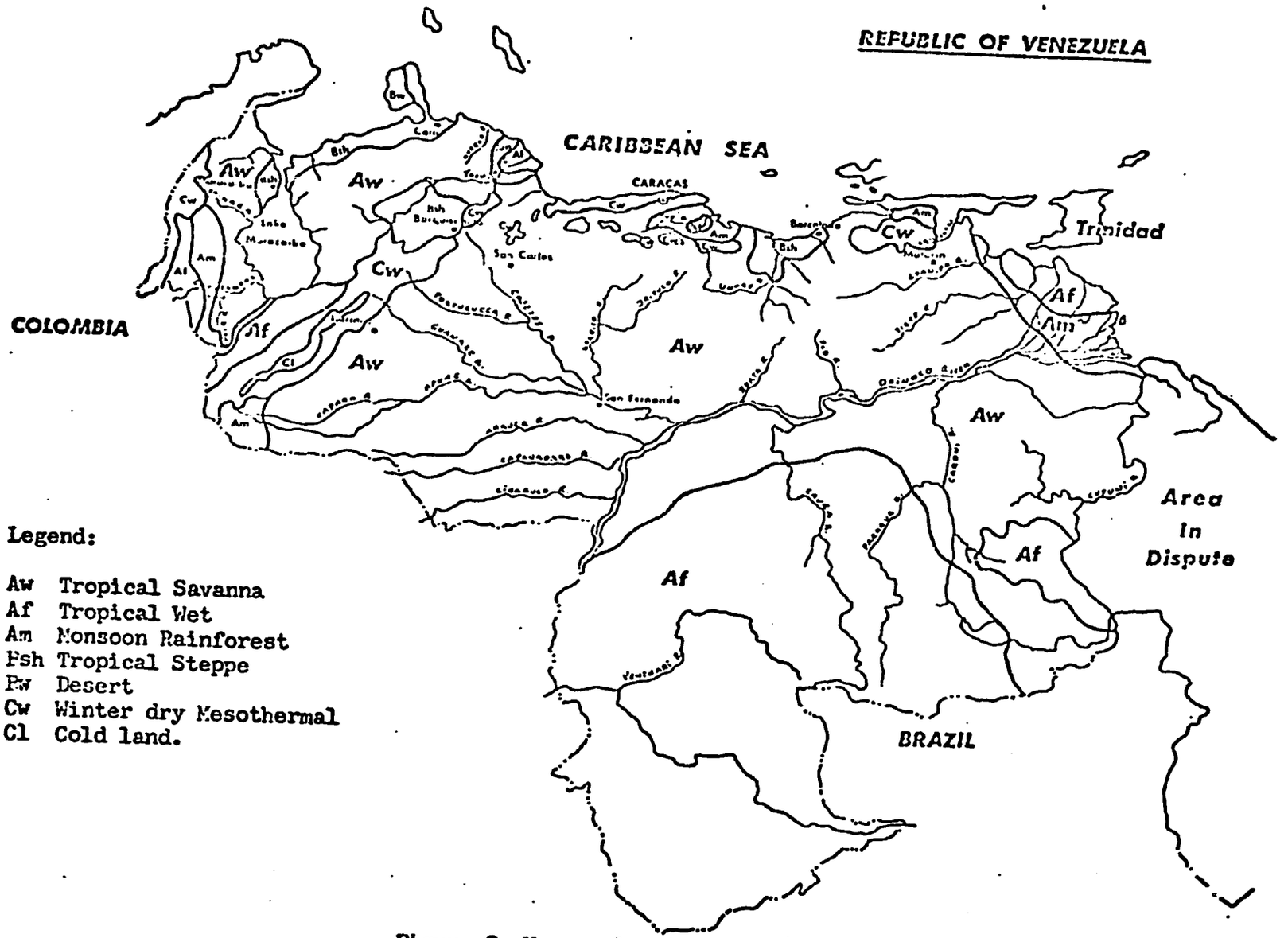


Figure 2. Venezuela climatic zones.

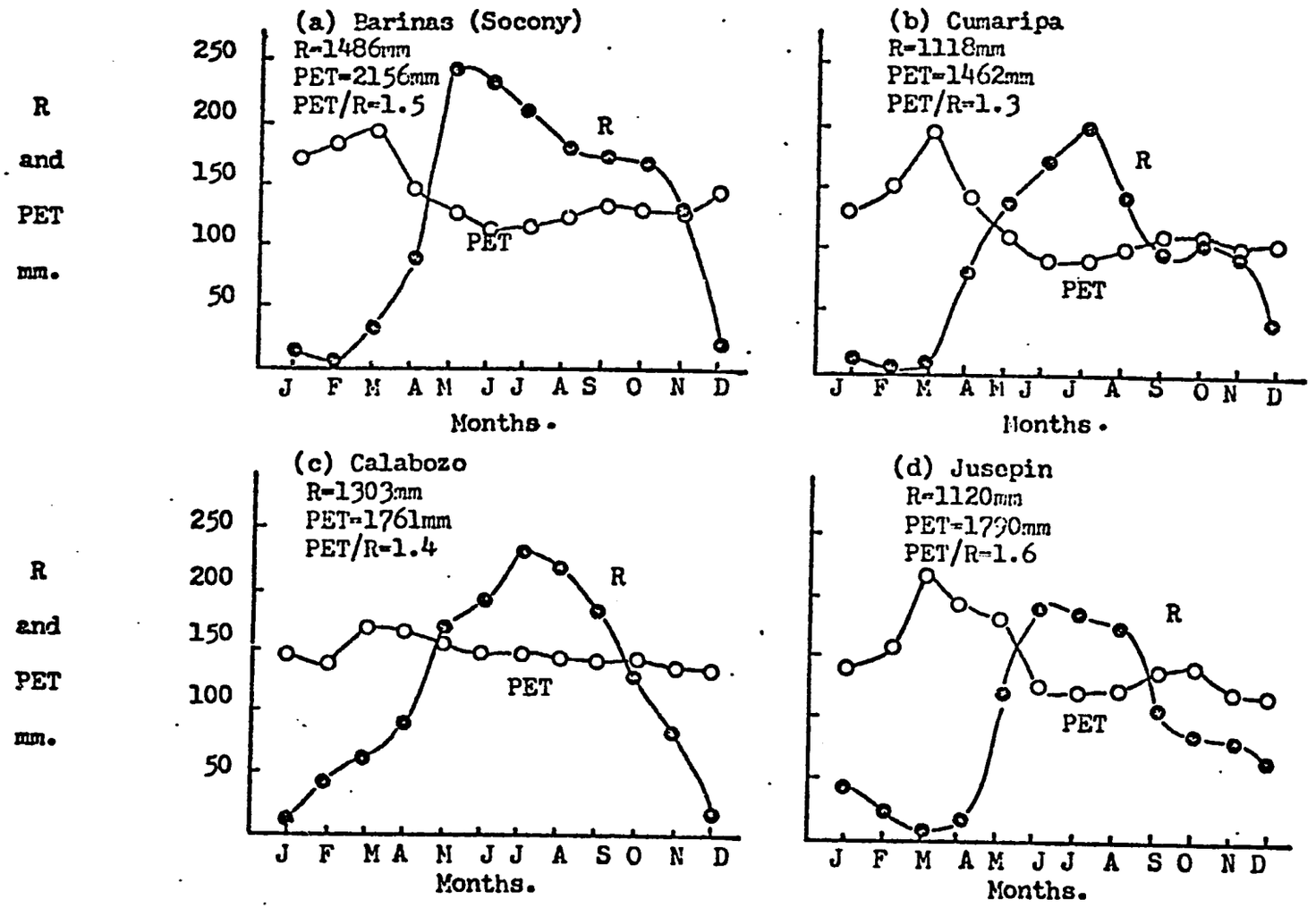


Figure 3. Rainfall (R) and potential evapotranspiration (PET) for four locations within the tropical savanna climatic region.

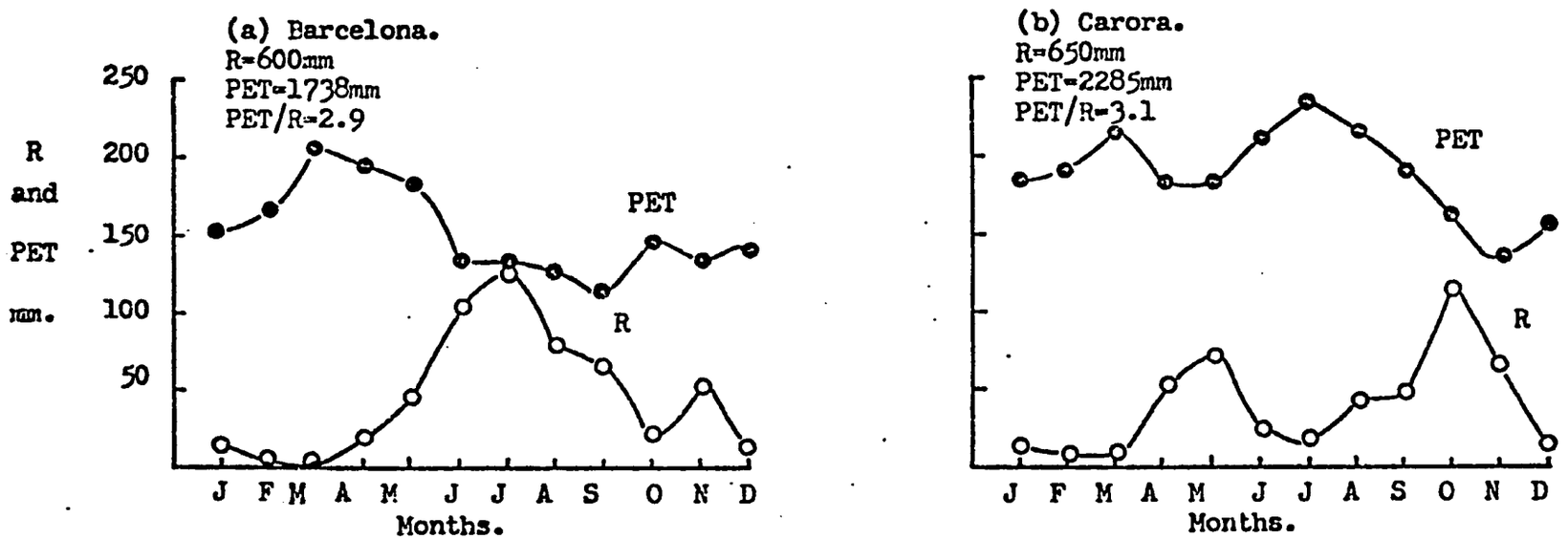


Figure 4. Rainfall (R) and potential evapotranspiration (PET) for two locations within the tropical steppe (semiarid) climatic region.

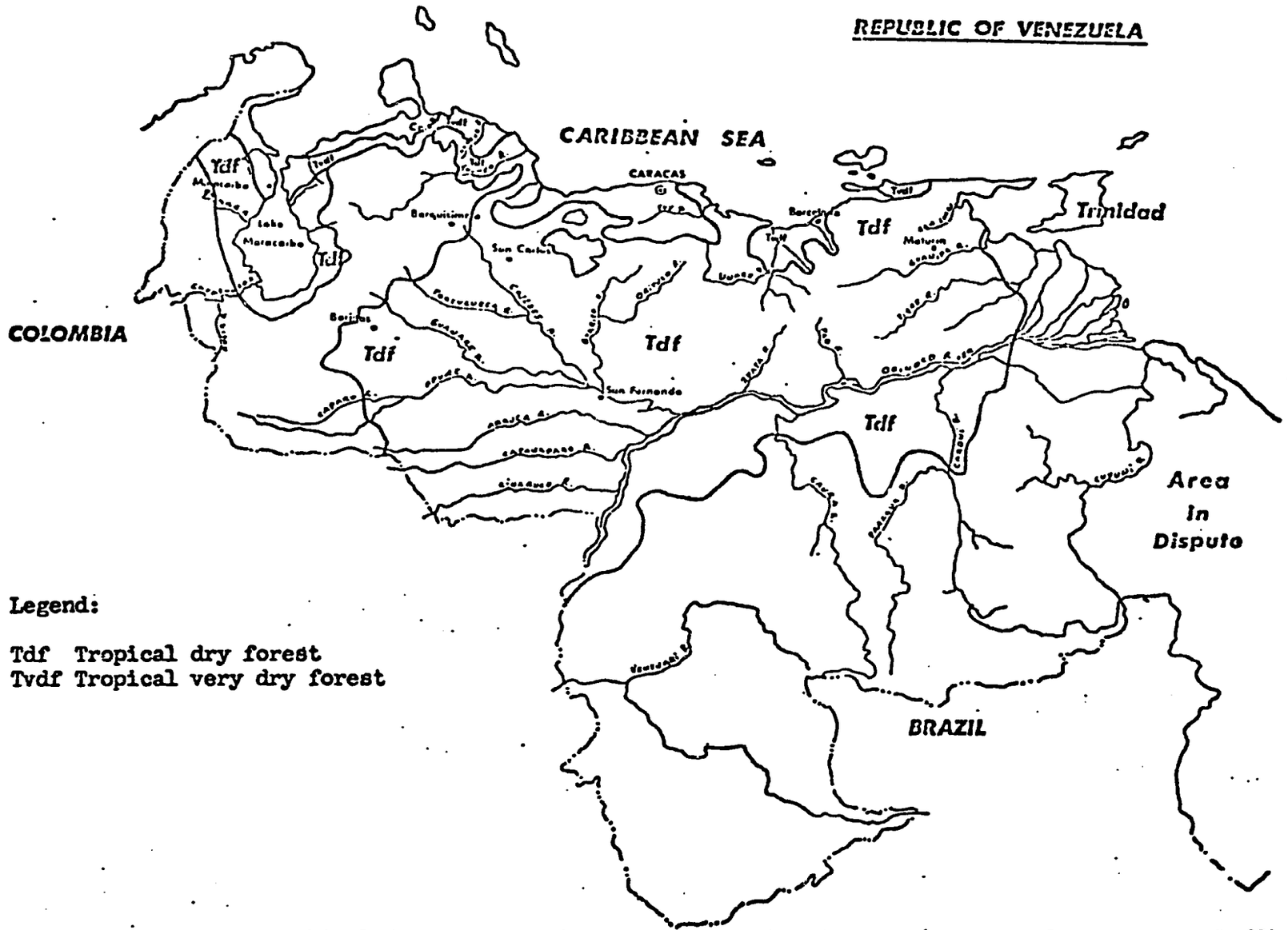


Figure 5. Distribution of tropical dry forest and tropical very dry forest. (After Ewel and Madriz,1968).

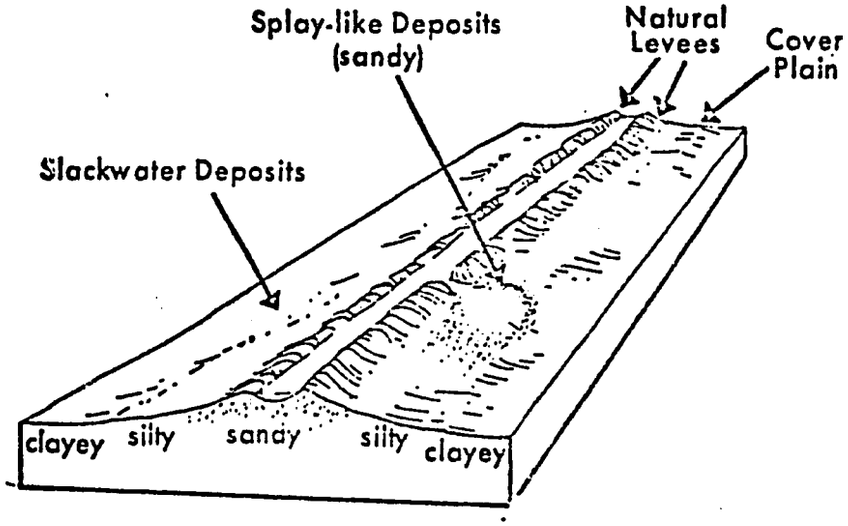


Figure 6. Floodplain landscape model

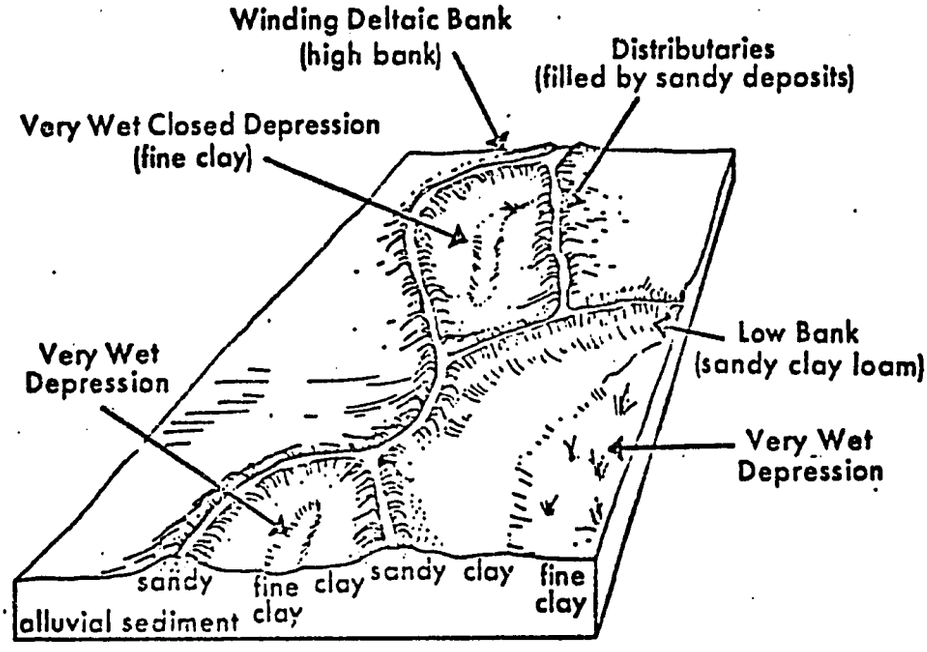


Figure 7a. Internal fluviodeltaic landscape model.

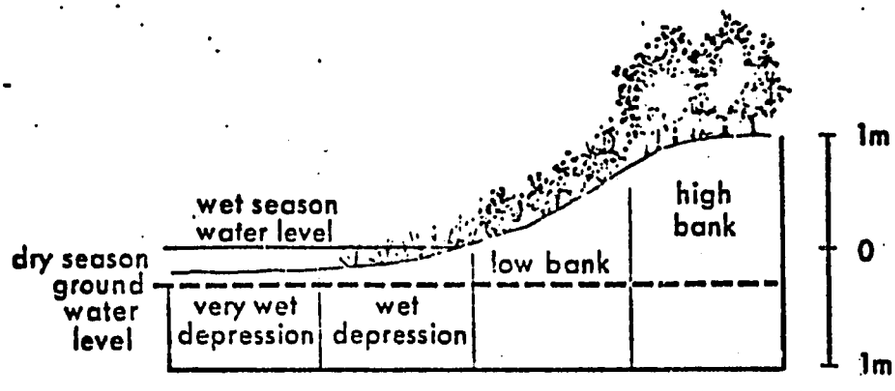


Figure 7b. Cross section of the internal fluviodeltaic landscape. (After Colmenares et al, 1972)

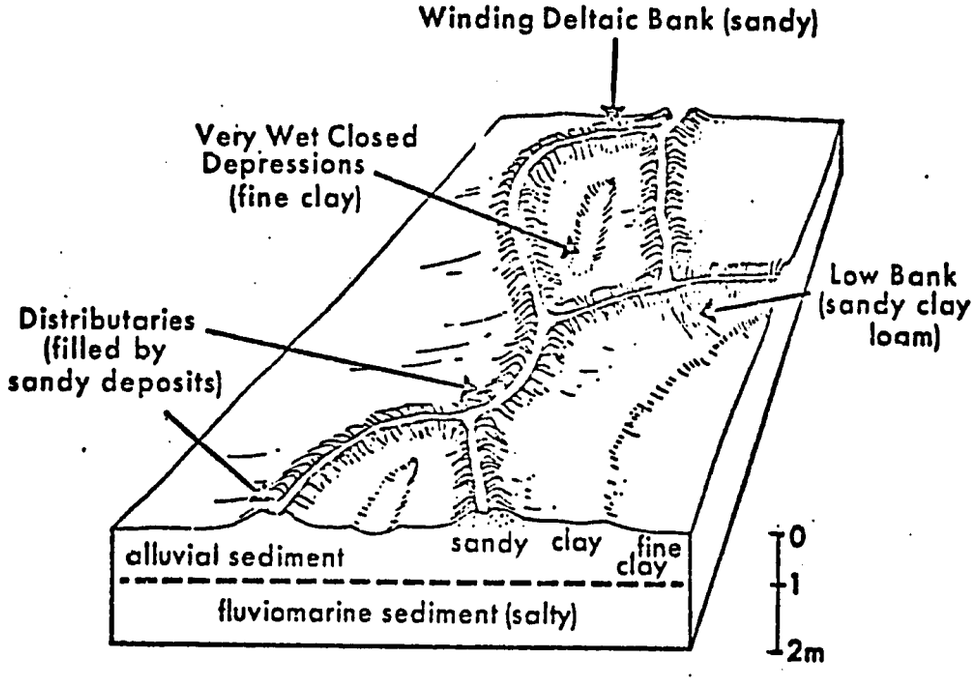


Figure 8. Littoral fluviodeltaic landscape model.

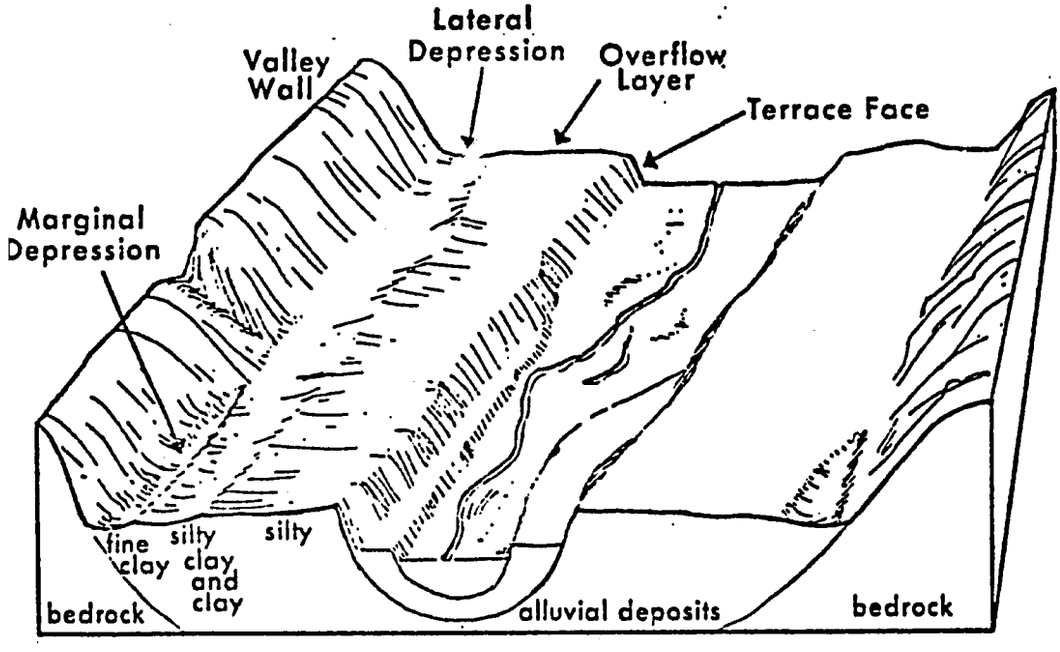


Figure 9. Entrenched valley hypothetical landscape model.

MATERIALS AND METHODS

Soil Pedon Selection and Sampling

For the present study, six soils from different parts of the country embracing a range of climatic conditions have been selected for mineralogical characterization and classification. These soils have in most cases been extensively mapped and widely used for agricultural production.

Soil profile descriptions along with analytical data were obtained from either published soil survey reports, or from the field reports in those areas that are now being surveyed. The approximate location of the soil profiles are shown in figure 10 and additional information may be found in the profile descriptions enclosed in the appendix.

Many soil samples of some profiles selected were obtained directly from the laboratory stock room in which they had been stored since May 1971. Other samples were taken from pits dug in the field during January 1973. The sampling of the soil profiles was done by horizons, from which nearby two kilograms of disturbed material were taken and stored in plastic bags.

Air-dried soil samples were ground in a porcelain mortar and passed through a 2mm sieve to separate the coarser fraction (> 2mm), which was negligible in all horizons, however, a few iron-manganese nodules were crushed in the process.

Horizon Selection

Typically the kind of soil used in the present study shows little horizon differentiation because the influence of the soil forming factors is subdued by cracking and churning. The profile descriptions and the

accompanying analytical data, indicate a lack of distinct horizonation. They tend to be rather uniform with depth, particularly in clay content, pH, cation exchange capacity and the color in the subsurface horizons.

For these reasons, only two horizons from each profile were selected for initial analysis; the top horizon usually corresponding to the plow layer which is important in terms of use and management of the soil, and a subsurface horizon where properties are diagnostic for these soils as a group. Among the latter features were the presence of slickensides and cracks more than 1 cm wide. In the majority of the cases the lower horizon selected was at depths between 50 and 135 cm.

Pretreatment and Fractionation

Twenty grams of soil from the selected horizon were treated with 0.5 N NaOAc, pH 5, for removal of carbonates (Jackson, 1956) and then, the removal of organic matter was readily accomplished by sodium hypochlorite (Anderson, 1963 and Lavkulich, 1970). The removal of free iron oxides was achieved by sodium dithionite as recommended by Jackson, (1956).

Once the pretreatment was completed, the coarse clay (2-0.2μ and medium plus fine clay (< 0.2μ) size fractions were separated by centrifugation and decantation (Jackson, 1956).

According to the available data (Appendix I) the sand contents are low and silt contents are moderate. Only the clay fraction was selected for initial mineralogical characterization.

X-ray Diffraction Analysis (XRD)

The clay fractions were Mg and K saturated and mounted on glass slides as outlined by Jackson (1956). A separate Mg saturated slide was glycerol solvated and irradiated at room temperature.

The K saturated slide was first X-rayed at room temperature, and then

after each heat treatment (350°C, and 550°C).

A Norelco X-ray diffractometer with a wide angle goniometer was used to analyze the samples. They were scanned with nickel filtered, copper radiation (CuKα) produced at 35 Kv and 15 ma at a rate of 2 2θ per minute. For each specimen the peak-height intensities of the dominant reflections were recorded and measured (tables 16 and 17 , in appendix).

On the X-ray diffraction patterns no clear evidences of any discrete 2:1 clay mineral was consistently found. However, it was thought that discrete 2:1 expansible clays might be present but possibly masked by high amorphous material content. The presence of substantial amounts of non-crystalline materials reduces the efficiency of XRD analysis for crystalline clay minerals by either scattering of the X-ray beam out the diffraction path, or by absorption of the X-ray beam, or by preventing the parallel orientation of the sample. Therefore, amorphous materials were removed (Hashimoto and Jackson, 1960) before Mg saturated and glycerol solvated samples were prepared and X-rayed. The resulting patterns confirmed the presence of vermiculite and montmollonite. Consequently, it was decided to use quantitative chemical methods to better evaluate the kinds and amounts of expansible clays in the samples.

Differential Thermal Analysis (DTA)

For this analysis Ca-saturated samples were mixed with ignited Al_2O_3 in a ratio of one part of clay to two parts Al_2O_3. The samples were allowed to stand for 48 hours in an evacuated dessicator over a saturated solution of $Mg(NO_3)_2 \cdot 6H_2O$ prior to obtaining the DTA curve, (Mackenzie, 1964).

Kaolinite was estimated from the integrated hydroxyl-peak area, obtained from the DTA curve, and corrected for the contribution of OH in

2:1 layer silicates present. By using the equation KL= B-0.70aB, where KL is the corrected peak area due to kaolinite, B is the total integrated hydroxyl-peak area, and a is the fraction of 2:1 minerals present in a given sample, the kaolinite content was estimated. The percentage of 2:1 clay minerals were obtained by chemical allocation procedures as indicated in the following section.

Chemical Methods for Clay Minerals Allocation

The laboratory procedures used to determine the clay minerals are listed below and the tabulated results are given in Appendix 3.

Amorphous Material.

Estimates of amorphous material were obtained by dissolution in boiling 0.5 N NaOH for 2.5 minutes (Hashimoto and Jackson, 1970). The silicon and aluminum mobilized by the dissolution treatment were measured colorimetrically as outlined by Weaver et al (1968), and Mclean (1965), respectively. A Coleman Spectrephotometer was used for measurement.

The amorphous material content was calculated using the following formula which assumes the material to have 10 percent water.

$$\% \text{ Amorph. Mat.} = \frac{\% \text{ Si } O_2 + \% Al_2O_3}{0.9}$$

Vermiculite and Montmorillonite content.

Estimates of vermiculite and montmorillonite content were obtained by procedures based on the CaEC and K//EC determination of Alexiades and Jackson (1965) as modified by Chapman et al (1969) to include weighing of excess salt solution.

The equations used to calculate the amounts of these clay minerals are given below:

$$\% \text{ Verm.} = \frac{\text{CaEC} - \text{K//EC}}{154} \times 100$$

$$\% \text{ Mont.} = \frac{K//EC - (5+105 \text{ (amorph) })}{105} \times 100$$

In the last equation a correction of the 5 meg/100g edge charge attributable to various clays is included because the SiO_2/Al_2O_3 molar ratio of the amorphous material is commonly more than 3, which indicates that a montmorillonite-like product has dissolved in 0.5 N NaOH.

Mica Content.

As the X-ray diffraction analysis indicated an absence of any K-feldspar, the total K_2O was allocated to mica. It was obtained by digestion of samples with $HF-H_2SO_4$ as suggested by Priden and King (1969). A K_2O content of 10 percent was assumed for mica (1% K_2O = 10% mica) as outlined by Jackson and Mackenzie (1964).

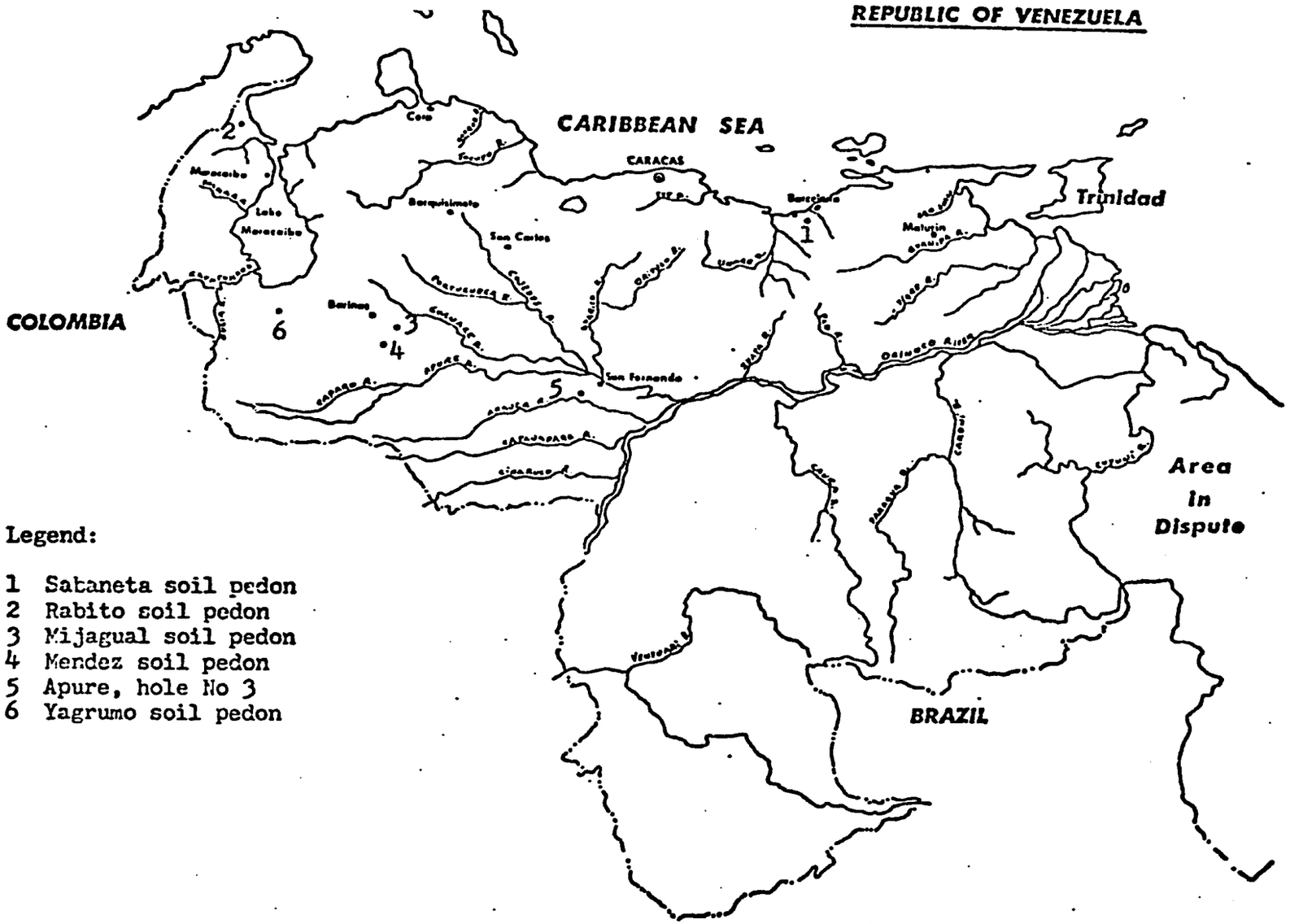


Figure 10. Approximate location of the sampled soil pedons.

RESULTS AND DISCUSSION

The available information in regard to soil morphology and physical-chemical properties along with the mineralogical data produced in this study is used to characterize the soils under investigation. The discussion is intended to point out the presumed effect of the soil-forming factors and processes during the course of soil formation. The genesis interpretation and pedogenetic properties serve as the basis for the classification of the soils.

Particular attention is given to the problem of recognition of lithologic discontinuities to establish whether or not the soil system has been developed from one uniform material. Such recognition is important to distinguish between genetic soil properties and those properties that are produced by depositional changes of materials. Abrupt changes in the trend of depth functions constitute a basis for identification and location of discontinuities in the soil system (Arnold, 1968).

After judging the uniformity of the soil system, soil morphological features are considered. Emphasis is placed upon those physical-chemical properties that give rise to horizon differentiation and that are considered diagnostic for classification. Mineralogical soil properties are taken into account to attain a better understanding of genetic properties, and to visualize what changes might have occurred in the soil material along the course of soil development. Furthermore, mineralogical data is utilized for classifying the soil at the family level.

The x-ray diffraction patterns were interpreted following the

conventions indicated by Whittig (1965). The low angle asymmetry and peak broadening consistently observed in the Mg-glycerol solvated slides were taken as evidence of random interstratification of 2:1 clay minerals (Mills and Zwarich, 1972).

Several methodologies suggested by Freas (1962), and Pierce and Siegel (1969) were tested to estimate semi-quantitatively the proportions of kaolinite and mica in the fine clay fraction. The results obtained by these procedures were then compared against the available data determined by chemical analyses. The method based on the relative peak-height intensities of the clay minerals in the Mg-glycerol solvated slides repeatedly gave the most reasonable approximation to the expected values of mica and kaolinite. Consequently, as quantitative data for mica and kaolinite in the coarse clay fraction were not determined, the former procedure was used to estimate the relative proportion of these silicate clay minerals.

To illustrate the procedure, consider the data for the Blsa horizon of the Sabaneta soil pedon (Table 3). Vermiculite, montmorillonite and amorphous material in the coarse clay fraction add up to 10 percent, therefore, the remaining 90 percent ascribed to mica and kaolinite is proportionally distributed between both minerals according to their relative peak-height intensities (pk-ht), which are 3 cm and 15 cm, respectively (Table 16). In attaining the relative proportions of the former minerals in the sample, the following formulas were used:

$$\% \text{ mica} = 90\% \times \frac{\text{3 cm pk-ht. for mica}}{\text{18 cm pk-ht. for mica + kaol.}} = 15$$

$$\% \text{ kaolinite} = 90\% \times \frac{\text{15 cm pk-ht. for kaol.}}{\text{18 cm pk-ht. for mica + kaol.}} = 75$$

The contents of mineral species in the clay fraction were accounted for in defining mineralogical families within which the pedon studied are

classified (Soil Survey staff, 1970). The amounts of mineral species present in the total clay fraction (Table 5) were calculated considering the relative proportions of coarse and fine clay and the respective contents of given mineral species (Tables 3 and 4). For instance, the B22g horizon of the Yagrumo soil pedon contains 77.5 percent kaolinite in 70 percent coarse clay and 38 percent in 30 percent fine clay. Therefore, the total content of this clay mineral based on the whole clay fraction is:

$$\% \text{ kaolinite} = \frac{(77.5 \times 70) + (38 \times 30)}{100} = 65.7$$

Other mineral species were also calculated by the same procedure.

Some additional soil physical properties, such as liquid limits, degree of dispersion, and 1/3-bar moisture retention were calculated in the horizons selected for mineralogical characterization by means of the equations proposed by El Swaify et al (1970) for Tropical Black Earth soils. He indicated that the physical properties considered are functions of the saturating cations as proportions of the total bases in the exchange complex. The formula are:

$$\text{L.L} = 1814 - 17.4\ (\%Ca) - 17.2\ (\%Mg) - 15.9\ (\%Na) - 17.3\ (\%K) \quad (1)$$
$$\text{D.D} = 1229 - 11.9\ (\%Ca) - 11.8\ (\%Mg) - 11.5\ (\%Na) - 12.0\ (\%K) \quad (2)$$
$$\text{1/3-bar M.R} = 2092 - 20.4\ (\%Ca) - 20.7\ (\%Mg) - 19.5\ (\%Na) - 20.5\ (\%K) \quad (3)$$

To illustrate the calculations consider the 6 to 38 cm horizon of the Sabaneta soil pedon. The horizon selected contains 18, 7, 1.5, and 0.5 meg/100g of calcium, magnesium, sodium and potassium, respectively. As the total bases represent 27.0 meg/100g, the individual cations account for 66.4, 26.1, 5.5, and 2.0 percent of the total bases, respectively. If these data are used in formulas (1), (2), and (3) the results obtained for liquid limit, degree of dispersion and 1/3-bar moisture retention are: 88 percent, 44 percent and 49 percent, respectively (Table 6).

Pedon 1: Sabaneta Soil.

Uniformity of soil material.

More than one line of evidence is observed (Figure 11) to support the presence of two lithologic discontinuities in the soil system below 100 cm depth. Clay distribution in the soil profile indicates contrasting changes in the clay and silt content at this depth. Other depth functions such as percent of base saturation, exchangeable calcium, exchangeable sodium, cation exchange capacity and electrical conductivity also support the existence of lithologic discontinuities. On the contrary, the organic carbon distribution decreases regularly with depth, which might indicate that the contrasting layers do not represent part of a buried soil developed under a prior pedogenetic system. Still, as these layers appear not to have undergone important modification other than iron segregation similar to the horizons above, one may discard the possibility of a truncated soil profile buried by more recent sediments.

It is concluded that the differences in the particle size distribution in the soil system likely are of depositional origin. It is thought that pedogenetic processes have been active throughout the whole system and the soil has developed across the interface of three different materials.

Morphological features.

According to the soil profile description (Appendix, pedon 1) cracks more than 1 cm wide extend down to 170 cm and are usually open from December to May. Well-defined intersecting slickensides are increasingly observed with depth from 6 cm to 62 cm. Clay distribution is relatively uniform within the first 100 cm of soil depth, with the exception of the top layer. Well developed angular blocky structure is predominant above 60 cm in the pedon, but massive structure dominates at greater depth.

Gray mottles are also observed to be increasing with depth below 62 cm.

In general, the described physical features suggest that more than one pedogenetic process has been active in the course of soil genesis. On the one hand, the presence of cracks and slickensides developed under an alternating wet and dry soil moisture regime indicate that the soil is subject to a shrink-swell process. This process seems to be predominant within the first 62 cm in the pedon because the blocky structure and the slickensides are well expressed at this depth.

On the other hand, the observed gray mottling below 62 cm in the soil profile reveals that iron segregation and reduction is an operative process in the transformation of minerals.

Physical-chemical properties.

Most of the soil depth functions (Figure 11) are relatively uniform above 100 cm, except for the top layer and at the discontinuities. However, the electrical conductivity and chloride distributions increase progressively downward, while the percentage of exchangeable sodium exhibits a bimodal trend.

If one considers only the physical-chemical properties of the soil above 1 meter, they indicate that clay, bases and carbonates have not been appreciably translocated downward. These translocations would not be expected to be operative under conditions of low rainfall coupled with an impermeable parent material, as is the case under study.

On the contrary, the electrical conductivity and chloride concentration are observed to increase with depth throughout the discordant materials without a complementary relationship in the distribution of any other soil property. This phenomenon may be explained if one considers that the soil has been developed on alluvial sediments originally deposited

in depressional coastal areas filled by saline water. Consequently, it appears that the soil system has been partially resaturated from below by saline groundwater, and by the concomitant effect of capillary rise above the limit of the saturated zone.

Clay mineralogy.

The coarse clay in the second horizon is dominated by kaolinite (75%), with mica as a lesser component (15%). The fine clay fraction (less than 0.2μ) contains kaolinite, montmorillonite, mica, amorphous material and vermiculite, with about 30, 23, 20, 13, and 11 percent, respectively (Table 3).

These relatively high contents of kaolinite and amorphous material would not be normally expected in a soil developed from clayey impermeable alluvial parent material under a semi-arid climate (Jackson, 1957 and Barshad, 1957). Therefore, one might assume they have been inherited from parent rocks or materials that were previously subjected to pronounced weathering before being eroded and deposited in the lowland (Jackson, 1957).

On the other hand, montmorillonite and vermiculite contents are higher in the fine clay fraction. The increases in this fraction can be partly ascribed to the combined effect of particle size selection during the process of deposition of sediments (Jackson and Sherman, 1953) and to the weathering of the mica to form vermiculite and montmorillonite as indicated by broadening and low angle asymmetry of the mica peak (10 Å) (Figure 17), (Jackson, et al, 1952). Vermiculite is less than half of the montmorillonite content which possible indicates that the weathering of mica proceeds all the way through montmorillonite with the intermediate phase vermiculite being unstable in a very strongly acid soil reaction (pH 4.95). It is thought that these expansible clay minerals are largely

responsible for the swelling properties exhibited by the soil, and the associated cracks and slickensides.

Classification.

The soil pedon has more than 30 percent clay in all horizons, intersecting slickensides between 25 cm and 1 m, and cracks more than 1 cm wide extending down to more than 50 cm that remain open for more than 90 cumulative days in most years. Therefore, the pedon meets the properties that are diagnostic for the Ustert suborder within the Vertisol order as considered by U. S. Soil Taxonomy (Soil Survey staff, 1970).

The moist chromas of the soil matrix in the upper 30 cm are more than 1.5. The soil color is, therefore, lighter than that defined for Pellusterts, but it fits the definition provided for the Chromustert great group. On the other hand, other diagnostic properties for the typic subgroup, such as, color values of the upper 30 cm, structural aggregates with no clay skins on ped faces, and cracks open for more than 150 days are also observed in the pedon.

Within the control section, the clay content is more than 60 percent; the mineralogy of this fraction is dominated by kaolinite and the mean soil temperature is more than 22°C, with less than 5°C difference between mean summer and winter. In view of the set of soil properties mentioned above, the Sabaneta soil pedon can be classified as a Typic Chromustert, very fine, kaolinite, isohyperthermic.

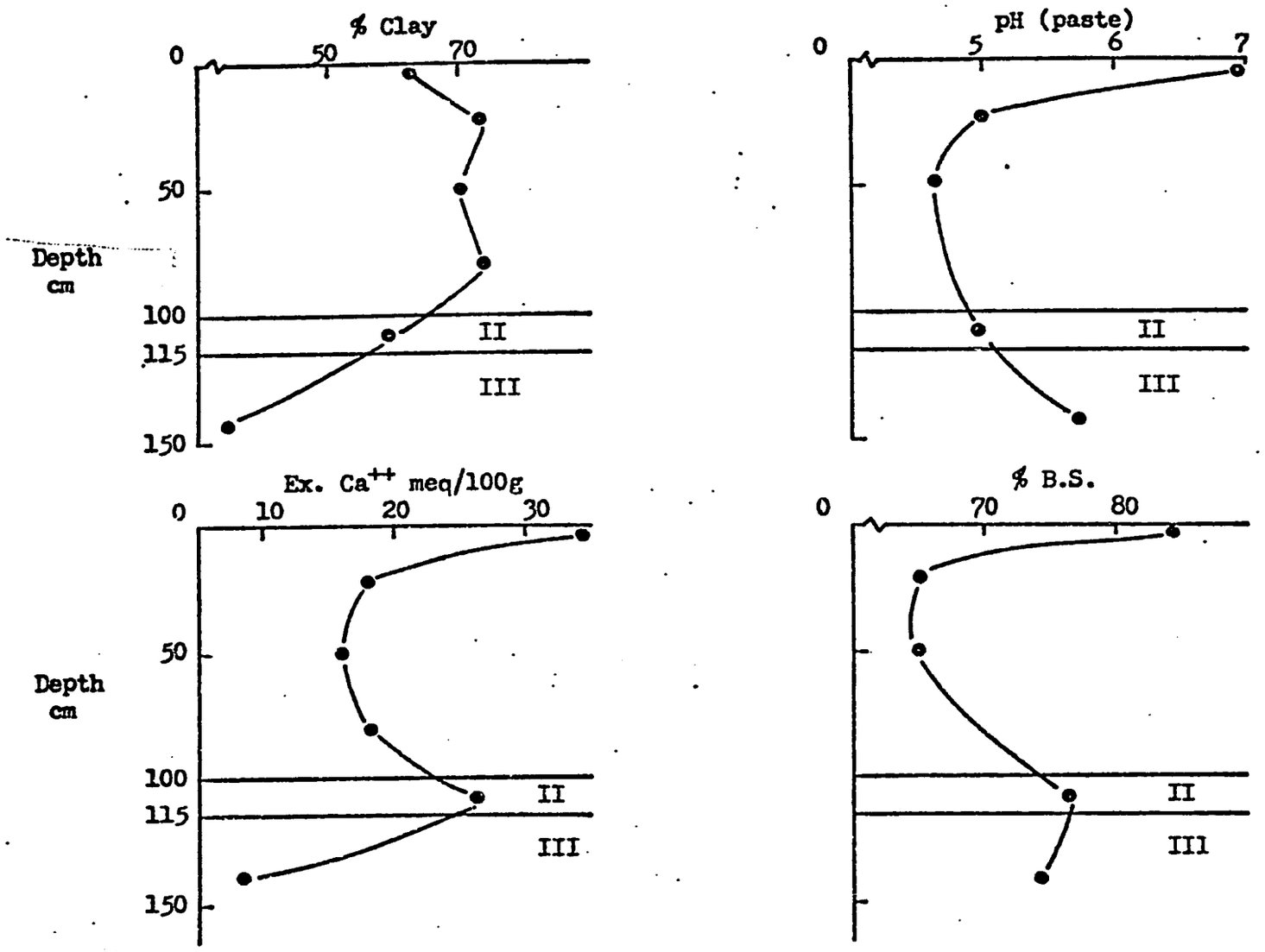


Figure 11. Depth functions of selected properties of the Sabaneta soil pedon.

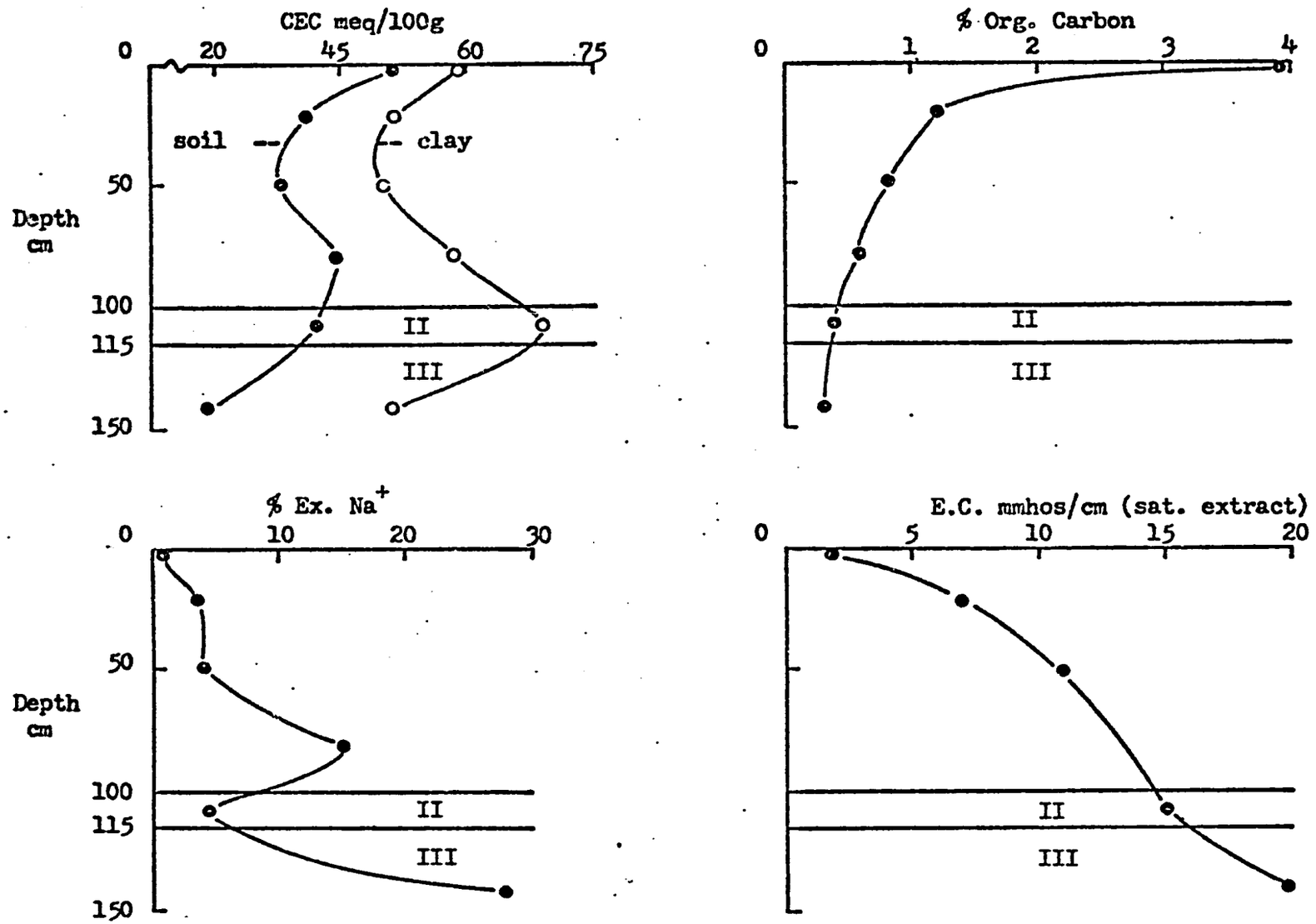


Figure 11. Continued. Depth functions of selected properties of the Sabaneta soil pedon.

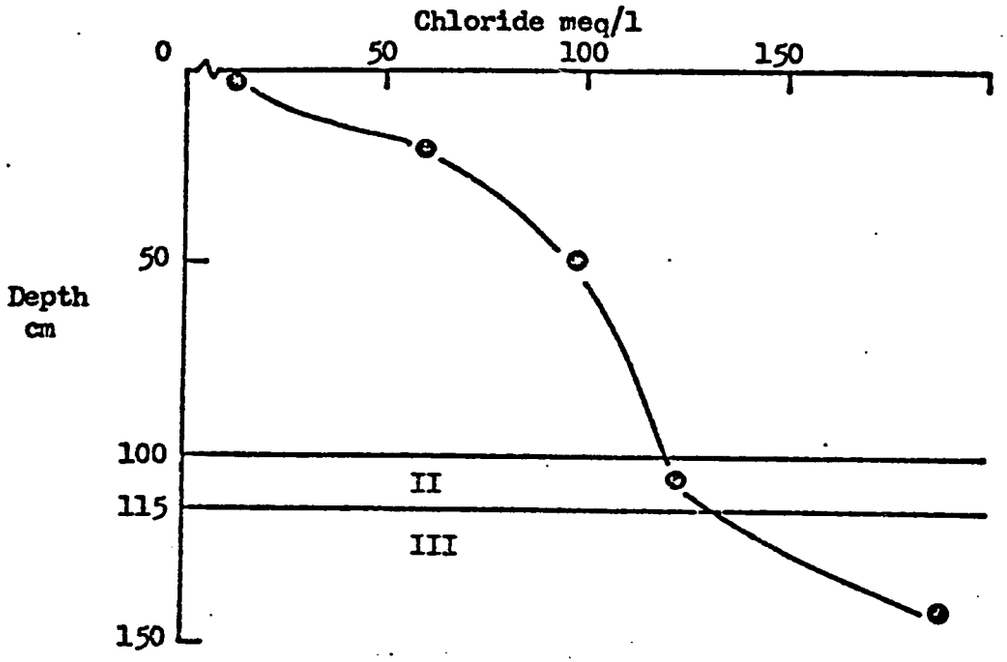


Figure 11. Continued. Depth functions of selected properties of the Sabaneta soil pedon.

Pedon 2: Rabito Soil.

Uniformity of soil material.

The material from which the soil has formed shows a high degree of uniformity along the vertical axis (Figure 12). With the exception of percent exchangeable sodium, electrical conductivity and chloride concentration, the other soil properties demonstrate a marked homogeneity to the extent that their distributions with depth vary within a very narrow range Exchangeable sodium, chloride concentration and electrical conductivity display an increasing trend downward in the soil pedon. These properties often associated with marine environments are well expressed below 130 cm, therefore, one might consider this soil layer as a separate entity composed of marine sediments or alluvial sediments laid down by fresh water, but resaturated by salty water.

Morphological features.

Impressive morphological characteristics observed in the soil pedon include wide cracks down to 200 cm, and the presence of well-formed intersecting slickensides. Prisms that part into angular blocky aggregates are dominant in the profile. A few low chroma mottles occur between 77 and 130 cm. Iron-manganese concretions increase with depth below 16 cm, and calcium carbonate nodules are also found below 77 cm. Clay skins occur below 130 cm in the soil profile.

Above 130 cm it seems that shrinking and swelling of the soil material accompanied by its mixing effect, and transformation of minerals have been the prevailing processes in the course of soil formation, rather than leaching of soluble salts and carbonates. Below 130 cm clay skins are observable along with slickensides. One might assume that at present the processes of expansion and contraction are not in operation at this depth,

and that clay has been flushed down through the deep cracks and deposited on the ped faces, instead of being translocated down the soil profile.

The mottles of low chromas, and calcium carbonate concretions found from 77-130 cm suggest the effect of wetness due to a fluctuating water table. Such fluctuations may have contributed to the calcium carbonate build-up, and its accumulation in the form of concretions. At present, the water table has dropped to a greater depth, and is not thought to be active in this zone.

Physical-chemical properties.

Even though most of these properties exhibit a linear trend with depth in their distribution, the electrical conductivity, chloride concentration and exchangeable sodium show a tendency to increase progressively with depth. The concentration of sodium and chloride are particularly important below 130 cm. Above this depth, the tendency is to decrease abruptly in content.

These facts emphasize the marine nature of the sediments below 130 cm.

Clay mineralogy.

In the horizon selected for characterization of the clay mineralogy, the results indicate that the coarse clay fraction is dominated by kaolinite (52%) and mica (28%). In the fine clay fraction, montmorillonite (35%) and mica (20%) are predominant with lesser amounts of vermiculite (16%), kaolinite (15%) and amorphous material (13%) (Table 3).

As with pedon 1, the high proportion of kaolinite and mica is thought to be inherited from parent rock that was previously subjected to weathering before the deposition of the sediments took place. Vermiculite and montmorillonite may be partially formed in situ by weathering of mica. Evidence to further this assumption is found in the pronounced peak

broadening and low angle asymmetry of the mica peak (10 A) indicating that this clay mineral is in the process of weathering to form expansible clay minerals (Figure 17). Further evidence of transformation of minerals is also indicated by low chromas and high chroma mottles due to segregation of iron in different states of oxidation. The high montmorillonite content is assumed to be formed by reconstitution of other degraded clays after reaching the marine environment (Weaver, 1957).

Classification.

The soil pedon has more than 30 percent clay in all horizons, intersecting slickensides between 25 cm and 1 m, and cracks more than 1 cm wide extending down to more than 50 cm that remain open for more than 90 cumulative days in most years. Consequently, the pedon meets the diagnostic properties established for the Ustert suborder of Vertisols (Soil Survey staff, 1970).

As the moist chromas of the soil matrix in the upper 30 cm are more than 1.5, the pedon can be included in the Chromustert great group. Because the pedon has, at the same depth mentioned above, lighter color values than those defined for Typic, cracks open for more than 150 cumulative days, and no clay skins on ped faces, it matches the definition for the Entic Chromustert subgroup.

Within the control section, the clay content is less than 60 percent; the mineralogy of this fraction is not made up by a single clay mineral of more than 40 percent; and the mean soil temperature remains above 22 C all year with minor variation between mean summer and winter. The former set of properties lead us to classify the soil pedon as an Entic Chromustert, fine, mixed, isohyperthermic.

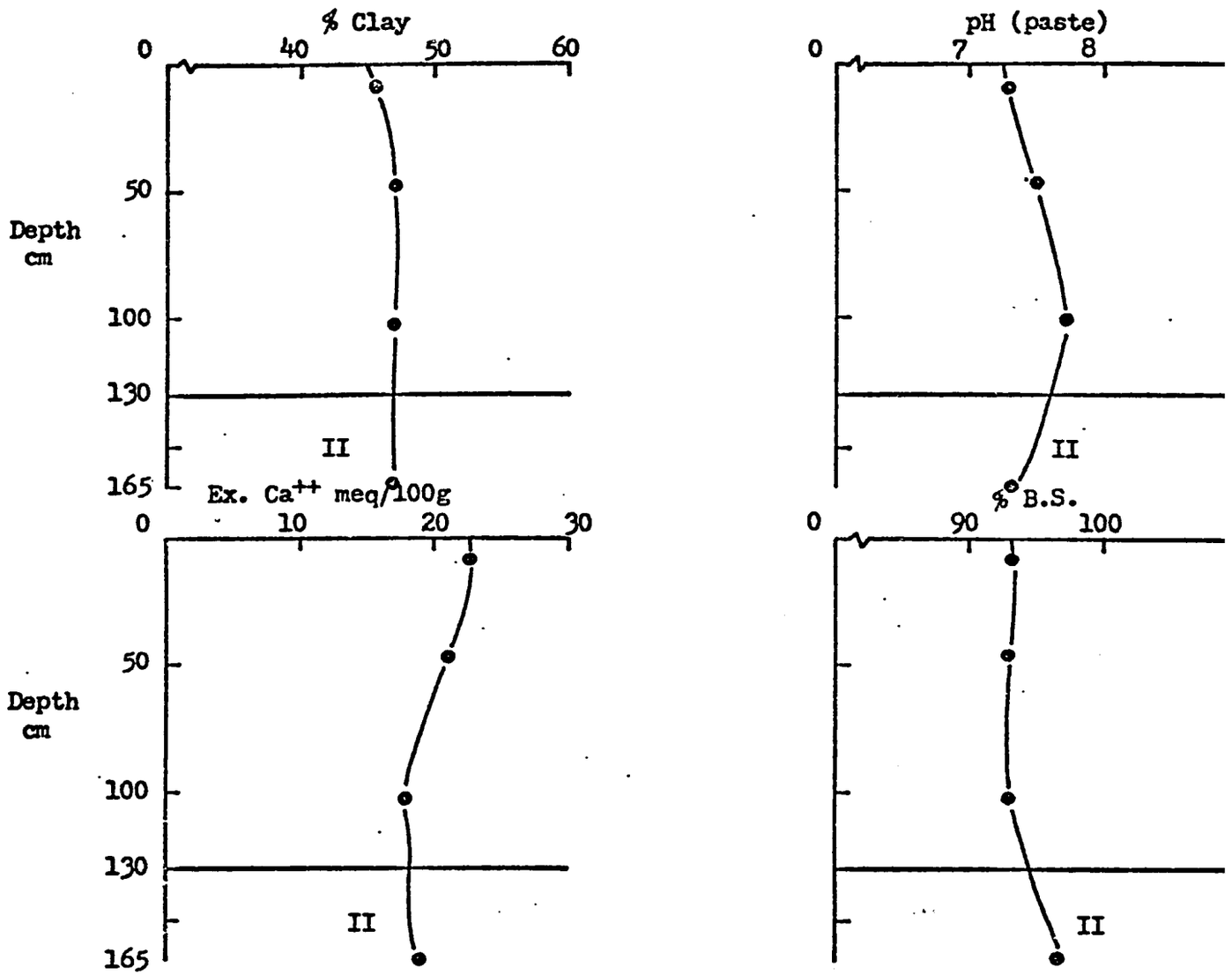


Figure 12. Depth functions of selected properties of the Rabito soil pedon.

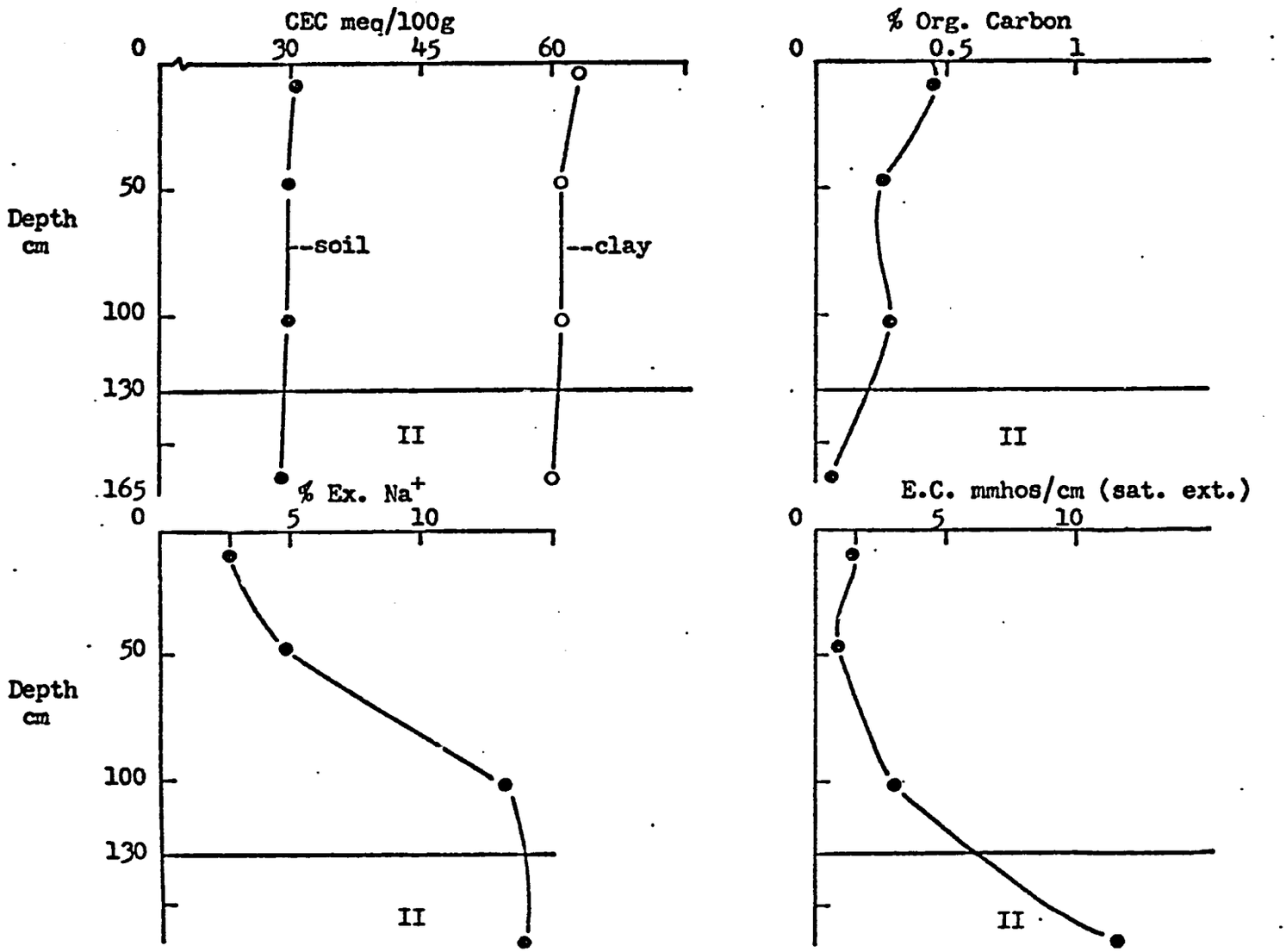


Figure 12. Continued. Depth functions of selected properties of the Rabito soil pedon.

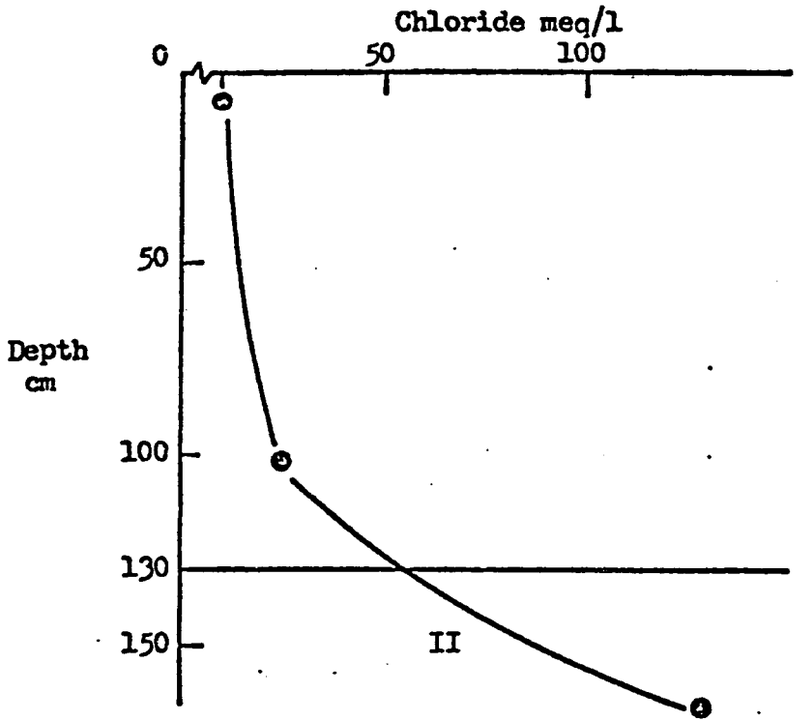


Figure 12. Continued. Depth functions of selected properties of the Rabito soil pedon.

Pedon 3: Mijagual Soil.

Uniformity of soil material.

The particle size distribution observed in the pedon (Figure 13) suggests the presence of a lithologic discontinuity at 154 cm, with the overlying horizon considered transitional to either the deposition of a different material above, or to a different mode of deposition of a similar material. The other soil properties, however, do not show complementary relationships indicating contrasting materials.

Morphological features.

Cracks more than 1 cm wide extending below 50 cm remain open for more than 90 cumulative days, but less than 150 days during the year in most years. Intersecting slickensides are described as increasing in number with depth below 17 cm. They are particularly well-expressed between 35 and 113 cm in the pedon, although some are still observed at greater depth. Moderately developed medium and coarse angular blocky structure predominates in the profile to a depth of 113 cm, and weak coarse prismatic structure occurs at greater depth.

The soil has moist chromas of more than 1.5 in the matrix of the upper 30 cm. The proportion of low chromas mottles increases with depth below 17 cm but does not become dominant in any horizon.

Iron-manganese segregation is predominant in the second horizon (17 to 35 cm), and the greater number of concretions described in the pedon occur at this depth. Below 35 cm, the proportion and size of concretions decrease and become softer.

From the preceding discussion, it seems that two major pedogenetic processes have affected the soil material. On the one hand, the swelling characteristics of the soil material would account for the presence of

deep cracks, slickenside formation, and for the development of structure under the effect of an alternate wet and dry cycles. On the other hand, the presence of low chromas and iron-manganese concretions constitute evidence of sufficient alteration of minerals in which iron segregation must have been intense enough to produce contrasting mottling and accumulation of iron in form of nodules. These properties reflect the important role that wetness and time have played in the horizon differentiation in the soil under consideration, even though a cambic horizon cannot be identified as defined by the U. S. Soil Taxonomy (Soil Survey staff, 1970).

Physical-chemical properties.

Exchangeable calcium, percent base saturation, pH and percent calcium carbonate equivalent show a slight increase with depth, which indicates some degree of leaching and translocation of bases and soluble substances downward the soil profile. Because the soil contains high proportions of clay and has a slow permeability, leaching of soluble components are presumed to have occurred through the deep cracks at the beginning of the wet periods.

Clay mineralogy.

In the horizon selected for characterization, the coarse clay fraction is mostly made up by kaolinite (43%) and mica (41%). Montmorillonite is predominant in the fine clay fraction (25%) with lesser amounts of mica (22%) and kaolinite (20%). Vermiculite content is about 14 percent (Table 3). No clay mineral species constitutes 40 percent of the clay fraction when considered as a whole (Table 5). It seems that the relatively high proportion of kaolinite has been mainly derived from a parent rock subjected to prior weathering before the deposition of sediments took place. It is very difficult to think that clay minerals might be intensively

weathered to form kaolinite under conditions of a high pH and a fine-textured impermeable parent material, as is the case under investigation. However, it seems probable that mica has been altered to produce vermiculite and montmorillonite which are the minerals responsible for the swelling properties exhibited by the soil pedon. Iron transformations observed as low chromas mottles and concretions, and the low angle asymmetry of the mica peak (10 A) recognized in the x-ray diffractograms of the Mg-glycerol slide (Figure 17) are indications of weathering in the layer.

Classification.

The Mijagual soil pedon possesses similar diagnostic characteristics to those defined for the Vertisol order, such as, more than 30 percent clay down to 50 cm, intersecting slickensides between 25 cm and 1 m, and cracks more than 1 cm wide going down to more than 50 cm. Furthermore, as cracks remain open for more than 90 cumulative days in most years, it can be classified within the Ustert suborder.

Because the chromas of the matrix are more than 2 in the matrix of the upper 30 cm, and the cracks usually stay open less than 150 cumulative days, the pedon meets the requirement to be classified as an Udorthentic Chromustert.

The soil pedon also has more than 60 percent clay throughout the control section, and no single clay mineral species constitutes more than 40 percent of the clay fraction. The mean soil temperature remains above 22 C all year with no significant variation between mean summer and winter. Because of this set of diagnostic characteristics this pedon is classified as an Udorthentic Chromustert, very fine, mixed, isohyperthermic.

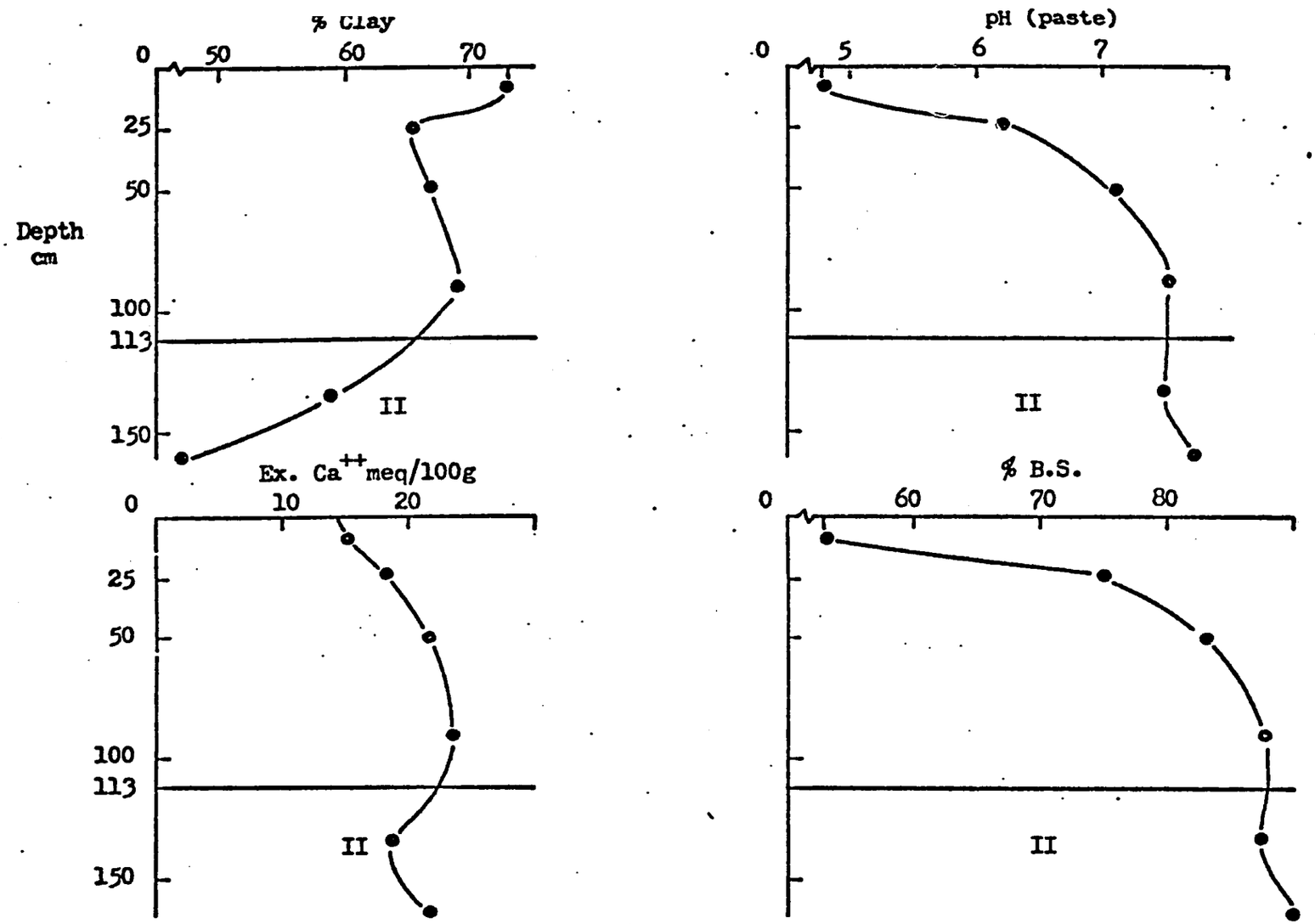


Figure 13. Depth functions of selected properties of the Mijagual soil pedon.

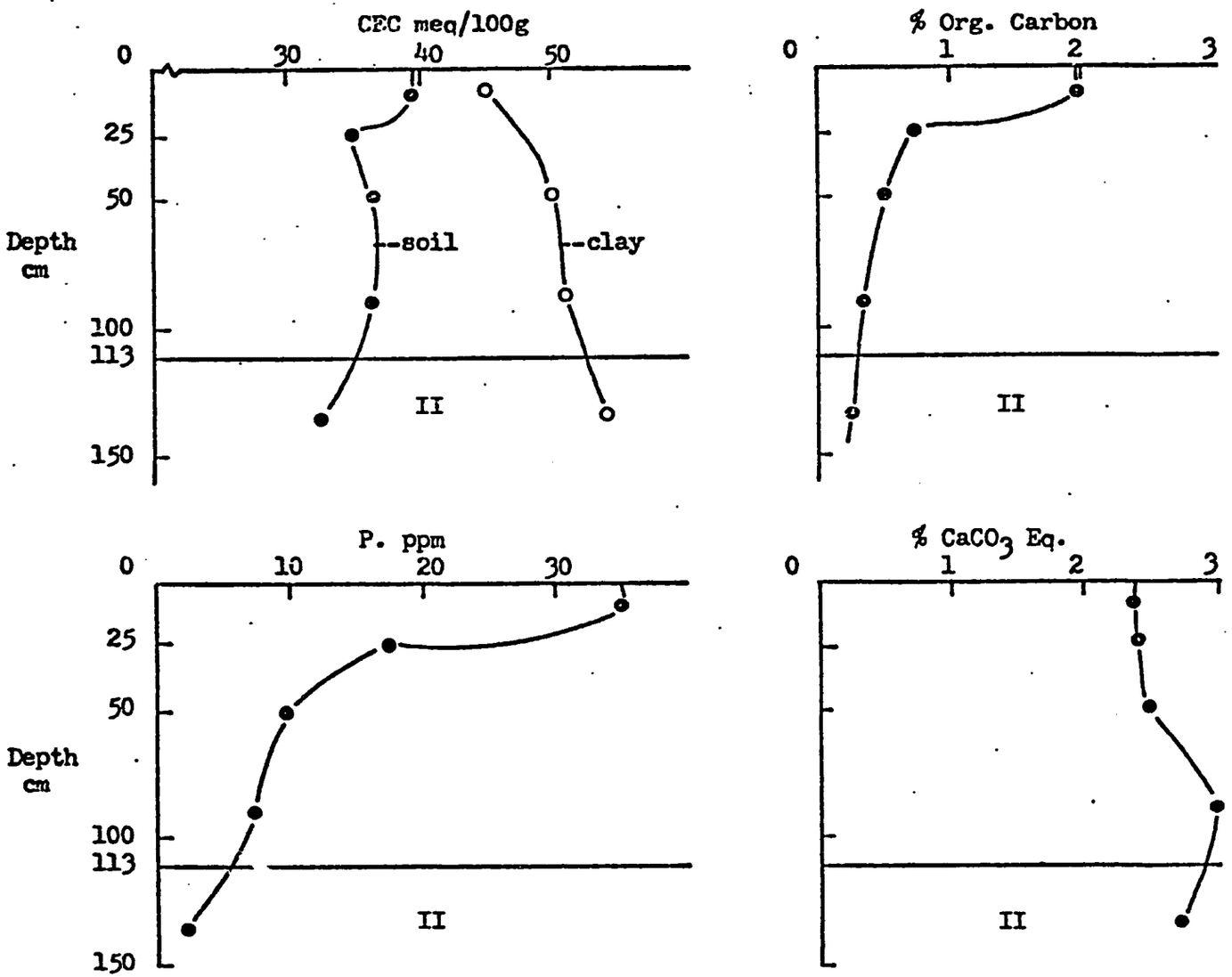


Figure 13. Continued. Depth functions of selected properties of the Mijagual soil pedon.

Pedon 4: Mendez Soil.

Uniformity of soil material.

As can be noticed in Figure 14, the distribution of different soil properties consistently exhibit two successive major changes, one at 100 cm and another at 120 cm. It is particularly evident in the depth functions of clay and cation exchange capacity per 100g of clay.

The organic carbon distribution tends to decrease regularly with depth, and its content in the lower layers is considered very low. Therefore, no evidence is observable to substantiate the existence of a buried A horizon. A frequent number of slickensides are only described below 120 cm where the marked change in clay content has been detected. These properties might suggest that the layer below 120 cm represents a truncated soil developed under prior pedogenetic processes. Although the overlying layer also differs in particle size compared to the material above, it is regarded as a transitional layer deposited at the onset of a more recent process of sedimentation.

Morphological features.

The soil pedon does not have cracks nor slickensides within the control section, although some of the latter are described below 120 cm. Angular blocky structure predominates in the profile above 120 cm. Below this depth there is strong prismatic structure.

High chromas mottles are found associated with very low chromas in the matrix of the soil below 7 cm. The iron segregation and reduction have been quite intense under the effect of wetness produced by a fluctuating water table, and part of it has been accumulated as concretions below 24 cm in the profile. Therefore, the alteration of the soil material has proceeded to the extent that recognition of a cambic horizon is possible.

Physical-chemical properties.

Bimodal trends in the distribution of the pH, exchangeable calcium, percent of base saturation and clacium carbonate equivalent indicate that the soil profile has been somewhat leached. Calcium and calcium carbonate have been slightly translocated from the second and third horizon, and accumulated below. A similar distribution is also observed for citrate-soluble phosphorus, however, this is attributed to a depositional origin rather than to the effect of leaching, because of the relative immobility of phosphorus in soils.

Clay mineralogy.

In the horizon selected for analysis, mica is the dominant clay mineral (45%) in the coarse clay fraction with kaolinite amounting to 37 percent. Mica and montmorillonite contents are approximately equal in the fine clay fraction, being 27 percent and 25 percent, respectively. Kaolinite makes up about 20 percent of the same fraction, and the vermiculite content is very low (8%) (Table 3). In a recent soil such as the Mendez, one would not expect the clay minerals to weather all the way to form a relatively high proportion of kaolinite (Jackson and Sherman, 1953, and Jackson, 1957). Therefore, most of its mineralogical characteristics are thought to be inherited from parent rocks or material subjected to intense weathering prior to the deposition of the sediments in the lowland.

On the other hand, the low angle asymmetry observed in the Mg-glycerol x-rayed sample suggests that mica has been partially weathered to form hydrous mica and montmorillonite (Figure 17), although for the major part, the last clay mineral is assumed to be derived from the parent sediment, as well.

Finally, it is worthy to note that the clay fraction does not contain

more than 40 percent of any single clay mineral species.

Classification.

As the soil has a cambic horizon produced by iron segregation and reduction taking place under the effect of fluctuating groundwater table, and because the soil stays wet and saturated at some period of the year, in most years, it is considered to be an Aquept at the suborder category.

Because the soil temperature regime is more or less uniform throughout the year with minor seasonal variations, and there are prominent low chroma mottles in the upper 75 cm, the soil pedon can be classified as a Typic Tropaquept.

Finally, if other properties within the soil control section are considered, such as, particle size distribution, mineralogy, soil reaction and the soil temperature regime, the soil can be classified as a Typic Tropaquept, fine, mixed, acid, isohyperthermic.

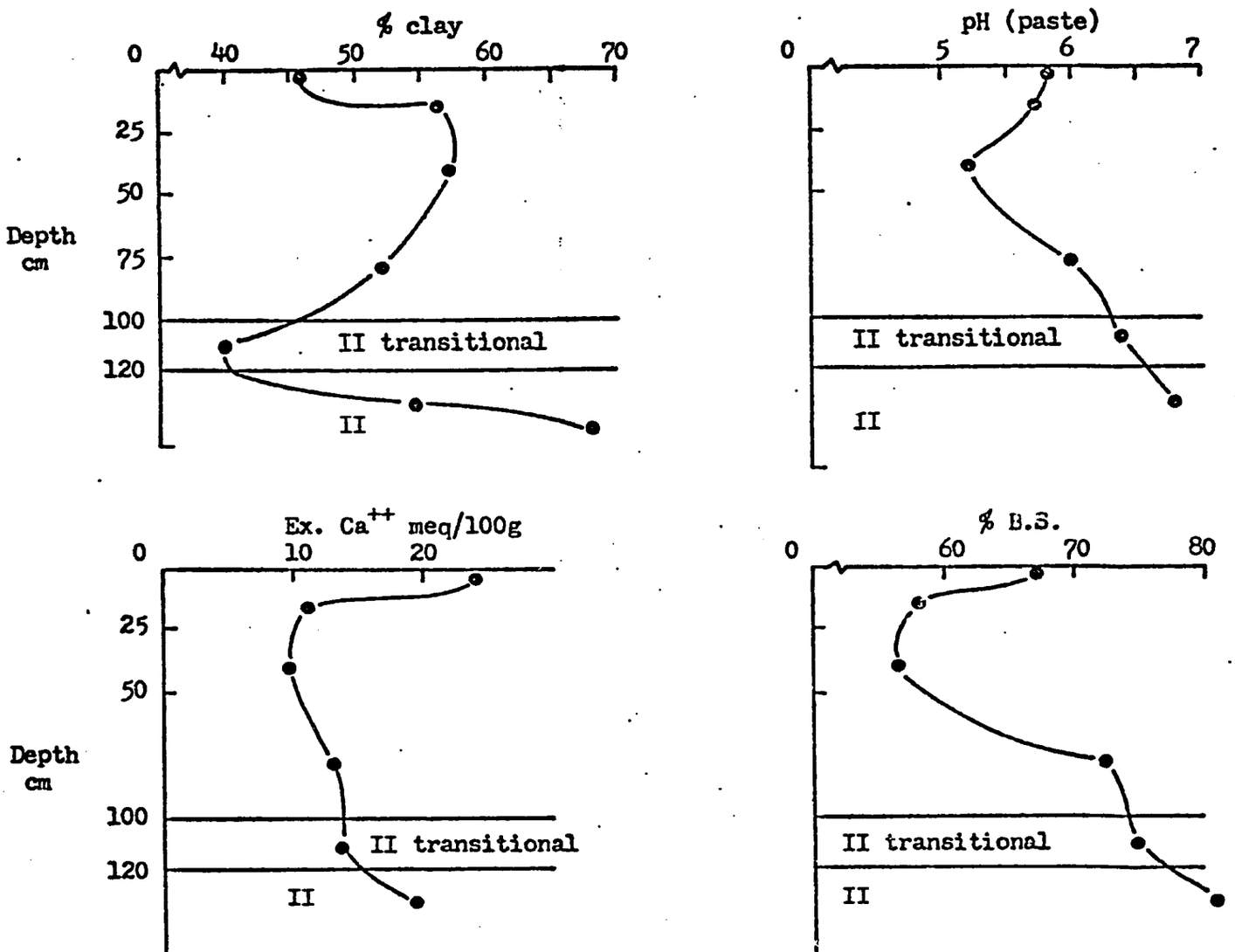


Figure 14. Depth functions of selected properties of the Mendez soil pedon.

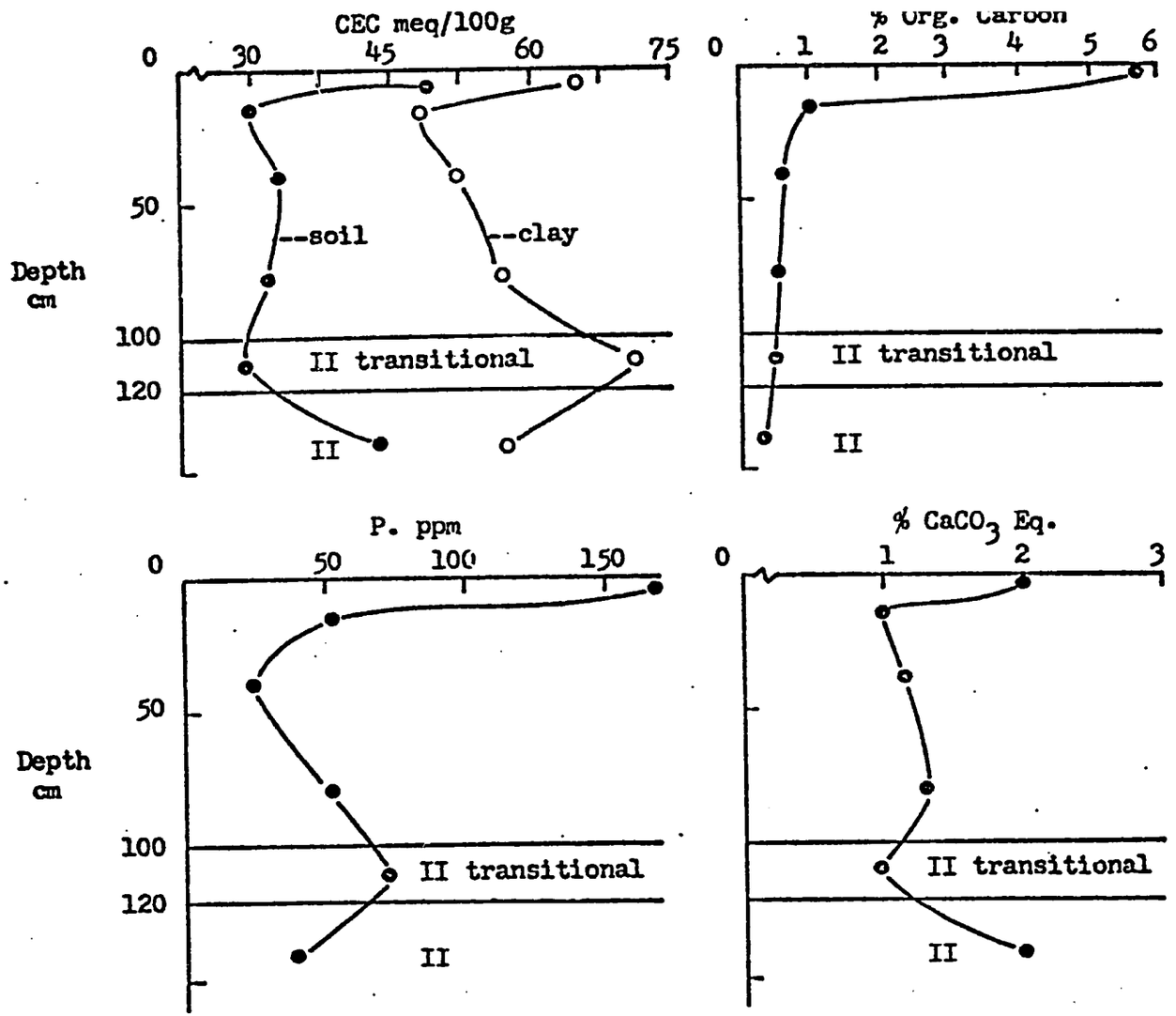


Figure 14. Continued. Depth functions of selected properties of the Mendez soil pedon.

Pedon 5: Apure, hole No. 3.

This soil had only been tentatively established at the time this study began because the soil survey field operation had not been completed The soil was included because it occupies extensive areas in the Lower Llanos.

Uniformity of soil material.

The distributions of clay, cation exchange capacity and carbonate show major breaks at 98 cm and 128 cm indicating the existence of several materials (Figure 15). The different proportions of sand and clay in the material below 98 cm may be part of a transitional layer deposited at the beginning of a new cycle of deposition. The underlying horizon is clearly a separate deposition because of remarkable differences in the silt and clay contents.

Based on this evidence it is assumed that this pedon has developed in a two-layer parent material.

Morphological features.

The soil pedon has cracks that are 1 cm or more wide at a depth of 50 cm. Slickensides occur below 19 cm throughout the profile but they are not present in such frequency as to intersect each other. Moderate to strong medium prismatic structure is predominant in the pedon. Ped faces in the B22 (48 to 77 cm) horizon have a gray color which differs from that of the ped interiors.

The color of the matrix and mottles indicate that alteration of minerals is still taking place in the zone affected by fluctuating groundwater The iron segregation and reduction have brought about the development of contrasting low chromas mottles which are particularly abundant in the control section. Because the intensely mottled horizon has an upper boundary

within 50 cm, the horizon qualifies as a cambic horizon.

Physical-chemical properties.

The increasing trend in the distribution of soil pH and base saturation with depth indicates that bases have been leached and accumulated lower in the profile. Nevertheless, the distribution of exchangeable calcium and calcium carbonate equivalent do not display a complementary relationship to back up the former statement. This apparent contradiction is resolved when one recognizes that the top horizon is a recently deposited material which is now being subjected to leaching and desaturation. At the same time, the underlying horizon is gaining some bases and carbonates from the upper layer. The increase in exchangeable calcium and calcium carbonate above the discontinuity can also be attributed to the flushing of these components through the cracks open at the beginning of the wet season.

The organic carbon distribution decreases regularly with depth. It is probable that the soil materials are members of a continuous depositional process without any significant time intervals between the deposition of the stratified materials and across their interfaces.

Clay mineralogy.

In the horizon selected for characterization (48 to 77 cm), the coarse clay fraction is dominated by kaolinite which amounts to 66 percent. Mica content in this fraction is lower (17%), compared to Mendez soil which is a similar soil developed under the same climate and similar parent material but on a younger surface (Tables 3 and 7).

In contrast to what has been found for the other soils in this study, vermiculite and amorphous material in the fine clay fraction of the Apure, hole No. 3 pedon have the highest observed values. The kaolinite remains relatively high at 25 percent, with lesser amounts of mica (20%) and

montmorillonite (16%).

As the soil has been developed under a aquic moisture regime which has been active for a relatively long time (since K_2 period), the clay minerals are expected to be more intensively altered than in any other soil in this study. One might, therefore, attribute the high vermiculite and amorphous content to the weathering of the mica. The relatively high proportion of kaolinite in the soil is ascribed, for the most part, to the parent source which is thought to have contained a high proportion of this mineral.

Finally, it is important to point out that the total clay fraction does contain more than 40 percent kaolinite (Table 5).

Classification.

As the soil pedon has a cambic horizon produced by iron segregation and reduction taking place under the effect of fluctuating groundwater table, and because the control section stays wet and saturated at some period of the year, it is considered to be an Aquept.

The soil temperature regime is quite uniform throughout the year with minor seasonal variations, thus the pedon is within the definition of Tropaquepts.

The soil pedon has throughout the control section more than 35 percent clay, cracks more than 1 cm wide at depth of 50 cm that extend upward to the surface, non-intersecting slickensides, and a coefficient of linear extensibility (COLE) assumed to be 0.09 or more in horizons at least 50 cm thick. Consequently, the soil meets the requirements defined for the Vertic subgroup.

Finally, owing to the facts that the clay content in the control section is less than 60 percent with a kaolinite content of more than 40

percent (Table 5), a pH less than 5.5 in water, and a soil temperature regime relatively uniform during the year, the pedon may be classified as a Vertic Tropaquept, fine, kaolinitic, acid, isohyperthermic.

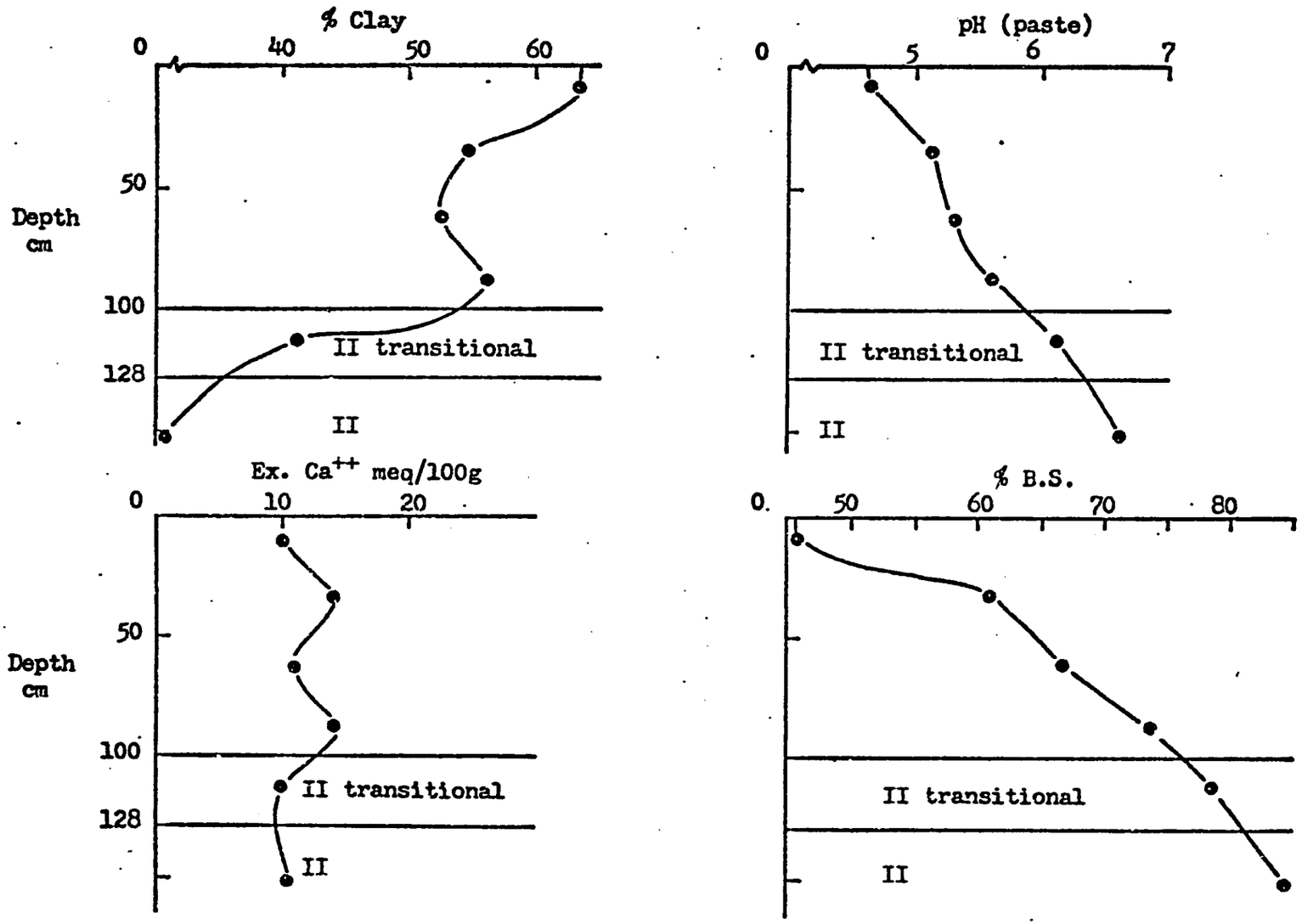
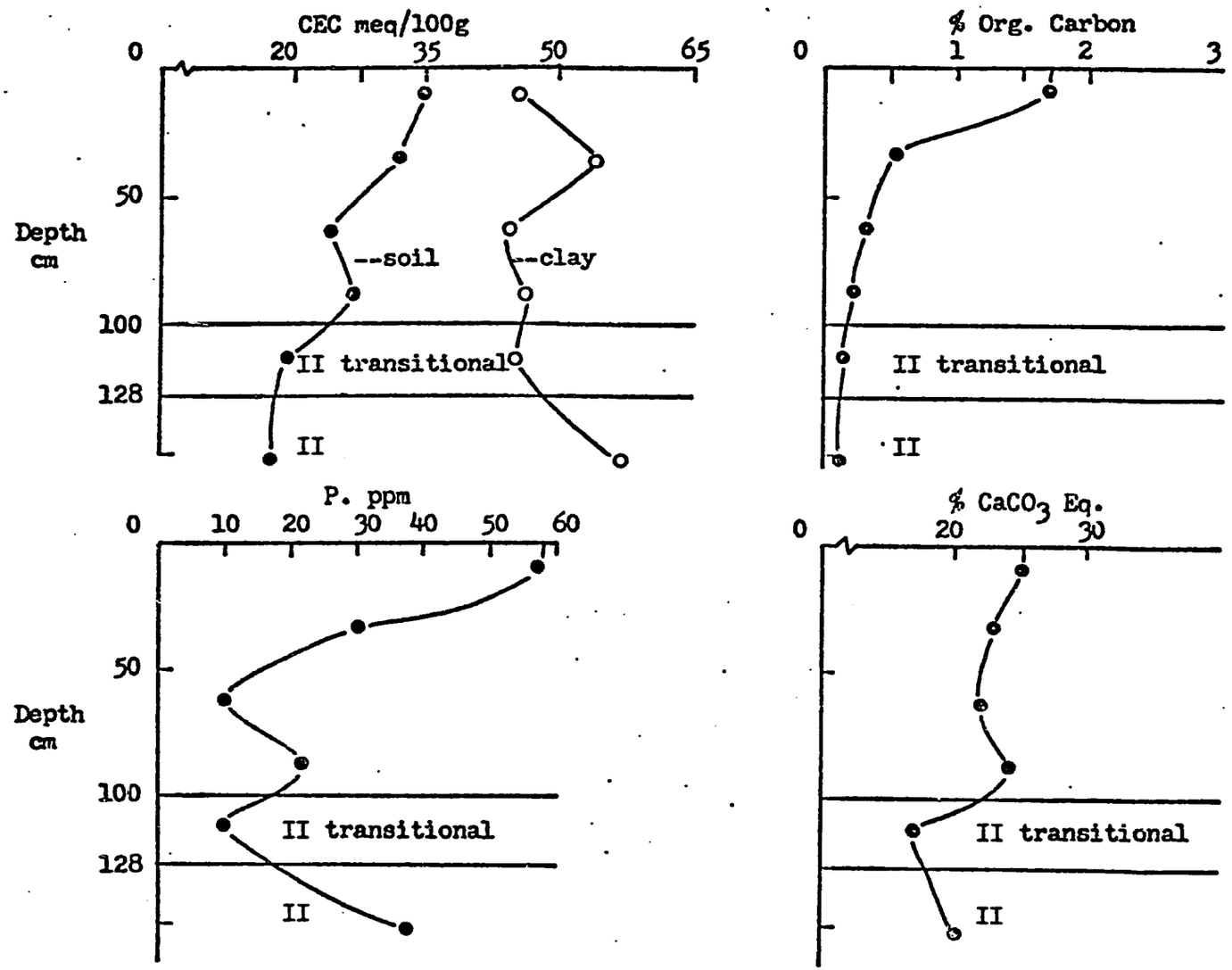


Figure 15. Depth functions of selected properties of the Apure, hole No 3 soil pedon.



-Figure 15. Continued. Depth functions of selected properties of the Apure, hole No 3 soil pedon.

Pedon 6: Yagrumo Soil.

Uniformity of soil material.

Abrupt changes observed in the magnitude and distribution of the soil properties (Figure 16) help to distinguish a discontinuity at or near 50 cm in the profile. The stratification of the soil material is reflected by pronounced breaks in the depth functions for clay, base saturation, cation exchange capacity and organic carbon. A buried soil is recognized below 50 cm.

Morphological features.

The soil pedon does not have cracks open at any time along the year, and no slickensides have developed in any part in the described soil profile. A moderate coarse angular blocky structure predominates in the upper 50 cm, whereas, at greater depth the distinctness and the degree of aggregation of the peds decrease progressively in such a way that the soil becomes massive below 135 cm.

The color of the soil is dominated by low chromas mottles (chromas less than 2 and values more than 4) present in the matrix, and on the ped faces. Since iron segregation and reduction has been very intense under the effect of prolonged wetness and saturation of the soil (aquic mositure regime), one may consider that transformations of minerals have been responsible, to a considerable extent, for the observed horizon differentiation.

As the alteration of the soil material occurs at shallow depth (above 50 cm) and the degree of alteration is strongly expressed by the color and proportion of the mottles, the upper subsoil qualifies as a cambic horizon.

Physical-chemical properties.

Similar trends exhibited by the distribution of exchangeable calcium,

base saturation, and pH below 50 cm suggest that leaching of bases has also been an important pedogenetic process in soil differentiation at these depths. On the other hand, dissimilar trends are noted above 50 cm. The organic carbon content sharply increases in the 50 to 93 cm horizon (Figure 16).

Owing to the fact that the distributions of the former properties do not have complementary relations across the stratified materials, it seems that material II represents part of a different soil buried by recent sediments. This hypothesis is also supported by the presence of contrasting structure below 50 cm and by the sharp break in the distribution of organic carbon.

The overlying material I is considered to be more recent, but it has also been subjected to intense alteration under the effect of a humid climate, which in conjunction with the geomorphic position of the soil in the landscape favors the occurrence of an aquic moisture regime.

Clay mineralogy.

Two horizons have been selected for mineralogical characterization, each representative of different materials present in the soil system.

Although these horizons are developed in separate strata, the mineralogy is markably similar not only in the kinds, but also in the proportions of clay minerals in the different clay fractions (Table 3). It is concluded, therefore, that the parent materials in the pedon differ mainly by their mode of deposition and not from the source of their materials. Kaolinite amounts to 77 percent in the coarse clay and 40 percent in the fine clay fraction. When the kaolinite percentage is calculated on the basis of the total clay fraction, it is more than 40 percent (Table 5).

The kaolinite content in the soil is ascribed to a parent source

that originally contained a high proportion of this clay mineral, although, a major contribution derived from the weathering of the mica might be expected in the B2gb horizon due to the age attributed to this material.

Classification.

The alteration of the soil minerals under the effect of prolonged saturation has been intense enough as to produce a horizon dominated by low chroma mottles at shallow depth which is recognized as a cambic horizon. These diagnostic properties allow us to classify the soil as an Aquept at the suborder level.

Because the soil temperature is quite uniform along the year with negligible seasonal variation, it is considered to be a Tropaquept. As the low chroma mottles do not constitute more than 60 percent of the matrix of all subhorizons between the A1 and 75 cm, it is included in the Aeric Tropaquept subgroup.

As the clay content in the control section is more than 60 percent, the clay fraction contains more than 40 percent by kaolinite, and the soil pH less than 5.5 in water, the pedon is classified as an Aeric Tropaquept, very fine, kaolinitic, acid, isohyperthermic.

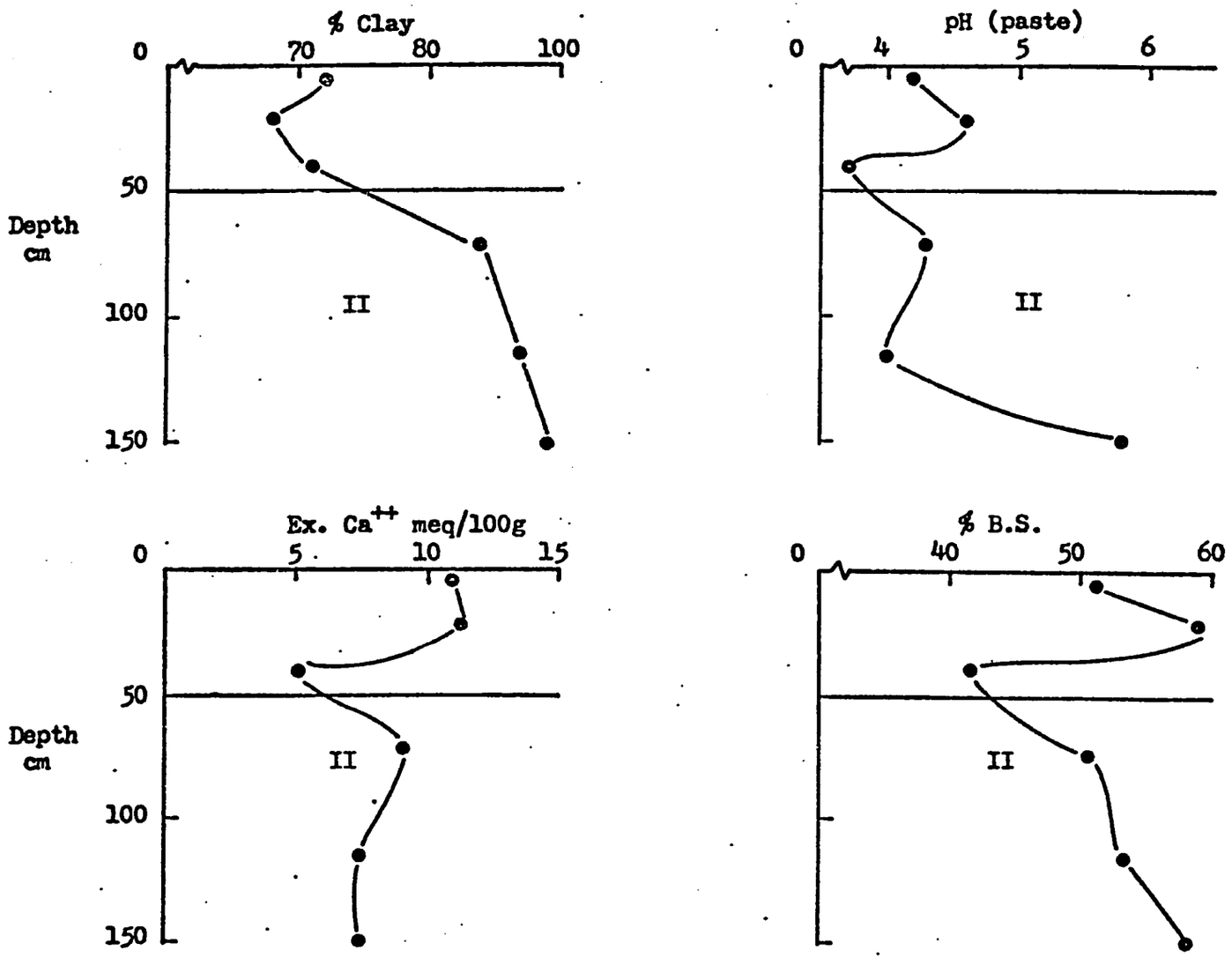


Figure 16. Depth functions of selected properties of the Yagrumo soil pedon.

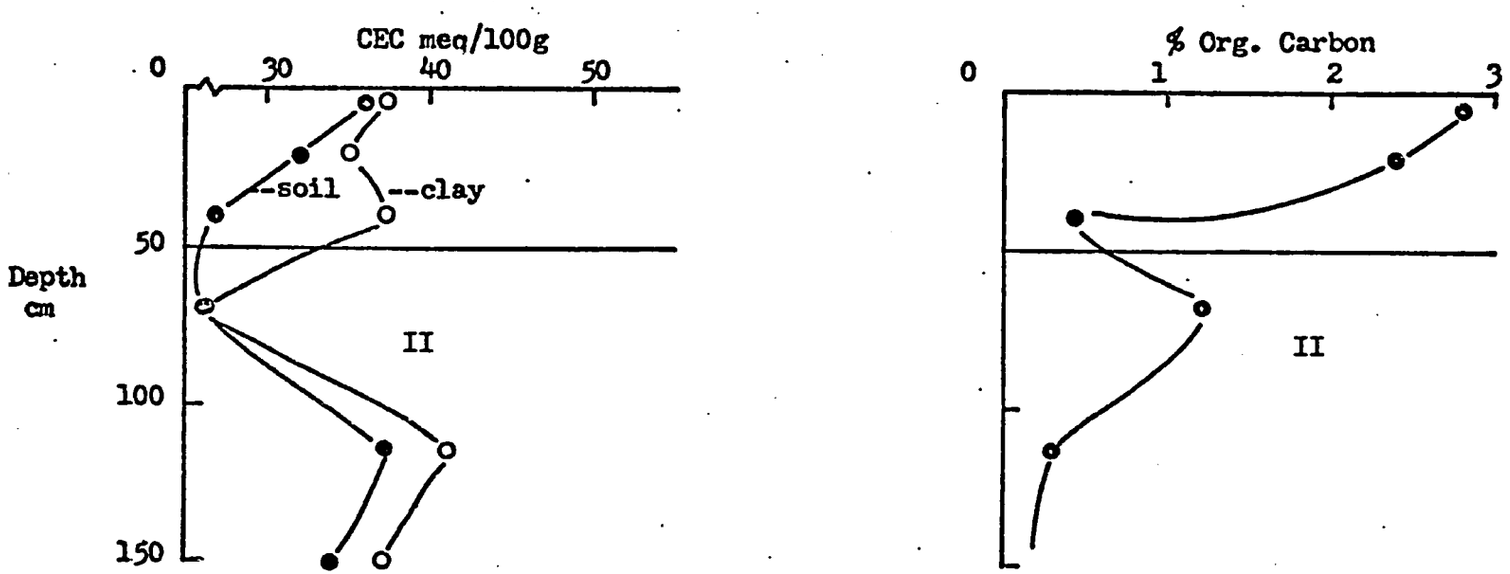


Figure 16. Continued. Depth functions of selected properties of the Yagrumo soil pedon.

Table 3. Mineralogy of the Coarse and Fine Clay Fractions for Selected Horizons of Six Clayey Soils of Venezuela.

Soil Pedon	Depth cm	Horizon design	Coarse clay separate (2-0.2μ) %					Fine clay separate (< 0.2μ) %				
			Verm.	Mont.	Mica (1)	Kaol. (1)	Amorp. mat.	Verm.	Mont	Mica	Kaol.	Amorp. mat.
Sabaneta	6 - 38	B1sa	4	0	15	75	6	11	23	20	30	13
Rabito	77 - 130	C1	6	6	28	52	9	16	35	20	15	13
Mijagual	63 - 113	B22	8	2	41	43	6	14	25	22	20	14
Mendez	55 - 101	B22g	7	8	45	37	3	8	25	27	20	12
Apure, hole No. 3	48 - 77	B22g	6	6	17	66	5	25	16	20	25	16
Yagrumo	30 - 50	B22g	4	0	14	78	5	9	18	21	38	13
	93 - 135	B2gb	3	0	16	77	4	12	16	21	41	12

(1) Mica and kaolinite have been estimated from x-ray diffraction peak-height intensities of the Mg-glycerol specimen

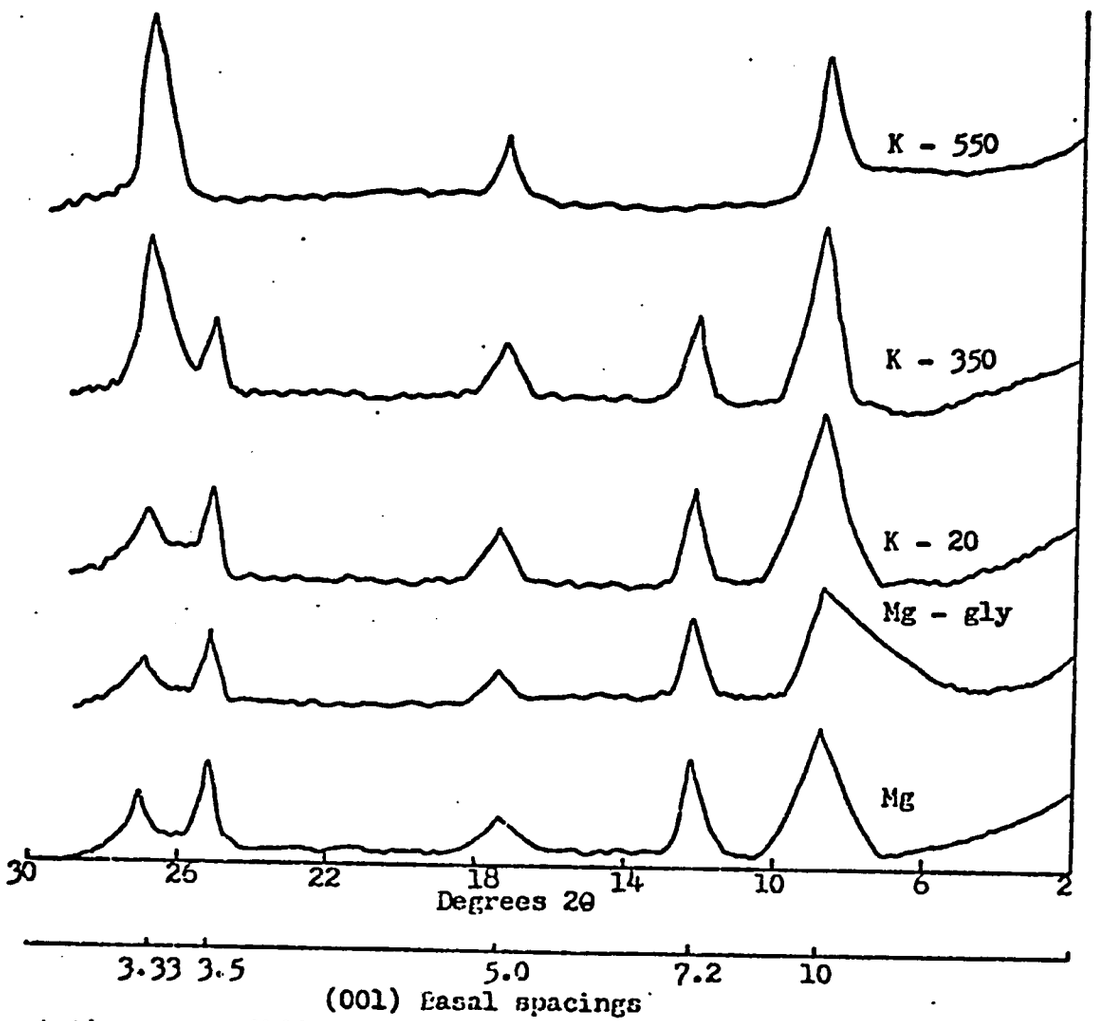


Figure 17. Representative x-ray diffraction pattern of the soils under study. Fine clay fraction of the Mijagual soil.

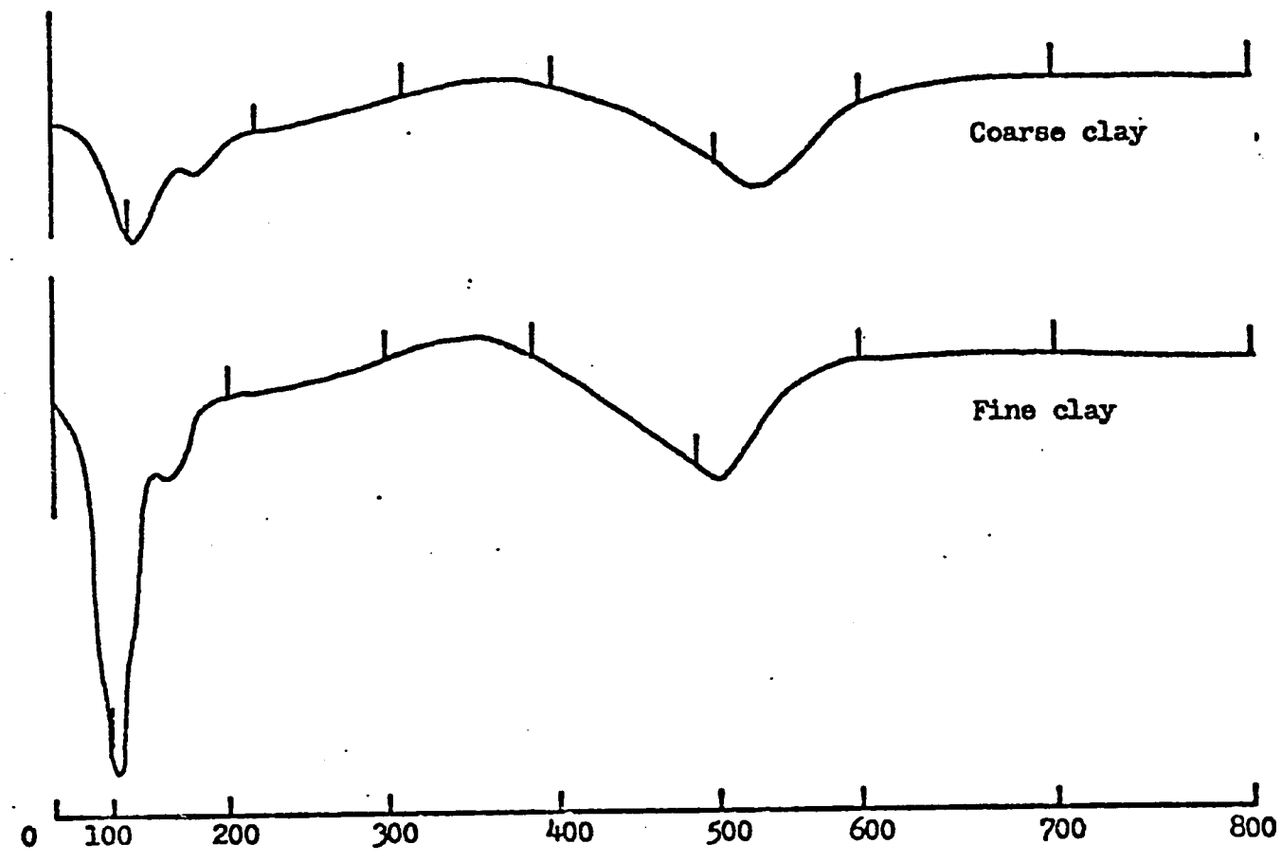


Figure 18. Representative DTA pattern of the soil studied. Mijagual soil pedon.

General Relationships Among the Soils Studied.

Under the constraints imposed by the limited number of soils studied and available data, some generalizations can be made in regard to other soil characteristics and relationships that have not been discussed in the preceding section. These generalizations based on similarities and differences exhibited by the pedons investigated are of two kinds: (a) relationship observed among selected soil properties, and (b) relationship between selected soil properties and factors of soil formation. They will be considered below in the same order.

The cation exchange capacity per 100g of clay often tends to increase proportionally as: (1) the fine to coarse clay ratio increases (Figure 19), and (2) as the montmorillonite to montmorillonite plus kaolinite ratio increases, both in the fine clay fraction and total clay (Figure 19). The first observed trend is reasonably consistent except for pedon 4 which has a much higher content of mica in both clay fractions than other soils studied (Table 3). As might be expected, the second observed relationship is much more clearly expressed and is conveniently explained by the cation exchange capacities estimated for each mineral.

A similar relationship has been observed between calcium exchange capacity per 100g of clay (CaEC) and the ratio montmorillonite to montmorillonite plus kaolinite in the fine clay, except for the value for pedon 4 (Figure 19). If one calculates CaEC of mica, the range is from 2.1 to 4.2 meg for each percent of this mineral and the lowest value is for pedon 4. This discrepancy may be due to the fact that pedon 4 has a high mica content and this mica has a lower calcium exchange capacity.

Potassium exchange capacity K//EC has also been compared to the

relative content of clay minerals in the fine clay fraction. A positive relationship is observed between the ratio of montmorillonite and montmorillonite plus kaolnite and the K//EC, except for the value for pedon 5. The very low K//EC determined for pedon 5 is found to be consistent with the higher proportion of vermiculite contained in this soil which may in turn bring about an increased K-fixation, therefore, the K//EC will be diminished accordingly. If one calculates in the fine clay the K/EC of the mica (Table 19), the values range from 1 to 2.8 meg for each percent of mica. The value calculated for pedon 5 is the lowest of all, thereby indicating that the mica present is likely a highly resistent species. It may have been residually concentrated after the easily weatherable mica was thoroughly altered to form other clay mineral species. This hypothesis is also supported by the high content of amorphous material which likely indicates a greater degree of weathering.

Fine-textured soils occur most often in the lower segments on ground-surfaces of different ages, and in different landscapes, provided they have sequentially developed without major interruptions in their normal evolution. They mostly occupy depressional areas in fluviomarine, fluviodeltaic, flood plain and entrenched valleys landscape. Depressions accumulate water for a longer period of time. The soils occupying the slightly concave depressions remain moist for a prolonged period and dry out later than other associated soils on the same geomerphic surface. In these situations the soil moisture regime does not always correspond to what would be expected from the regional climate, because the relative position, topography configuration and characteristics of the parent material of the soils may override the relationships with regional climate.

Most of the soils under study formed on relatively impermeable fine-

textured alluvial and fluviomarine sediments. The soils studied contain a much higher proportion of kaolinite than that normally expected for relatively young soils developed upon such kinds of parent materials. It is assumed that this clay mineral has, for the major part, been inherited from sources which were intensely weathered prior to the deposition of sediments.

Soils derived from fluviomarine sediments have been consistently found to be different from those formed on alluvial sediments in importan genetic properties. The imprint of a marine environment is strongly reflected in the profile distribution of some soil properties such as: exchangeable sodium, concentration of sodium, chloride and sulfate, and the electrical conductivity of a saturation extract (pedon 1 and 2). These important differentiating properties are not considered in the definition of any taxon within the Vertisol order in which these pedons are classified. Thus, in the U. S. Soil Taxonomy (Soil Survey staff, 1970) the only place at which saline and non-saline Vertisols can be separated is at the lowest category of the system. This fact has an important bearing upon soil mapping in Venezuela. To adequately map those units as distinct kinds of soils requires detailed soil surveys of medium and low intensities, and definition of soil series. Therefore, general soil maps in areas where these soils are expected to occur will not provide mapping units sufficiently horogeneous to appropriately specify kinds of uses and management.

Differentiating characteristics as defined for the Vertisol order seem to be associated with poorly and somewhat poorly drained soils developed under ustic and udic moisture regimes, on groundsurfaces dating from K_2 period or older. Vertic characteristics are observed in

other soils developed under an aquic moisture regime but only on groundsurfaces of K_2 age or older.

In contrast, Inceptisols having at shallow depths a horizon dominated by low chroma mottles are particularly associated with aquic moisture regime on groundsurfaces dating mainly from K_1, and K_2 to a lesser extent. The strong alteration of weatherable minerals and the accompanying iron segregation and reduction are influenced by degree of wetness and waterlogged conditions under which these soils have developed.

Some additional physical properties of these soils, such as liquid limit, degree of dispersion and 1/3-bar moisture retention, have been predicted in selected horizons of the soils investigated, by using equations devised by El Swaify et al (1972). It is necessary to stress the limitations imposed by assuming that these formulas would be applicable to the soils under study, and the constraints due to limited number of available data. Consequently, the data calculated only have value as predictions that should be tested against actual data determined by current laboratory procedures.

The calculated values exhibit wide variability. Liquid limit ranges between 72 and 126 percent, degree of dispersion varies from 36 to 54 percent and 1/3-bar moisture retention from 34 to 72 percent (Table 6). Different trends appear to be related to the nature of the adsorbed cations and their proportions in the total bases. For instance, the highest observed values are consistently associated with the highest proportion of sodium saturation. This would be attributed to the greater degree of hydration exhibited by this cation and the concomitant effect upon increased degree of swelling. In contrast, the lowest values seems to be associated with higher contents of calcium and magnesium. These cations, being less

hydrated, have a positive effect upon the floculation of particles and reduce the degree of swelling of the clays. (Baver, et al, 1972.)

Table 4. Fine-Coarse Clay Ratio and Cation Exchange Capacity of Selected Horizons of the Soil Pedon.

Soil Pedon	Depth cm	Horizon design	Coarse clay o/o	Fine clay o/o	Fine clay / Coarse clay	CEC meg/100g clay
Sabaneta	6 - 38	B1sa	50.3	49.7	1.0	51
Rabito	77 - 130	C1	36.0	64.0	1.78	61
Mijagual	63 - 113	B22	53.7	46.3	0.86	51
Mendez	55 - 101	B22g	68.0	32.0	0.47	57
Apure, hole No. 3	48 - 77	B22g	56.8	43.2	0.76	44
Yagrumo	30 - 50	B22g	70.0	30.0	0.43	36
	93 - 135	IIB2gb	61.0	39.0	0.64	41

CEC/100g of clay was calculated using the percent clay as determined by pipette method. The organic matter contribution was also accounted for assuming a CEC equal to 200 meg/100g.

Table 5. Relative Proportions of Clay Minerals in Selected Horizons of the Soil Pedon (whole clay fraction).

Soil Pedon	Depth cm	Horizon design	Verm.	Mont.	Mica	%	Kaol.	Am. mat.	Kaolinite / Kaol.+Mont.
Sabaneta	6 - 38	B1sa	7.4	11.6	17.5		52.5	10.0	0.82
Rabito	77 - 130	C1	12.4	24.7	22.7		28.7	11.7	0.54
Mijagual	63 - 113	B22	11.0	13.0	32.0		32.0	9.4	0.71
Mendez	55 - 101	B22g	7.4	13.4	39.0		31.6	6.0	0.71
Apure, hole No. 3	48 - 77	B22g	14.0	10.5	18.3		48.4	10.0	0.81
Yagrumo	30 - 50	B22g	5.5	5.4	16.1		66.0	7.5	0.93
	93 - 135	IIB2gb	6.5	6.2	18.0		63.0	7.1	0.93

Table 6. Cation Saturation (% of tc . . bases), and Predicted Values for Liquid Limit, Degree of Dispertion and 1/3-bar Moisture Retention of Selected Horizons of the Soil Pedons.

Soil Pedon	Depth cm	Cation Saturation % of total bases				Liq. Limit (%)	Degree of Dispersion (%)	Moisture ret. 1/3 bar. (%)
		Ca	Mg	Na	K			
Sabaneta	6 - 38	66.4	26.1	5.5	2.0	88	44	49
Rabito	77 - 130	66.0	16.0	17.0	1.0	103	47	61.5
Mijagual	63 - 113	73.0	20.6	6.0	1.0	77	36	38.5
Mendez	55 - 101	59.1	38.6	1.5	1.0	81	41	38.5
Apure, hole No. 3	48 - 77	69.0	29.0	1.6	1.0	72	36	33.5
Yagrumo	30 - 50	46.0	38.0	16.0	0.4	100	45	47.0
	93 - 135	40.0	31.0	28.3	0.5	126	54	72.0

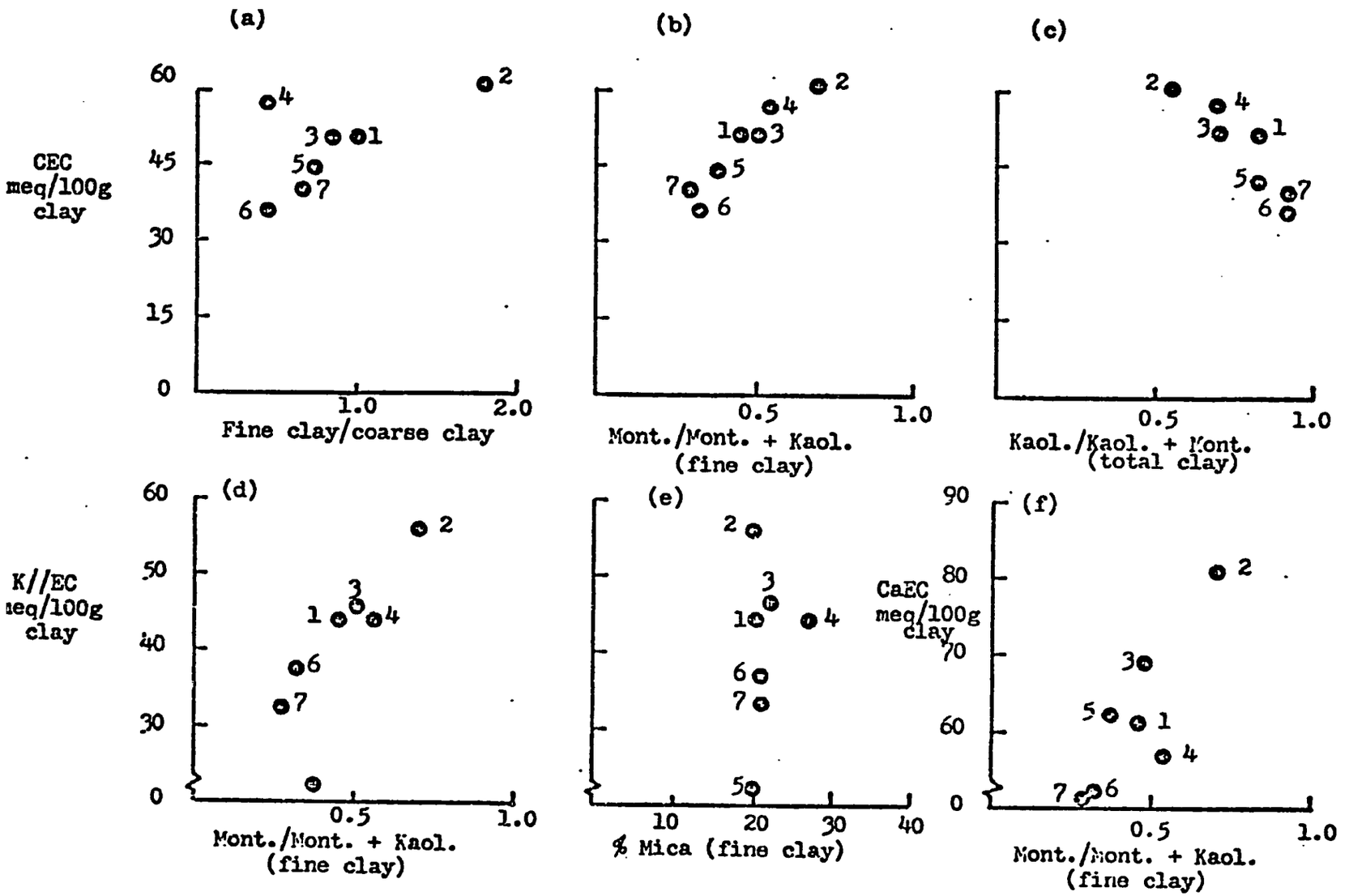


Figure 19. Some relationships among selected properties of the soils studied. (numbers refer to pedons).

SUMMARY AND CONCLUSIONS

There are extensive areas of clayey soils in Venezuela. The total estimated area of these soils in the country amounts to 5,256,200 ha. They occur in several regions having different types of climate and vegetation.

This research has been intended as an initial study to better characterize the diversity of these soils, previously grouped together as "clayey soils." Six soils thought to be representative of different soil forming conditions were selected for mineralogical characterization and classification. These soils have developed on ground surfaces of different ages, dating from the Late Pleistocene (K_2 and K_1 periods). They occupy depressional areas in the landscape in which water accumulates in the rainy season, and remain moist part of the dry season. The parent materials from which soils are assumed to have formed are dominantly fine-textured alluvium or fluviomarine sediments containing a relatively high proportion of kaolinitic clay. The source of materials are quite diverse but the sediments were mixed during transport and sorted during the process of deposition. They mostly occur within wet and dry climates under Tropical dry forest and Savanna type vegetation. Some are also found in semiarid climates under Tropical very dry forest vegetation (Table 7).

All the soils studied have one or more lithologic discontinuities. Transitional layers were also observed between the deposition of contrasting materials. In the case of the Yagrumo pedon, a buried soil was recognized. Most of the lithologic discontinuities are thought to be related to changes in the mode of deposition of materials from the same or similar

source areas.

In the soils formed on fluviomarine sediments (Rabito and Sabaneta) in fluviodeltaic landscape under semiarid climates and tropical very dry forest vegetation, pedogenetic processes and genetic properties demonstrate the large effect played by the marine environment. To a considerable extent, these soils have been resaturated from below by saline water, and salts has been moved up in the soil profile due to the high evaporation taking place at the surface. It is certain, however, that shrinking, swelling and churning of the soil material have been the prevailing pedogenetic processes active in the course of soil formation, particularly in the upper 60 to 70 cm where the slickensides and structure achieve the maximum degree of development. Below these depths, the soil systems have not been appreciably differentiated. The limited amount of rainfall is not sufficient to moisten the whole soil volume, except through the reduced space provided by the cracks open at the beginning of the wet period.

Once the cracks in the top layer are closed, the water does not infiltrate to greater depth. Because of this fact, the soil material has undergone little differentiation attributed to leaching of bases, and segregation of iron produced by alteration of soil minerals. Although some carbonates and soluble salts might be flushed down the open cracks when the rainy season starts, no consistent evidence was found to support this hypothesis.

These two soils were tentatively classified as Typic Chromusterts and Entic Chromusterts. There is a problem with these taxa, however, because they do not reflect appropriately some important genetic properties of these soils, primarily the increasing salinity with depth that would differentiate them from other non-saline soils at the same level of abstraction.

Salinity not only affects the genesis of soil, but also, it is an important criterion to separate saline and non-saline soils that differ in terms of the kinds of uses and management practices under which they could be utilized. Within the Vertisol order no provisions have been made to recognize such differences even at the family category. If soils having these properties turn out to be extensive, sufficient data should be gathered to study adequately the nature, distribution and range of variability of salinity, and how it may affect the use of the soils for different objectives. Then a new basis for differentiation could be proposed, perhaps, at the subgroup categorical level as is provided for other taxa in the U.S.A. Soil Taxonomy.

In the Tropical wet and dry (savanna) climate, the representative clayey soils are classified in three taxa: Udorthentic Chromusterts (very fine texture family); Typic Tropaquepts (fine texture family); and Vertic Tropaquepts (fine texture family).

Within this region Vertisols are found on groundsurfaces dating from K_2 period (late Pleistocene), they are poorly drained soils developed upon very fine-textured parent material and commonly have grass vegetation. The very fine texture of the soil, the alternate wet and dry climate, and particularly the age of the soil material have exerted a major control on the genetic pathway of these soils. Shrinking and swelling of the material have been the most important processes by which the observed diagnostic properties of the soils have been developed. Other soils of the same age (K_2) which have lesser amounts of clay (fine texture family) and an aquic moisture regime develop some of the vertic characteristics. The moisture regime favors the strong alteration of minerals and segregation and reduction of iron to form a cambic horizon. The former pedogenetic process

dominates the course of soil formation, and curtails the further development of a Vertisol. More recent soils (K_1 period) formed on fine-textured (< 60% clay) parent material under an aquic moisture regime and forest vegetation did not develop any vertic characteristics. The genesis of these soils has been dominated by organic matter accumulation and transformation of soil minerals of which iron segregation and reduction is a part.

Recent clayey soils (K_1 period) of more humid climates (tropical rain forest) which have developed on very fine parent material (> 60% clay) under an aquic moisture regime and forest vegetation, undergo the same pedogenetic processes as indicated above, except for the intensity. With these climatic conditions, soils remain saturated for longer periods, the former pedogenetic processes are speeded up, and the soils reach a higher degree of development in a shorter time.

The six soils are grouped into two orders: Vertisols and Inceptsols, and also into two great groups: Chromusterts and Tropaquepts. Subgroup differences are related to minor variations in moisture regimes, differences of age and/or texture of the sediments. Based on these ranges one might predict other taxa on groundsurfaces dating from late Pleistocene (K_1 and K_2 periods). Predicted taxa in fine-textured soils developed under Tropical very dry forest and semiarid climates could be: (a) Typic and Entic Chromusterts on K_2 surfaces, and (b) on K_1 surfaces, Vertic Ustropepts and Eutropepts. In the Tropical dry forest with Tropical savanna climate, and on K_2 surfaces the potential taxa are: (a) Typic, Udorthentic, and Udic subgroups in both Chromustert and Pellustert great groups, (b) Vertic Tropaquepts, and (c) Typic Tropaquepts on K_1 surfaces. In Tropical rainforest climates, predicted taxa for fine-textured soils are: (a) Typic and Aeric Tropaquepts on K_1 groundsurfaces, and (b) Vertic Tropaquepts possibly on

K_2 groundsurfaces.

Based on the clay mineralogy of the soils studied, several conclusions can be made:

1. Despite the different sources of parent materials upon which the soil are formed, the same kinds of clay minerals were detected with only the amounts of each varying. This has been attributed to the large effect played by the sorting of the fine-sized particles during the process of deposition of the sediments.

2. The high proportion of kaolinite present in the soils developed under different climatic regions is for the most part inherited from source areas that originally contained high amounts of this mineral.

3. Evidence was obtained from the x-ray diffraction analysis indicating that mica has undergone weathering to form expansible clay minerals, and kaolinite to a lesser extent.

4. The expansible clay minerals occur mostly interstratified with mica, because no discrete 14Å and 17.7Å peaks were detected in the x-ray diffraction analysis. Broadening and low angle asymmetry of the mica (10Å) peak observed in the Mg-glycerol solvated slide disappeared after K-saturation and heating. These latter properties exhibited by the mica were taken as positive evidence of interstratification.

5. The laboratory procedures used in the course of this investigation are suggested for further studies of clayey soils in Venezuela, where the purpose is mainly characterization rather than detailed research. Consistent and uniform patterns were observed in the x-ray diffractograms, therefore, only the preparation of Mg-saturated, glycerol-solvated and K-saturated (room temperature) oriented specimens would only be necessary for quick-checking the kinds of clay minerals present in these soils.

Quantitative chemical analysis is needed for mineral allocation and to estimate the relative proportion of the different crystalline and non-crystalline substances. If the x-ray diffractograms indicate the same kinds of clay minerals to those consistently detected in this research (figure 17), the analyses recommended are: (a) Selective dissolution analysis for amorphous material, (b) calcium exchange capacity and potassium exchange capacity for montmorillonite and vermiculite determination, and (c) total K_2O for mica . Kaolinite can be obtained by difference. If any other minerals are detected, kaolinite may be determined by selective dissolution analysis or by thermal gravimetric analysis.

Finally, it is important to emphasize that there are striking differences among the so-called "clayey soils or fine textured soils." By describing, characterizing and classifying these soils, their significant differences can be given more importance in research programs, and in applying the technology required for improved use and management of such soils not only for agriculture but also for non-farm purposes.

Table 7. Soil-forming factors and classification of six clayey soils of Venezuela.

Soil Pedon	Climate	Veget.	Relief	P. material.	Age	Soil Moist. Reg.	Drainage class	Classification
Sabaneta	Tropical steppe (semiarid)	Tropical very dry forest	Littoral Fluvio-deltaic depression	Fluvio-marine	K_2	Ustic	Somewhat poorly drained	Typic Chromustert, very fine, kaolinitic, isohyperthermic
Rabito	Tropical steppe (semiarid)	Tropical very dry forest	Littoral Fluvio-deltaic depression	Fluvio-marine	K_2	Ustic	Somewhat poorly drained	Entic Chromustert, fine, mixed, isohyperthermic
Mijagual	Tropical savanna	Tropical dry forest	Flood plain depression	Alluvial mixed	K_2	Ustic marginal to Udic	Poorly drained	Udorthentic Chromustert, very fine, mixed, isohyperthermic
Mendez	Tropical savanna	Tropical dry forest	Flood plain, wet	Alluvial mixed	K_1	Aquic	Very poorly drained	Typic Tropaquept, fine, mixed, acid, isohyperthermic
Apure Hole No. 3	Tropical savanna	Tropical dry forest savanna	Fluvio-deltaic wet depression	Alluvial mixed	K_2	Aquic	Very poorly drained	Vertic Tropaquept, fine, kaolinitic, acid, isohyperthermic
Yagrumo	Tropical rain forest	Forest	Flood plain wet depression	Alluvial mixed	K_1	Aquic	Poorly drained	Aeric Tropaquept, very fine, kaolinitic, acid, isohyperthermic

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APPENDICES

APPENDIX I

PROFILE DESCRIPTIONS AND ANALYTICAL DATA OF SOIL PEDONS

Pedon 1: Sabaneta Soil

Location: Barbacoa agricultural settlement, Barcelona. Anzoategui State.

Parent Material: Clayey Fluviomarine sediments.

Climate: Mean annual rainfall is about 600 mm. Dry period is commonly 7 months. Mean potential evapotranspiration is 1738 mm. annually. No excess of water is present in the wet period.

Topography: Less than 0.5% slope gradient in a depressional areas of a Littoral Fluviodeltaic landscape.

Vegetation: Tropical very dry forest.

Drainage class: Somewhat poorly drained.

Classification: Typic Chromustert, very fine, Kaolinitic, isohyperthermic.

Profile description

Horizon	Depth (cm.)	Morphology
A1	0 - 6	Grayish brown (10YR 5/2,dry), very dark brown (10YR 2/2,moist); clay; moderate medium subangular blocks; slightly hard, friable, very sticky and very plastic; moderately slow permeability; cracks more than 1 cm wide; frequent fine roots; non-calcareous; clear smooth boundary.
B1sa	6 - 38	Grayish brown (10YR 5/2,dry), very dark grayish brown (10YR 3/2,moist); clay; strong medium angular blocks; extremely hard, very firm, very sticky and very plastic; cracks more than 1 cm wide; well-defined intersecting slickensides; slow permeability; few fine roots; noncalcareous; gradual smooth boundary.
B21sa	38 - 62	Dark brown (10YR 4/3,dry), olive brown (2.5Y 4/4, moist); clay; frequent (5-10%) medium distinct dark gray (5Y 4/1) and few (2%) fine prominent yellowish red (5YR 4/6) mottles; strong medium angular blocks; extremely hard, very firm, very sticky and very plastic; cracks more than 1 cm wide; well-defined intersecting slickensides; slow permeability; few fine roots; noncalcareous; gradual smooth boundary.

B22sa	62 - 100	Yellowish brown (10YR 5/4,dry), light olive brown (2.5YR 5/4,moist); clay; frequent (20%) medium distinct dark gray (5YR 4/1) and frequent (20%) medium prominent yellowish (5YR 5/6) mottles; weak, coarse angular blocks to massive; extremely hard, very firm, very sticky and very plastic; cracks 0.5 to 1 cm wide; no slickensides; slow permeability; noncalcareous; clear smooth boundary.
IIB23sa	100 - 115	Yellowish brown (10YR 5/5,dry), light olive brown (2.5YR 5/4,moist); silty clay to clay; frequent (10%), medium distinct olive gray (5Y 5/2) and frequent (5-10%), fine distinct yellowish red (5YR 5/6) mottles; weak coarse blocks to massive; very hard, firm, very sticky and very plastic; cracks 0.5 to 1 cm wide; no slickensides; slow permeability; frequent gypsium crystals; noncalcareous; clear smooth boundary.
IIIC1sa	115 - 170	Brown to dark yellowish brown (10YR 4/3.5,dry), light olive brown (2.5Y 5/4,moist) to yellowish brown (10YR 5/6,moist); silty clay loam; many (30%), medium distinct olive gray (5Y 5/2) and frequent (20%), fine prominent yellowish red (5YR 5/6) mottles; weak, coarse angular blocks to massive; very hard, firm, very sticky and very plastic; cracks 0.5 to 1 cm wide; no slickensides; slow permeability; noncalcareous

Table 8. Particle size distribution and physical-chemical properties of pedon 1, Sabaneta soil.

Depth cm	Horizon	Size class and diameter of particles (mm)								Text. class	pH paste	%O.C.
		V.C.sand 2-1	C.sand 1-0.5	M.sand 0.5-0.25	F.sand 0.25-0.1	V.F.sand 0.1-0.05	Total sand	Silt 0.05-0.002	Clay 0,002			
0 - 6	A1	0	0.2	0.4	1.4	2.0	4.0	33	63	c	7.00	3.9
6 - 38	B1sa	0	0.2	0.7	1.0	2.0	4.0	23	73	c	4.95	1.2
38 - 62	B21sa	0	0.0	0.1	0.4	0.4	1.0	28	71	c	4.65	0.8
62 -100	B22sa	0	0.0	0.3	0.3	1.0	1.0	25	74	c	-	0.6
100 -115	IIB23sa	0	0.0	0.3	0.3	0.5	1.1	40	59	c to sc	4.95	0.4
115 -170	IIIC1sa	0	0.0	0.1	0.0	1.3	1.3	63	35	scr	5.95	0.3

Table 8. Continued. Particle size distribution and physical-chemical properties of pedon 1, Sabaneta soil.

Depth cm	E.C. mmhos/cm	P citric acid ppm	CEC meg/100g sumation	Extractable Cations meg/100g					%BS	$\%CaCO_3$ Eq.	PES + %Ex.Na	CEC meg/100g clay
				Na	K	Ca	Mg	H+Al				
0 - 6	2	275	51	0.3	2.0	34.5	6.4	8.0	84.7	3.1	0.6	59
6 - 38	7	54	41	1.5	0.5	18.0	7.0	14.5	70.0	2.0	3.6	51
38 - 62	11	35	38	1.6	0.4	16.3	6.6	13.3	65.0	2.3	4.1	50
62 -100	-	-	45	6.6	0.3	18.2	7.0	12.4	-	-	15.0	58
100 -115	15	35	42	1.8	0.2	26.4	5.0	8.6	76.0	1.7	4.4	69
115 -170	20	25	19	5.2	0.2	8.6	4.0	5.0	74.0	1.7	27.8	51

Table 9. Analysis of saturation extract of pedon 1, Sabaneta soil.

Depth cm	Horizon	E.C. mmhos/cm	Cations (meq/l)				Anions (meq/l)			
			Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4
0 - 6	A1	2	2.5	0.82	10.3	4.0	0	2.5	12.5	2.3
6 - 38	B1sa	7	24.6	0.24	27.4	12.3	0	0.2	59.4	3.0
38 - 62	B21sa	11	52.0	0.19	37.8	17.7	0	0.2	96.8	8.4
62 -100	B22sa	-	-	-	-	-	0	-	-	-
100 -115	IIB23sa	15	85.0	0.14	54.3	24.6	0	0.2	123.8	42.0
115 -170	IIIC1sa	20	116.0	0.12	60.4	35.0	0	0.2	189.1	20.0

Pedon 2: Rabito Soil

Location: 3 km. east from Moina Village and 700 m. at right hand of Paraguaipoa-Moina road. La Guajira. Zulia State.

Parent Material: Clayey Fluviomarine sediments.

Climate: Mean annual rainfall is 685 mm. Erratic rainfall distribution throughout the year; more than 7 dry months. Evapotranspiration is about 1800 mm. Pronounced water deficit during the year.

Topography: Less than 0.001% slope, gilgai microrelief in depressional areas within a Littoral Fluviodeltaic landscape.

Vegetation: Tropical very dry forest.

Drainage class: Somewhat poorly drained.

Classification: Entic Chromustert, fine, mixed, isohyperthermic.

Profile description

Horizon	Depth (cm.)	Morphology
A11	0 - 16	Yellowish brown (10YR 5/4,dry), reddish brown (2.5YR 4/4,moist); clay; moderate coarse angular blocks; very firm, very hard, sticky and plastic; cracks more than 1 cm wide; slow permeability; few fine rocks; gradual smooth boundary.
A12	16 - 77	Reddish brown (2.5YR 5/4,dry), reddish brown (2.5YR 4/4,moist); clay; moderate coarse prisms that part into strong coarse angular blocks; very firm, very hard, sticky and plastic; cracks more than 4 cm wide; few small soft iron-manganese nodules; no roots; gradual smooth boundary.
C1	77 - 130	Yellowish brown (10YR 5/4,dry), dark yellowish brown (2.5YR 4/4,moist); weak very coarse prisms that part into strong medium angular blocks; very firm, very hard, sticky and plastic; cracks more than 2 cm wide; frequent intersecting slickensides; slow permeability; few small calcium carbonate concretions; few small soft iron-manganese nodules; gradual smooth boundary.

IIC2	130 - 200	Yellowish brown (10YR 5/6,dry and moist); clay; moderate coarse prisms that part into strong coarse angular blocks; very firm, very hard, sticky and plastic; cracks more than 2 cm wide; common intersecting slickensides; slow permeability; many small soft iron-manganese nodules.

Table 10. Particle size distribution and physical-chemical properties of pedon 2, Rabito soil.

Depth cm	Horizon	Size class and diameter of particles (mm)								Text. class	pH paste	%O.C.
		V.C.sand 2-1	C.sand 1-0.5	M.sand 0.5-0.25	F.sand 0.25-0.1	V.F.sand 0.1-0.05	Total sand	Silt 0.05-0.002	Clay 0,002			
0 - 16	A11	0.2	0.6	0.9	4.0	17	23	32	45	c to cl	7.3	0.5
16 - 77	A12	0.2	0.3	0.8	4.0	17	22	31	47	c to cl	7.5	0.3
77 -130	C1	0.3	0.3	0.6	3.5	17	22	32	47	c to cl	7.7	0.3
130 -200	IIC2	0.7	0.7	1.0	4.6	18	25	28	47	c to cl	7.3	0.1

Table 10. Continued. Particle size distribution and physical-chemical properties of pedon 2, Rabito soil.

Depth cm	E.C. mmhos/cm	P citric acid ppm	CEC meg/100g sumation	Extractable Cations meg/100g					%ES	%$CaCO_3$ Eq.	PES + %Ex.Na	CEC meg/100g clay
				Na	K	Ca	Mg	H+Al				
0 - 16	1.4	66	30	1.0	0.4	23	4.3	2.2	98	-	2.7	63
16 - 77	0.7	77	30	1.8	0.3	21	4.4	2.0	93	-	4.9	61
77 -130	2.9	-	30	4.7	0.3	18	4.5	2.0	93	-	13.1	61
130 -200	11.4	-	29	4.8	0.2	19	3.5	1.0	96	-	13.7	60

Table 11. Analysis of saturation extract of pedon 2. Rabito soil.

Depth cm	Horizon	E.C. mmhos/cm	Cations (meq/l)				Anions (meq/l)			
			Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4
0 - 16	A11	1.4	3.6	0.08	6.4	4.0	-	1.4	9.1	3.0
6 - 77	A12	1.0	-	-	-	-	-	-	-	-
7 -130	C1	2.9	23.0	0.08	2.9	3.1	-	1.3	24.0	8.0
0 -200	IIC2	11.4	100.0	0.10	27.5	15.1	-	1.0	128.8	12.2

Pedon 3: Mijagual Soil

Location: Bocono Irrigation Project. Coordinates MOP S9 + 500 E12. Barinas State.

Parent Material: Alluvium derived from crystalline rocks and sedimentary rocks.

Climate: 1354 mm. mean annual rainfall, rainy season from May to October. Dry season November to April. Mean annual temperature 27.6 C. Daily temperature variation is highly significant. Excessive water during rainy season. Mean annual potential evapotranspiration 1770 mm.

Topography: 0.1 to 0.4% slope gradient in depressional areas of a flood plain landscape. Gilgai microrelief.

Vegetation: Tropical dry forest. Natural grasses.

Drainage class: Poorly drained.

Classification: Udorthentic Chromustert, very fine, mixed, isohyperthermic.

Profile description

Horizon	Depth (cm.)	Morphology
A1	0 - 17	Gray (N 5.5/0,dry), dark gray (N 4/0,moist); clay; many, fine, prominent, yellowish red (5YR 5/8) mottles; weak coarse prisms that part into moderate coarse sub-angular blocks; very firm, very hard, very sticky and very plastic; very slow permeability; many very fine and few fine pores; many fine rocks; clear smooth boundary.
B1	17 - 35	Grayish brown (2.5Y 5/2,dry), very dark grayish brown (2.5Y 3/2,moist); clay; many fine faint olive brown (2.5Y 4/4) and common fine faint very dark gray (N 3/0) mottles; moderate coarse angular blocks; common intersecting slickensides; very firm, very hard, very sticky and very plastic; very slow permeability; common very fine pores; common very fine roots; many small hard iron-manganese concretions; gradual smooth boundary.

B21	35 - 63	Grayish brown (2.5Y 5/2,dry), very dark grayish brown (2.5Y 3/2,moist); clay; many fine faint dark gray (10YR 4/1) and common, fine faint very dark gray (N 3/0) mottles; moderate coarse to very coarse angular blocks; many intersecting slickensides; very firm, very hard, very sticky and very plastic; very slow permeability; common very fine pores; few roots; few small soft iron-manganese nodules; diffuse smooth boundary.
B22	63 - 113	Light brownish gray to light yellowish brown (2.5Y 6/3,dry), dark grayish brown to olive brown (2.5Y 4/3,moist); clay; common fine, faint very dark gray (N 3/0) and common fine faint dark yellowish brown (10YR 4/4) mottles; moderate and weak coarse angular blocks; many intersecting slickensides; very firm, extremely hard, very sticky and plastic; very slow permeability; common very fine pores; very few roots; few small soft iron-manganese concretions; diffuse smooth boundary.
IIC1	113 - 154	Light brownish gray to light yellowish brown (2.5Y 6/3,dry), dark grayish brown to olive brown (2.5Y 4/3,moist); silty clay; common fine faint very dark gray (N 3/0) and common fine faint dark yellowish brown (10YR 4/4) mottles; weak medium prisms; common slickensides; very firm, very hard, very sticky and very plastic; very slow permeability; few small soft iron-manganese nodules.

Table 12. Particle size distribution and physical-chemical properties of pedon 3, Mijagual soil.

Depth cm	Horizon	Size class and diameter of particles (mm)								Text. class	pH paste	%O.C.
		V.C.sand 2-1	C.sand 1-0.5	M.sand 0.5-0.25	F.sand 0.25-0.1	V.F.sand 0.1-0.05	Total sand	Silt 0.05-0.002	Clay 0,002			
0 - 17	A1	0	0	0	0	0	0	27	73	c	4.8	1.95
17 - 35	B1	0	0	0	0	0	0	34	66	c	6.2	0.74
35 - 63	B21	0	0	0	0	0	0	33	67	c	7.1	0.51
63 -113	B22	0	0	0	0	0	0	31	69	c	7.5	0.35
113 -154	IIC1	0.1	0.2	0.2	0.3	0.1	0.9	40	59	sc	7.5	0.23
154 -190	IIC2	0.1	0.3	0.3	0.4	0.5	1.6	52	47	sc	7.7	0.20

Table 12. Continued. Particle size distribution and physical-chemical properties of pedon 3, Mijagual soil.

Depth cm	E.C. mmhos/cm	P citric acid ppm	CEC meg/100g sumation	Extractable Cations meg/100g Na	K	Ca	Mg	H+Al	%BS	%$CaCO_3$ Eq.	PES + %Ex.Na	CEC meg/100g clay
0 - 17	0.2	35.0	39.6	0.33	0.73	14.7	5.18	18.6	53	2.37	-	45
17 - 35	0.1	17.5	35.1	0.62	0.46	18.4	6.87	8.8	75	2.37	-	50
35 - 63	0.2	10.0	36.4	1.16	0.32	21.5	7.22	6.3	83	2.47	-	51
63 -113	0.6	7.5	36.4	1.85	0.28	23.4	6.60	4.3	88	2.97	-	51
113 -154	0.6	2.5	32.5	1.96	0.20	18.7	7.55	4.1	87	2.57	-	54
154 -190	0.6	27.5	40.0	1.96	0.15	22.0	7.20	3.5	90	3.07	-	73

Pedon 4: Mendez Soil

Location: Bocono Irrigation Project. Coordinates MOP N2 M4 + 500. Barinas State.

Parent Material: Alluvium derived from crystalline rocks and sedimentary rocks (shales).

Climate: 1354 mm. mean annual rainfall, rainy season from May to October. Dry season from November to April. Mean annual temperature 27.6 C. Excessive water during rainy season. Mean annual potential evapotranspiration about 1770 mm.

Topography: 0.2 to 0.4% slope gradient in depressional areas of a flood plain landscape.

Vegetation: Tropical dry forest. Forest cover.

Drainage class: Very poorly drained.

Classification: Typic Tropaquept, fine, mixed, acid, isohyperthermic.

Profile description

Horizon	Depth (cm.)	Morphology
A1	0 - 7	Gray (10YR 5/1,dry), dark gray (10YR 4/1,moist); silty clay; few, fine, faint yellowish brown (10YR 5/6) mottles; moderate fine subangular blocks; friable; hard, sticky and plastic; moderately slow permeability; many very fine pores; many roots; abrupt smooth boundary.
B1g	7 - 24	Gray (10YR 6/1,dry) gray (10YR 5/1,moist); silty clay; many (40%) medium prominent strong brown (7.5YR 5/6) mottles; moderate coarse angular blocks; firm, very hard, very sticky and very plastic; slow permeability; common very fine pores; many roots; clear smooth boundary.
B21g	24 - 55	Gray (10YR 6/1,dry), gray (10YR 5/1,moist); silty clay; many (40%) medium distinct dark brown to brown (10YR 4/3) mottles; strong medium angular blocks; firm, very hard, very sticky and very plastic; slow permeability; many very fine pores; common roots; few small soft iron-manganese nodules; clear smooth boundary.

IIB3g	101 - 120	Yellowish brown to light yellowish brown (10YR 5.5/4,dry), dark yellowish brown (10YR 4/4,moist) silty clay loam; many (40%) fine distinct gray (10YR 5/1) mottles; weak medium prisms that part into moderate medium angular blocks; firm, very hard, very sticky and very plastic; slow permeability; many very fine pores; few roots; few small soft iron-manganese nodules; abrupt smooth boundary.
IIC1g	120 - 160	Gray (N 6/0,dry), dark gray to gray (N 4.5/0, moist); clay; many (40%) medium distinct strong brown (7.5YR 5/6) mottles; moderate to strong medium prisms; common slickensides; very firm, very hard, very sticky and very plastic; slow permeability; few very fine pores; few roots; few small soft iron-manganese.

Table 13. Particle size distribution and physical-chemical properties of pedon 4, Mendez soil.

Depth cm	Horizon	Size class and diameter of particles (mm)								Text. class	pH paste	%O.C.
		V.C.sand 2-1	C.sand 1-0.5	M.sand 0.5-0.25	F.sand 0.25-0.1	V.F.sand 0.1-0.05	Total sand	Silt 0.05-0.002	Clay 0,002			
0 - 7	A1	0	0.0	0.2	0.6	0.6	2	53	46	sc	5.75	5.70
7 - 24	B1g	0	0.0	0.2	0.3	0.3	1	43	56	sc	5.60	1.00
24 - 55	B21g	0	0.1	0.2	0.5	0.7	1	42	57	sc	5.20	0.60
55 -101	B22g	0	0.0	0.1	0.4	0.5	1	48	51	sc	6.00	0.50
101 -120	IIB3g	0	0.1	0.3	0.6	1.0	2	59	39	scl	6.40	0.50
120 -160	IIC1g	0	0.0	0.0	0.0	0.0	0	32	68	c	6.80	0.35

Table 13. Continued. Particle size distribution and physical-chemical properties of pedon 4, Mendez soil.

Depth cm	E.C. mmhos/cm	P citric acid ppm	CEC meg/100g sumation	Extractable Cations meg/100g					%BS	%$CaCO_3$ Eq.	PES + %Ex.Na	CEC meg/100g clay
				Na	K	Ca	Mg	H+Al				
0 - 7	0.9	167	49	0.1	1.2	24	7.3	16	67	3.0	-	65
7 - 24	0.2	53	31	0.1	0.8	11	5.7	13	58	2.0	-	48
24 - 55	0.1	25	32	0.1	0.3	10	7.6	14	57	2.2	-	52
55 -101	0.2	53	31	0.3	0.2	13	8.7	9	73	2.0	-	57
101 -120	0.2	73	30	0.5	0.2	14	8.0	7	75	2.0	-	71
120 -160	0.3	40	40	1.5	0.2	20	10.5	7	81	3.0	-	57

Pedon 5: Apure, Hole No 3

Location: Biruaca area, hole No 3. Apure State.

Parent Material: Alluvial deposits.

Climate: Mean annual rainfall about 1500 mm., distributed along 7 consecutive months. Mean annual potential evapotranspiration is about 1425 mm. Considerable excess of water during the rainy season, and partly in the dry season.

Topography: Less than 0.1% slope, in wet depression in a fluviodeltaic landscape.

Vegetation: Tropical dry forest. Savanna type vegetation.

Drainage class: Very poorly drained soil.

Classification: Vertic Tropaquept, fine, Kaolinitic, acid, isohyperthermic.

Profile description

Horizon	Depth (cm.)	Morphology
Ap	0 - 19	Light gray (10YR 6/1,dry), dark gray (10YR 4/1, moist); clay; many fine distinct reddish brown (5YR 5/3) mottles; moderate coarse prisms; extremely hard, very firm, very sticky and very plastic; cracks more than 1 cm wide; slow permeability; many fine roots; noncalcareous; clear wavy boundary.
B21g	19 - 48	Dark gray (10YR 4/1,dry), very dark brown to dark brown (10YR 3.5/1,moist); silty clay; few fine faint brown (7.5YR 5/4) mottles; strong medium prisms; extremely hard, very firm, very sticky and very plastic; cracks, but no intersecting slickensides; slow permeability; few fine roots; noncalcareous; clear wavy boundary.
B22g	48 - 77	Light yellowish brown (2.5Y 6/4,dry), light olive brown (2.5Y 5/4,moist); silty clay; many (50%) fine distinct dark gray (10YR 4/1) and common (20%) fine distinct dark yellowish brown (10YR 4/4) mottles; strong fine and medium prisms; cracks and few non-intersecting slickensides; slow permeability; few fine roots; noncalcareous; clear wavy boundary.

B23g	77 - 98	Dark grayish brown (2.5Y 4/2,dry and moist); silty clay; common (20%) fine distinct dark yellowish brown (10YR 4/4) and few (2%) fine distinct yellowish brown (10YR 5/4) mottles; strong medium prisms; extremely hard, very firm, very sticky and very plastic; few cracks and few non-intersecting slickensides; slow permeability; common fine soft iron concretions; no roots; noncalcareous; clear wavy boundary.
B24	98 - 128	Light olive brown (2.5Y 5/4,dry), olive brown (2.5Y 4/4,moist); silty clay; common (20%) medium distinct yellowish brown (10YR 4/4) mottles; strong medium prisms; slightly hard, firm, sticky and plastic; few cracks, few non-intersecting slickensides; slow permeability; no roots; noncalcareous; clear wavy bourdary.
IIB3	128 - 178	Light olive brown (2.5Y 5/4,dry), olive brown (2.5Y 4/4,moist); silty clay loam; many (30%) fine distinct yellowish brown (10YR 5/4) mottles; moderate medium prisms; hard, firm, sticky and plastic; no cracks; few non-intersecting slickensides; slow permeability.

Table 14. Particle size distribution and physical-chemical properties of pedon 5, Apure, hole No 3.

Depth cm	Horizon	Size class and diameter of particles (mm)								Text. class	pH paste	%O.C.
		V.C.sand 2-1	C.sand 1-0.5	M.sand 0.5-0.25	F.sand 0.25-0.1	V.F.sand 0.1-0.05	Total sand	Silt 0.05-0.002	Clay 0,002			
0 - 19	Ap	0	0.2	0.6	0.7	0.8	2.4	34	64	c	4.7	1.7
19 - 48	B21g	0	0.4	0.7	1.0	2.1	4.0	41	55	sc	5.2	0.5
48 - 77	B22g	0	0.1	0.2	0.4	2.2	3.0	45	52	sc	5.3	0.3
77 -98	B23g	0	0.0	0.0	0.2	1.3	1.5	42	56	sc	5.6	0.2
98 -128	B24	0	0.0	0.0	0.5	9.6	10.0	49	41	sc	6.1	0.2
128 -178	IIB3	0	0.1	0.1	0.4	3.0	3.5	67	30	scl	6.6	0.1

Table 14. Continued. Particle size distribution and physical-chemical properties of pedon 5, Apure, hole No 3.

Depth cm	E.C. mmhos/cm	P citric acid ppm	CEC meg/100g sumation	Extractable Cations meg/100g					%BS	$\%CaCO_3$ Eq.	PES + %Ex.Na	CEC meg/100g clay
				Na	K	Ca	Mg	H+Al				
0 - 19	0.2	57	34	0.3	0.5	10	5.0	18.7	46	2.5	-	45
19 - 48	0.1	30	31	0.3	0.2	14	5.6	12.2	61	2.3	-	54
48 - 77	0.1	10	24	0.3	0.2	11	4.6	8.0	67	2.2	-	44
77 - 98	0.1	21	27	0.4	0.2	14	5.0	7.0	74	2.4	-	46
98 -128	0.2	10	19	0.3	0.1	10	4.4	4.1	78	1.7	-	45
128 -178	0.2	38	17	0.2	0.1	10	4.3	2.7	84	2.0	-	57

Pedon 6: Yagrumo Soil

Location: South of Maracaibo Lake. Coordinates E 20,000 - 30,000 N 40,000 - 50,000. Zulia State.

Parent Material: Alluvium deposited by Umuguena and Jabillos Rivers.

Climate: Mean annual rainfall is about 1800 mm. distributed throughout 9 months. Soil is almost never dry in some part of the moisture control section. Mean annual evapotranspiration is about 1200 mm. As rainfall exceeds the evapotranspiration, the soil is often saturated.

Topography: Less than 1% slope in depressional areas of a flood plain landscape.

Vegetation: Tropical rain forest.

Drainage class: Poorly drained soil.

Classification: Aeric Tropaquept, very fine, Kaolinitic, acid, isohyperthermic.

Profile description

Horizon	Depth (cm)	Morphology
A11	0 - 12	Brown (10YR 5/3,moist); clay; moderate coarse granular structure; firm, extremely hard, very sticky and very plastic; slow permeability; few fine pores; many roots; abrupt wavy boundary.
B21g	12 - 30	Gray (10YR 6/1) (60%) and dark yellowish brown (10YR 4/4) (40%); clay; moderate medium angular blocks; very firm, extremely hard, very sticky and very plastic; slow permeability; few fine pores; few roots; few small soft ironstone nodules; clear wavy boundary.
B22g	30 - 50	Gray (10YR 6/1) (50%) and dark yellowish brown (10YR 4/4) (40%); clay; moderate coarse angular blocks; very firm, very hard, very sticky and very plastic; slow permeability; few fine pores; few roots; many small soft iron-manganese concretions; clear wavy boundary.

IIA1b	50 - 93	Gray (10YR 6/1,moist); clay; many (55%) coarse prominent yellowish brown (5YR 5/6) mottles; weak fine angular blocks with tendency to be massive; very firm, extremely hard, very sticky and very plastic; slow permeability; few fine and very fine pores; few roots; few small soft ironoxide; clear wavy boundary.
IIB2gb	93 - 115	Gray (N 5/0,moist); clay; many (45%), fine prominent dary gray (2.5YR 5/6) mottles; masstive; very firm, extremely hard, very sticky and very plastic; slow permeability; few very fine pores; few roots; many small, soft iron-manganese nodules; gradual wavy boundary.
IIC1gb	135 - 200	Gray (10YR 6/1,moist); clay; many (25%), coarse prominent reddish brown (2.5YR 4/4) mottles; massive; very firm, very hard, very sticky and very plastic; slow permeability; few fine pores; many small soft iron-manganese nodules.

Table 15. Particle size distribution and physical-chemical properties of pedon 6, Yagrumo soil.

Depth cm	Horizon	Size class and diameter of particles (mm)								Text. class	pH paste	%O.C.
		V.C.sand 2-1	C.sand 1-0.5	M.sand 0.5-0.25	F.sand 0.25-0.1	V.F.sand 0.1-0.05	Total sand	Silt 0.05-0.002	Clay 0,002			
0 - 12	A11	0	0	0.6	1.4	2.0	3.0	25	72	c	4.2	2.8
12 - 30	B21g	0	0	0.5	1.0	2.5	4.0	27	69	c	4.6	2.4
30 - 50	B22g	0	0	0.6	1.0	1.3	3.0	26	71	c	3.7	0.4
50 - 93	A1b	0	0	0.3	1.7	3.0	5.0	11	84	c	4.3	1.2
93 -135	B2gb	0	0	0.3	0.6	1.1	2.0	11	87	c	4.0	0.3
135 +	C1gb	0	0	0.1	0.4	0.5	1.0	10	89	c	5.8	0.2

Table 15. Continued. Particle size distribution and physical-chemical properties of pedon 6, Yagrumo soil.

Depth cm	E.C. mmhos/cm	P citric acid ppm	CEC meg/100g sumation	Extractable Cations meg/100g					%BS	%$CaCO_3$ Eq.	PES + %Ex.Na	CEC meg/100g clay
				Na	K	Ca	Mg	H+Al				
0 - 12	0.7	-	36	0.30	0.55	10.9	6.2	18.0	43.2	-	-	37
12 - 30	0.7	-	32	0.35	0.48	11.2	5.0	15.0	47.2	-	-	35
30 - 50	0.6	-	27	1.80	0.05	5.2	4.3	16.0	42.2	-	-	37
50 - 93	0.6	-	26	0.35	0.40	9.3	5.2	11.0	50.3	-	-	26
93 -135	2.2	-	37	5.30	0.10	7.5	5.8	18.0	48.7	-	-	41
135 +	2.6	-	34	5.00	0.10	7.3	6.6	15.0	54.2	-	-	37

APPENDIX 2

X-RAY DIFFRACTION PEAK-HEIGHT INTENSITIES OF MINERALS IN THE COARSE AND FINE CLAY FRACTION OF SELECTED HORIZONS OF THE SOIL PEDONS

Table 16. Peak-Height Intensities of Minerals in the Coarse Fraction of Selected Horizons of the Soil Pedons.

Soil pedon	Depth cm	Treat-ment (1)	(001) Spacings 10A	7A	5A	4.3A	3.5A	3.33A
Sabaneta	6-38	Mg	12	30	3	4	24	27
		Mg-gly	3	15	5	4	20	25
		K-20	27	75	9	4	42	44
		K-350	35	65	15	5	53	44
		K-550	36	-	15	5	-	57
	62-100	Mg	14	33	4	4	25	36
		Mg-gly	5	19	4	4	29	28
		K-20	20	51	6	5	42	37
		K-350	27	48	8	6	38	45
		K-550	15	-	8	6	-	48
Rabito	0-16	Mg	22	25	7	4	20	35
		Mg-gly	10	15	6	4	15	26
		K-20	23	30	8	2	24	24
		K-350	35	36	13	2	30	36
		K-550	15	-	10	3	-	44
	77-130	Mg	22	29	6	4	18	33
		Mg-gly	12	22	7	4	17	30
		K-20	18	23	5	4	15	32
		K-350	24	25	8	4	16	35
		K-550	6	-	1	3	-	20
Mijagual	0-17	Mg	45	27	21	2	25	44
		Mg-gly	47	35	21	2	23	40
		K-20	67	42	28	2	32	58
		K-350	85	39	35	2	31	73
		K-550	57	-	35	2	-	95
	63-113	Mg	45	31	16	2	30	40
		Mg-gly	26	27	16	2	25	33
		K-20	78	63	24	3	41	60
		K-350	86	63	32	3	40	72
		K-550	68	-	33	3	-	95
Mendez	7-24	Mg	30	24	15	2	22	40
		Mg-gly	17	20	12	2	22	35
		K-20	47	40	20	2	27	42
		K-350	70	37	25	2	27	57
		K-550	46	-	25	2	-	73

Table 16. (continued), coarse clay (2-0.2μ)

Soil pedon	Depth cm	Treat-ment (1)	(001) Spacings 10A	7A	5A	4.3A	3.5A	3.33A
Mendez	55-101	Mg	43	23	14	2	17	32
		Mg-gly	22	18	12	2	15	27
		K-20	75	43	28	3	34	55
		K-350	95	42	43	3	34	74
		K-550	80	-	45	2	-	100
Apure, hole No 3	0-19	Mg	28	40	10	2	42	37
		Mg-gly	17	34	10	3	35	30
		K-20	35	52	13	3	40	34
		K-350	45	52	17	2	41	44
		K-550	32	-	16	3	-	48
	48-77	Mg	21	39	10	3	42	36
		Mg-gly	7	28	9	3	35	29
		K-20	32	68	13	3	51	40
		K-350	45	68	17	3	55	47
		K-550	41	-	17	4	-	53
Yagrumo	12-30	Mg	20	82	8	4	71	38
		Mg-gly	12	63	7	3	55	25
		K-20	40	168	14	4	120	48
		K-350	60	190	20	4	124	54
		K-550	46	-	19	4	-	56
	30-50	Mg	22	81	9	3	77	39
		Mg-gly	12	68	8	4	73	34
		K-20	43	180	14	1	130	40
		K-350	62	194	24	2	138	54
		K-550	52	-	23	3	-	57
	93-135	Mg	10	35	3	3	25	22
		Mg-gly	7	35	5	3	36	25
		K-20	10	47	4	3	37	23
		K-350	18	47	7	4	43	27
		K-550	15	-	6	3	-	28

(1) Mg: Magnesium saturated slide
Mg-gly: Magnesium saturated slide with glycerol solvation
K-20: Potassium saturated slide at room temperature
K-350: Potassium saturated slide heated at 350 C for two hours
K-550: Potassium saturated slide heated at 550 C for two hours

Table 17. Peak-Height Intensities of Minerals in the Fine Clay Fraction of Selected Horizons of the Soil Pedons.

Soil pedon	Depth cm	Treat-ment (1)	(001) Spacings [2] 10A	7A	5A	3.5A	3.33A
Sabaneta	6-38	Mg	60	45	13	47	30
		Mg-gly	25	35	17	53	37
		K-20	44	41	17	55	37
		K-350	47	40	20	52	49
		K-550	45	-	23	-	54
	62-100	Mg	73	60	12	51	27
		Mg-gly	35	55	20	56	35
		K-20	43	43	15	62	35
		K-350	41	36	20	54	50
		K-550	38	-	20	-	55
Rabito	0-16	Mg	31	12	8	11	14
		Mg-gly	15	9	9	15	15
		K-20	37	15	10	19	25
		K-350	40	14	13	17	30
		K-550	40	-	15	-	33
	77-130	Mg	40	13	10	14	17
		Mg-gly	21	10	10	17	17
		K-20	28	12	9	17	23
		K-350	32	10	13	16	32
		K-550	30	-	13	-	34
Mijagual	0-17	Mg	72	25	18	28	44
		Mg-gly	41	23	22	28	45
		K-20	53	22	23	28	50
		K-350	55	19	26	22	63
		K-550	30	-	23	-	59
	63-113	Mg	72	25	18	29	31
		Mg-gly	37	20	21	30	39
		K-20	60	21	18	29	43
		K-350	59	19	25	23	57
		K-550	44	-	18	-	43
Mendez	7-24	Mg	76	21	22	28	37
		Mg-gly	34	22	22	28	48
		K-20	76	21	18	22	36
		K-350	75	18	30	17	55
		K-550	31	-	19	-	48

Table 17. (continued), fine clay (< 0.2μ)

Soil pedon	Depth cm	Treat-ment (1)	(001) Spacings [2] 10A	7A	5A	3.5A	3.33A
Mendez	55-101	Mg	69	17	20	21	33
		Mg-gly	30	17	21	28	41
		K-20	64	17	16	19	31
		K-350	61	15	27	16	48
		K-550	42	-	20	-	41
Apure, hole No 3	0-19	Mg	53	42	15	47	35
		Mg-gly	31	36	21	50	40
		K-20	47	36	17	48	46
		K-350	47	34	21	39	53
		K-550	52	-	27	-	68
	48-77	Mg	43	31	9	22	16
		Mg-gly	22	29	9	24	14
		K-20	47	43	13	39	31
		K-350	48	37	16	32	36
		K-550	46	-	15	-	33
Yagrumo	12-30	Mg	31	33	6	26	12
		Mg-gly	15	35	11	40	19
		K-20	46	65	15	58	31
		K-350	45	56	16	51	35
		K-550	50	-	20	-	37
	30-50	Mg	49	57	11	53	25
		Mg-gly	27	61	17	66	27
		K-20	46	68	15	75	37
		K-350	46	57	23	67	45
		K-550	47	-	29	-	58
	93-135	Mg	60	86	15	85	37
		Mg-gly	35	95	23	100	40
		K-20	50	77	17	85	37
		K-350	47	86	22	79	50
		K-550	45	-	25	-	54

(1) Mg: Magnesium saturated slide
Mg-gly: Magnesium saturated slide with glycerol solvation
K-20: Potassium saturated slide at room temperature
K-350: Potassium saturated slide heated at 350 C for two hours
K-550: Potassium saturated slide heated at 550 C for two hours

2 No 4.3A peaks were observed in the diffractograms of the fine clay fractions.

Table 17. (continued)

Remarks: Peak broadening and low angle asymmetry were consistently observed for the 10A peak in the Mg-glycerol specimens of all samples. They disappeared after K-saturation and heating at 350 C (Figure 17).

APPENDIX 3

QUANTITATIVE CHEMICAL ANALYSES FOR MINERAL ALLOCATIONS

Table 18. Quantitative Chemical Analysis for Mineral Allocation. Coarse Clay Fraction (2-0.2μ)

Soil pedon	Depth cm	Horizon desig.	CaEC meg/100g	K//EC meg/100g	SDA (2) S_1O_2	SDA (2) Al_2O_3	Verm.	Mont. o/o	Mica (1)	Kaol. (1)	Am. Mat.
Sabaneta	6-38	B1sa	15.2	9.9	4.5	1.3	3.5	0.0	15.0	75.0	6.5
Rabito	77-130	C1	28.4	20.3	7.0	1.2	5.6	5.5	28.2	51.8	9.0
Mijagual	63-113	B22	26.2	13.8	4.4	1.1	8.1	2.3	41.0	42.6	6.1
Mendez	55-101	B22g	27.7	16.4	1.8	0.8	7.4	8.0	45.0	36.8	2.8
Apure, Hole No 3	48-77	B22g	21.3	11.4	2.7	1.8	6.4	6.1	16.6	66.0	4.9
Yagrumo	30-50	B22g	13.4	7.1	3.1	1.2	3.0	0.0	13.7	77.5	4.8
	93-135	IIB2gb	15.0	10.2	2.9	1.0	3.2	0.0	15.5	77.0	4.3

(1) Mica and Kaolinite content estimated from the peak-height intensities in the Mg-glycerol slides.

(2) Selective dissolution analysis.

Table 19. Quantitative Chemical Analysis for Mineral Allocation. Fine Clay Fraction (< 0.2μ)

Soil pedon	Depth cm	Horizon desig.	CaEC meg/100g	K//EC meg/100g	SDA (1) S_1O_2	SDA (1) Al_2O_3	Total K_2O	Verm.	Mont.	Mica	Kaol.	Am. Mat.
					o/o							
Sabaneta	6-38	B1sa	60.9	43.6	7.9	4.2	2.00	11.2	23.3	20.0	30.0	13.4
Rabito	77-130	C1	81.2	56.2	8.6	3.4	1.95	16.2	35.4	19.5	15.3	13.3
Mijagual	63-113	B22	67.8	45.9	8.6	3.5	2.15	14.3	25.4	21.5	19.5	13.5
Mendez	55-101	B22g	56.1	44.3	8.4	2.7	2.66	7.7	25.1	26.6	20.0	12.3
Apure, Hole No 3	48-77	B22g	59.7	21.5	8.8	5.2	1.98	24.8	15.7	19.8	25.1	15.5
Yagrumo	30-50	B22g	51.5	37.4	8.4	3.7	2.14	9.1	17.5	21.4	38.0	13.4
	93-135	IIB2gb	51.4	33.4	6.8	3.6	2.06	11.7	15.5	20.6	40.6	11.6

(1) Selective dissolution analysis.