MINERALOGICAL AND CHEMICAL CHARACTERISTICS OF SOME SOILS OF THE AMAZONIA OF COLOMBIA

by

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ABSTRACT

BENAVIDES, SERVIO TULIO. Mineralogical and Chemical Characteristics of Some Soils of the Amazonia of Colombia. (Under the direction of STANLEY WALTER BUOL).

Amazonia constitutes the southeast portion of Colombia and consists of undulating Cenozoic sediments and outcrops of older materials including Guayana Shield rocks. The mean annual temperature is 28°C and the mean annual rainfall is 3000 mm with no dry season. Amazonia is covered by evergreen tropical forest.

Physical, mineralogical and chemical characteristics and the classification of nine soil profiles were established in this region.

The soils were classified according to the U. S. Soil Taxonomy as Inceptisols, Inceptisols intergrading toward Oxisols and Ultisols. No one subsoil horizon of the soil profiles used in this study meet all the requirements of the oxic horizon, since they contain more than traces of micas and other 2:1 clay minerals.

The mineral composition of the sand and silt fractions was dominated by quartz. In the sand fraction of the soils nearest the Eastern Cordillera the presence of volcanic glass and volcanic rock fragments was observed. In the silt fraction mica, kaolinite and in some profiles 2:1-type minerals were present.

With few exceptions, kaolinite was the predominant clay minerals in all. Mica, vermiculite, 2:1-2:2 intergradational minerals and amorphous silicates were present in all soils and montmorillonite was present in some profiles. Soils classed as Udoxic Dystropepts contained some amounts of gibbsite. The SiO_2/Al_2O_3 molar ratio of the deferrated clay ranged from 2.2 to 4.4.

The cation exchange capacity of the deferrated clay varied between 8 and 50 meq/100 g clay, being directly related to the content of the 2:1 minerals present.

The free iron oxides and amorphous silicates were present in rather modest amounts (between 5 and 12% each). The SiO_2/Al_2O_3 molar ratio varied between 0.7 and 3.6.

The soils are very strongly acid, with high aluminum saturation, usually above 60%, and low base status. The effective cation exchange capacity varied between 5 and 20 meq/100 g and the pH-dependent cation exchange capacity was between 1 and 15 meq/100 g. Sources of pH-dependent cation exchange capacity seem to be related to the content of organic matter, and amount of hydroxy aluminum and iron oxide interlayers and coatings

Organic carbon content was relatively high. The C/N ratio decreased with depth to very low values. The amounts of indigenous fixed ammonium varied between 50 and 320 ppm and tended to increase with depth.

Available phosphorus content was very low. Total phosphorus ranged from 100 to 600 ppm, 40 to 70% of which is in organic form.

Micronutrients, zinc and copper were not low; however, manganese was high, which may indicate toxic effects to some crops.

Amazon soils used in the present study have a low fertility status which may limit their agricultural suitability. None of the soil features observed indicate that insurmountable conditions are present that would impede development of agriculture. For commercial crop production, liming and fertilization must constitute a fundamental part of any soil management program. To bring these lands into production, the economic feasibility of management practices must be established.

BIOGRAPHY

The author was born in Yacuanquer, Nariño, Colombia, son of Juan and Julia Rivera de Benavides.

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TABLE OF CONTENTS

	Page
LIST OF TABLES	vii
LIST OF FIGURES	ix
INTRODUCTION	1
DESCRIPTION OF THE AREA	5
Location	5
Climate	5
Geology	9
Geology of the Eastern Cordillera	12
Geology of the Amazonic Llanos	13
Geology of the Salient of Vaupes	15
Historical Geology	16
Physiography and Relief	17
Vegetation	20
Land Use	21
REVIEW OF LITERATURE	23
Studies in Colombia	23
Studies in Other Countries	24
MATERIALS AND METHODS	34
Sampling Sites	34
Sample Preparation	35
Physical Methods	35
Particle Size Distribution	35
Water-Dispersible Clay	35
Water Retention at 15 Bars	36
Mineralogical Methods	36
Sample Preparation	36
Mineralogy of the Sand Fraction	36
Mineralogy of Silt and Clay Fractions	36
X-Ray Diffraction	36
Differential Thermal Analysis (DTA)	37
Estimation of Kaolinite and Gibbsite	37
Estimation of Mica	37
Estimation of Quartz	37
Amorphous Alumino-Silicates	38

TABLE OF CONTENTS (Continued)

Page

Total SiO_2 and Al_2O_3 in Clays 38
Free Iron Oxide 38
CEC of the Clay 38

Chemical Methods 39

Soil pH 39
Exchangeable Acidity 39
Extractable Acidity 39
Mehlich Acidity Test 40

Solution A 40
Solution B 40

Exchangeable Bases 40
Ammonium Retention 40
Cation Exchange Capacity 41

1 N NH_4OAc pH 7 41
Effective Cation Exchange Capacity 41
CEC by Sum of Cations 41

Organic Carbon 41
Total Nitrogen 41
Indigenous Fixed Ammonium 42
Nitrogen Mineralization 42
Total and Organic Phosphorus 42
Available Phosphorus 43
Extractable Copper, Zinc and Manganese 43

Thin Sections 43

RESULTS AND DISCUSSION 44

Texture and Morphology 44
Mineralogy of the Sand 61
Mineralogy of the Silt 72
Mineralogy of the Clay 76

Soil 1 Miraf 91
Soil 2 Montan 97
Soil 3 Naval 101
Soil 4 Polvor 104
Soil 5 Tacana 107
Soil 6 Leguiz 110
Soil 7 Guavia 112
Soil 8 Floren 115
Soil 9 Asis 117

Weathering Means 120

TABLE OF CONTENTS (Continued)

Page

Chemical Properties 123

Soil Reaction 123
Exchangeable Bases, Exchangeable Acidity 123
Extractable Acidity, CEC, pH-Dependent CEC 133
Carbon and Nitrogen 142
Total Organic and Available Phosphorus 153

Micronutrient Analysis 158

CLASSIFICATION OF SOILS 160

Moisture Soil Regime 160
Temperature Soil Regime 160

Soils 1 and 2 160
Soils 3 and 4 163
Soils 5 and 6 164
Soil 7 165
Soils 8 and 9 165

SUMMARY AND CONCLUSIONS 167

LIST OF REFERENCES 173

APPENDICES 187

Appendix A. Description of the Soil Profiles 188
Appendix B. Micrmorphology of Selected Horizons of the Amazonia Soils 206
Appendix C. Preliminary Characterization of the Soil Fertility Status by Greenhouse Studies 216

LIST OF TABLES

Page

1. Mean monthly and mean annual temperature of selected locations 7
2. Mean monthly and mean annual rainfall of selected locations . 8
3. Fifteen-bar water percent; water-dispersible clay; total clay content determined by three procedures and 15-bar water percent/$NaPO_4$-clay percent ratio 45
4. Particle size distribution 49
5. Textural classes; silt to clay ratios 53
6. Mineralogy of the very fine sand by the grain counting method with petrographic microscope 63
7. Mineralogy of the silt by X-ray diffraction of magnesium-saturated specimens 73
8. Mineralogy of the clay 78
9. Quantification of the minerals in the deferrated clay 80
10. Analysis of the clay 84
11. Amorphous silica and alumina extracted from deferrated clay by selective dissolution analysis 88
12. Mean stage of chemical weathering in B horizon of the Amazonian soils 122
13. pH, exchangeable bases, exchangeable acidity and percent base saturation 124
14. Lime requirement according to Mehlich and Kamprath procedures 132
15. Extractable acidity by $BaCl_2$-TEA pH 8.2, cation exchange capacities by sum of cations, 1 N pH 7 NH_4OAc, unbuffered NH_4Cl, effective CEC, pH-dependent CEC 135
16. Organic carbon, total nitrogen, carbon: nitrogen ratio, nitrogen mineralized by aerobic and anaerobic incubations 143
17. Total nitrogen, indigenous fixed ammonium, organic nitrogen and organic carbon:organic nitrogen ratio 151

LIST OF TABLES (Continued)

Page

18. Total organic and available phosphorus 154

19. Manganese, copper and zinc extracted by North Carolina and modified Olsen solutions 159

LIST OF FIGURES

Page

1. Location of Amazonia in the Republic of Colombia 6
2. Rainfall-evapotranspiration balance for S. Gabriel da Cachoeira 10
3. General geological provinces of Amazonia and location of the sample sites 11
4. Mineralogical composition of the clay, Soil 1, Miraf 93
5. Mineralogical composition of the clay, Soil 2, Montan 99
6. Mineralogical composition of the clay, Soil 3, Naval 103
7. Mineralogical composition of the clay, Soil 4, Polvor 106
8. Mineralogical composition of the clay, Soil 5, Tacana 109
9. Mineralogical composition of the clay, Soil 6, Leguiz 111
10. Mineralogical composition of the clay, Soil 7, Guavia 114
11. Mineralogical composition of the clay, Soil 8, Floren 116
12. Mineralogical composition of the clay, Soil 9, Asis 119

INTRODUCTION

The primary goal for the agriculture of any country is to produce food for its own people.

To provide adequate supplies of food and fiber for the increasing populations, the South American countries are working in two main directions--(1) to increase the productivity of the soils already being used and (2) to increase the hectareage of food crops.

The increase of yields per hectare of the soils now in use appears to be the more efficient solution for the food shortage, in view of the results obtained with application of new technologies that resulted in the "green revolution." However, the population growth is of such a magnitude that additional lands are needed. F.A.O. estimates that 33 million hectares of forest and 8 million hectares of grassland should be cleared and brought into cultivation before 1985 in order to absorb the population growth of Latin America (cited by Aubert and Tavernier, 1972).

Obviously, Brazil, Colombia, Ecuador, Peru, and Bolivia are looking at the huge Amazon basin, which embraces more than 3 million square kilometers of almost virgin land, as the greatest reserve of soils that will solve the problems of land shortage.

There is a wide range of opinions about the potentiality of the Amazon basin. Some authorities have pointed out that the development of the Amazon resources may result in rapid economic and social development of the countries. Others have argued that because of the insurmountable problems and expenses involved in developing these regions, the potential is very low.

Some ecologists and soil scientists think that the incorporation of the Amazonian lands into the economy through the traditional systems of clearing and annihilation of the forest to bring the land into cultivation of annual crops is a great risk. They feel that such systems will lead to a transient agriculture and cause irreparable damage because of the disruption of the ecological equilibrium, and the nutrient recycling process, characteristic of the tropical forest (Del Llano, 1972). Others see nothing harmful in the destruction of forest for cultivation. In this case, the prevailing philosophy, according to Bartlett (1970), is that deforestation is not harmful if the forest contains many different species and the commercially valuable ones among them are too infrequent to make exploitation "pay." The forests are so vast that land must be cleared for grazing and agricultural uses which are more profitable than unmanaged forests.

The early views that luxuriant forest vegetation in tropical jungles is due to a high level of inherent fertility has been recognized to be in error and the actual prevalent concept is that the "tropical soils" are very poor and very infertile, which is probably another exaggerated opinion.

Blasco (1968) collected and analyzed samples in a 10.000-square kilometer area in Leticia and reported analyses that indicate striking differences in fertility status between the soils developed in old sedimentary materials and in recent alluvium. The recent alluvial soils have a slightly acid reaction and high base status while the older soils are very acid, depleted of bases and contain no weatherable minerals.

Unfortunately, the fertile soils on recent alluvium occupy only limited areas in the Amazon basin. Marbut and Manifold (1925) estimated that only 10% of the area is covered by the "alluvial plain" of the Amazon River and its tributaries; however, according to more recent estimates less than 1% of Amazonia is covered by Holocene (recent alluvium) and only a minor portion is actually available for agriculture. Antropologist Lathrap (1970) points out that the scarcity of "recent alluvial soils" has been a dominant factor affecting the evolution of culture in the Amazon basin. The archeological records indicate that the struggle for productive lands has been going on for a long time and began several millenia before the discovery of the Amazon River (1542).

What is the real meaning of the Amazonia to Colombia?

Colombia may be divided into three major ecological zones--(a) Andean mountain ranges running in the south-north direction and occupying the western portion of the country; (b) coastal plains in the north and west and (c) eastern region covering roughly two-thirds of the total area, and divided into two natural regions, "Llanos Orientales" covered by savanna vegetation and "Amazonia" covered by forest. The eastern region has not been incorporated to the national economy. It is very significant that less than 2% of the population lives in the eastern two-thirds of the country.

The Amazon forest region totals about 360,000 square kilometers with a population of a few thousand concentrated in small villages and a scattered Indian population that hunts, fishes and carries out a simple cultivation along the rivers.

Rubber extracted from scattered trees is probably the most important product. Small plots have been cleared for a subsistence agriculture in a "shifting cultivation" fashion. Amazonia is an economic and cultural vacuum. The Agrarian Reform Institute is interested in the development of colonization plans in several sites of Amazonia, but the available information and knowledge of the soils is extremely meager. For rationale use and development of the lands, a knowledge of their characteristics as well as their geographic distribution is fundamental. Previous to the development of any colonization program, the potential area must be surveyed and information about the chemical and fertility status of the soil must be obtained.

To gain the needed information about the soil properties, qualities and potential values, the writer feels that it is desirable to start with a general exploration of the physical, chemical and mineralogical characteristics of some "representative" soils distributed throughout Amazonia. With this idea in mind, several profiles were collected and characterized in several ways.

The major objectives of the present study are:

(1) To characterize physically, chemically and mineralogically, "representative" profiles of the Colombian Amazonia

(2) To determine quantitative criteria for their classification

(3) To evaluate the information in terms of fertility status

DESCRIPTION OF THE AREA

Location

The Amazonia of Colombia is located in the southeastern [illegible] the country, between 4° north and [illegible] south latitude [illegible] longitude. The Amazonia of Colombia is bounded by the [illegible] the north, by the Putumayo and Amazon Rivers on the south, [illegible] Cordillera on the west and Brazilian border on the east [illegible]

Climate

The climate of Amazonia is hot and humid. Rainfall is abundant during all the year with no dry month. The mean annual temperature is high and constant. The maximum difference between mean monthly temperatures is less than 5°C.

Table 1 shows the monthly and annual temperatures of selected locations. The mean temperature increases from about 2[illegible] in the east to 29°C in the west and then decreases again at the foothills of the Andes (Puerto Asis). The difference between the diurnal mean maximum and mean minimum temperatures is about [illegible]°C.

Moisture bearing winds from the Atlantic Ocean blow up river and deposit large quantities of moisture in the Amazon basin. The region has a high annual rainfall due to the strong convectional activity and to the orographic uplift of the Eastern Andes. The mean annual precipitation for the entire Amazon basin is estimated as 2300 mm per year. Leticia receives about [illegible] mm [illegible] eastern interior and the [illegible] receive about 3900 mm [illegible] [illegible]cia) (Table 2).

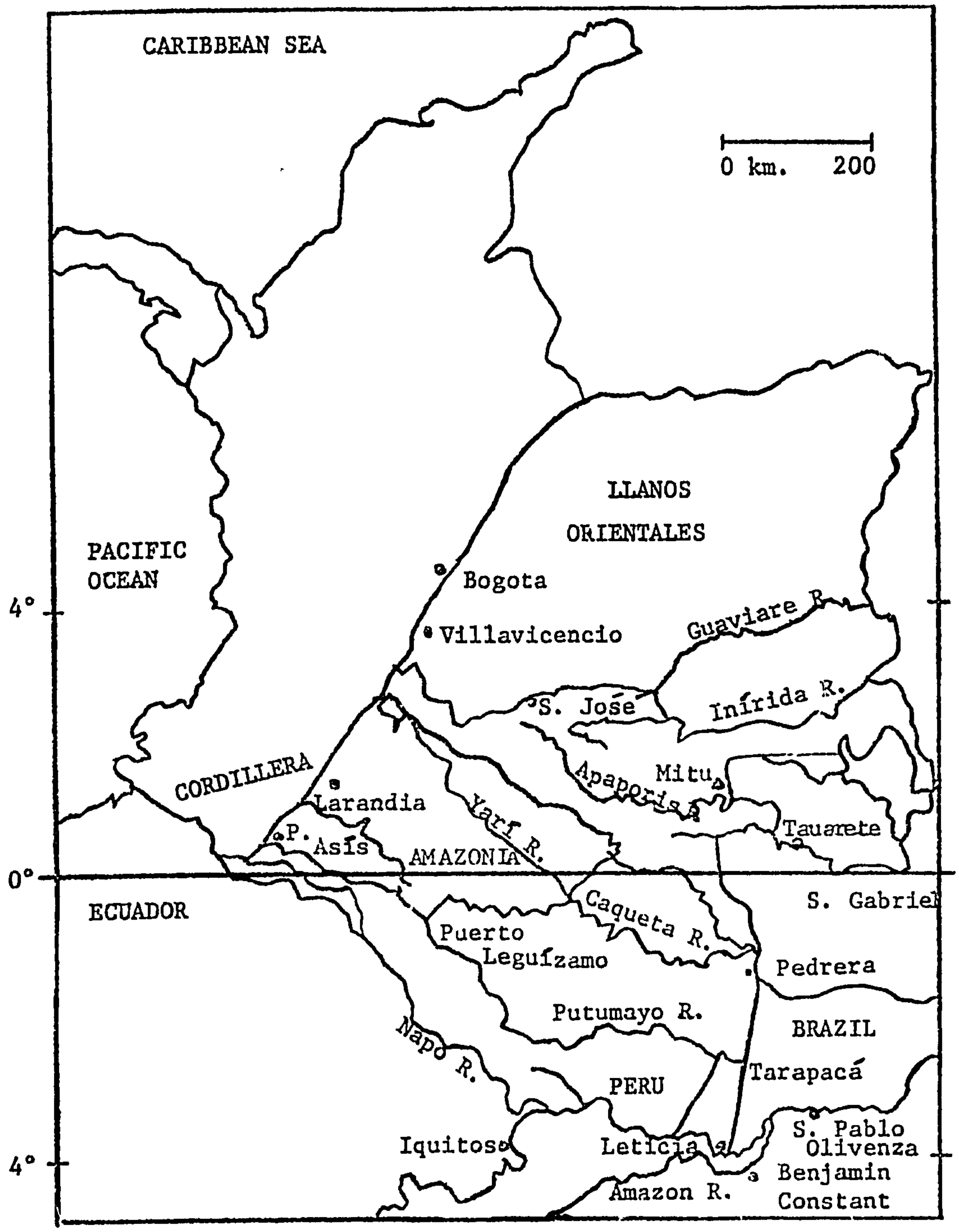

Figure 1. Location of Amazonia in the Republic of Colombia

Table 1. Mean monthly and mean annual temperature of selected locations

Location	Average temperature, °C												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Benjamin Constant													
Mean temperature	25.8	25.8	25.9	25.8	25.6	25.2	25.1	25.8	26.0	26.1	26.2	26.0	25.8
Maximum temperature	30.7	30.9	30.9	30.8	30.6	30.2	30.3	31.2	31.4	31.4	31.4	31.1	30.9
Minimum temperature	21.0	20.8	20.9	20.8	20.7	20.3	19.9	20.5	20.6	20.8	20.9	20.8	20.7
San Pablo de Olivenza													
Mean	25.8	25.8	25.8	25.8	25.5	25.4	25.2	26.0	26.2	26.2	26.2	26.2	25.8
Maximum	30.3	30.3	30.3	30.2	29.9	29.8	29.8	30.9	31.2	31.1	30.9	30.8	30.4
Minimum	21.4	21.2	21.3	21.4	21.1	21.0	20.7	21.0	21.3	21.3	21.6	21.7	21.2
San Gabriel Cachoeira													
Mean	25.4	25.5	25.6	25.3	25.0	24.5	24.3	24.8	25.4	25.6	25.9	25.5	25.2
Maximum	30.7	30.6	30.8	30.3	29.7	29.1	28.2	30.2	31.2	30.3	31.1	30.6	30.2
Minimum	22.5	22.5	22.6	22.5	22.4	21.8	21.6	21.7	21.9	23.0	22.6	22.5	22.3
Iauarete													
Mean	25.2	25.2	25.3	25.1	24.9	24.4	24.1	24.5	25.1	25.3	25.5	25.3	25.0
Maximum	30.7	31.1	31.3	30.3	29.8	29.3	29.0	30.1	31.3	31.2	31.2	30.8	30.5
Minimum	21.5	21.6	21.8	21.7	21.8	21.3	20.9	21.1	21.5	21.5	21.7	21.6	21.5
Miraflores													
Mean	28.2	29.5	29.5	28.5	28.0	27.7	28.7	28.4	28.5	27.0	27.8	26.5	28.2
San Jose Guaviare													
Mean	31.2	31.4	30.6	28.5	29.5	28.0	27.1	26.8	27.8	28.5	28.7	28.4	28.8
Puerto Asis													
Mean	24.6	24.3	24.2	23.7	23.7	24.3	24.1	24.4	25.2	25.8	25.8	25.8	24.6
Iquitos													
Mean	25.6	25.6	24.4	25.0	24.5	24.5	24.5	24.5	24.5	25.0	25.6	25.6	25.0

Table 2. Mean monthly and mean annual rainfall of selected locations

Location	Average rainfall, mm												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Benjamin Constant	374	284	358	320	239	145	124	123	180	226	234	295	2902
San Pablo de Olivenza	287	273	304	346	278	157	128	109	157	206	208	257	2710
San Gabriel de Cachoeira	275	250	285	267	317	250	246	195	148	173	202	306	2914
Iauarete	259	246	295	363	389	356	350	278	266	237	227	237	3505
Mitu	152	167	282	408	368	353	424	291	255	294	231	291	3516
Miraflores	---	229	170	248	552	490	428	331	197	251	306	273	(3476)
San Jose Guaviare	7	53	121	291	454	291	371	482	291	112	240	122	2835
Larandia	120	193	345	472	522	386	370	253	272	321	217	161	3632
Florencia	167	129	302	408	611	496	397	305	316	304	216	165	3816
Puerto Asis	221	210	380	425	440	385	313	220	357	428	354	261	3994
Iquitos	259	269	305	168	254	185	165	114	223	180	216	287	2625

San Jose Guaviare is near the boundary between Amazonia and the "Llanos Orientales," with savanna vegetation, and has a dry season of two months (December-February).

The annual mean relative humidity of Amazonia is about 87-95% with few variations.

The insolation varies between 1500 and 2000 hour/year and the cloudiness varies between 75% during rainiest times and 35% when rain is not so heavy (Eidt, 1969).

According to the Holdridge classification (Espinal and Montenegro, 1963) Amazonia is classified as "Tropical Humid" to "Tropical Very Humid Forest." According to Koppen's classification the climate is hot-humid without dry season, Af type.

The evapotranspiration calculated by Thornthwaite is about 1200-1500 mm so that for Leticia, for example, there is an annual moisture excess of more than 1500 mm. Figure 2 shows the rainfall-evapotranspiration balance for S. Gabriel da Cachoeira, east of Mitu, which probably is a good example of the climatic condition prevalent in most of the Upper Amazon basin (Bastos, 1972).

Geology

Colombian geologists (Hubach, 1954; Servicio Geologico Nacional, 1962) usually divide the Colombian Amazonia in two general geomorphic areas, "Amazonic Llanos" and "Salient of Vaupes" (Figure 3).

The Amazonic Llanos are formed by a low plain, but not a flat plain, filled by sedimentary deposits of Cenozoic age. It extends from the northwest to the southeast into Ecuador, Peru and Brazil. The Amazonic Llanos are bounded by the Eastern Cordillera and by the Salient.

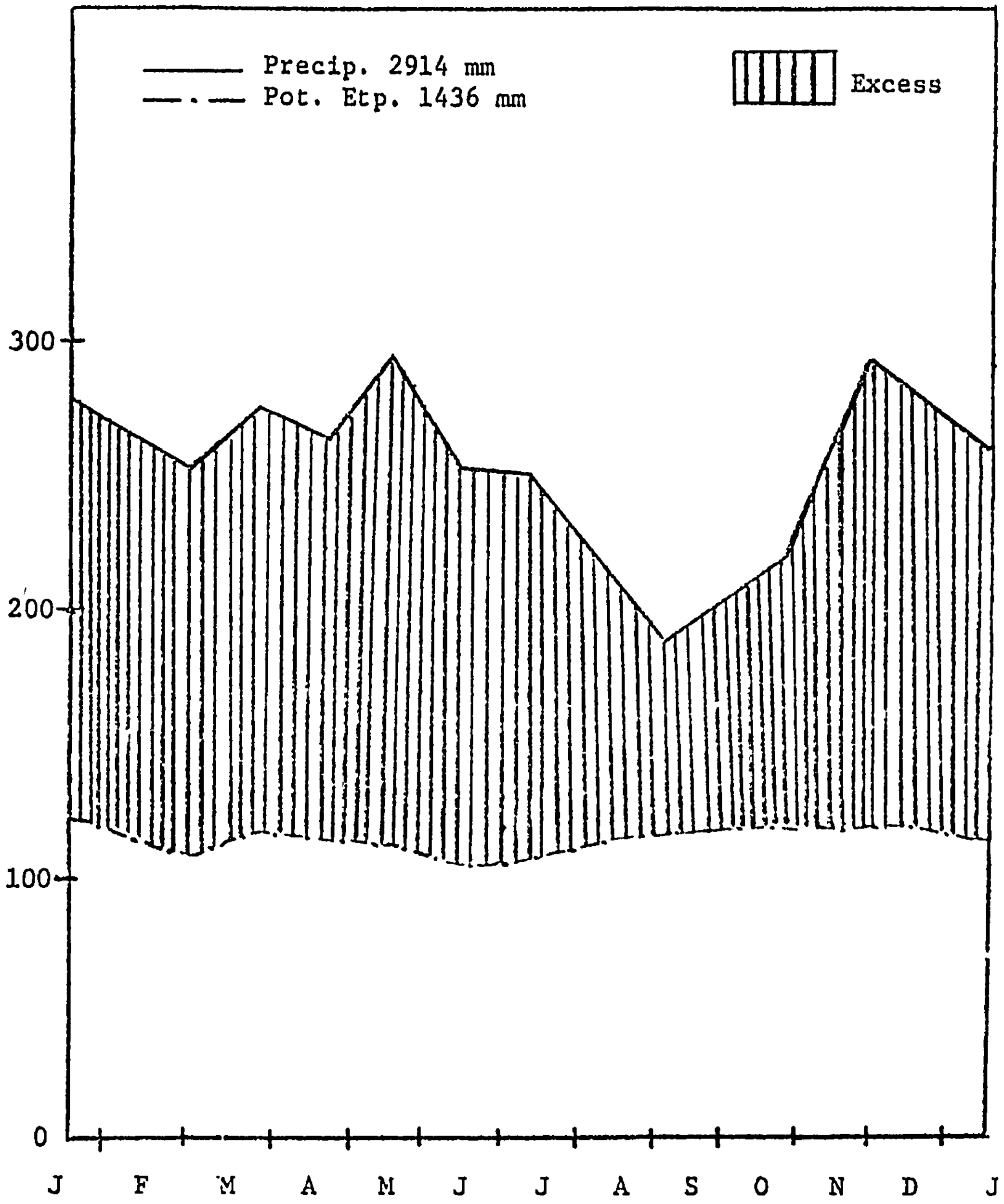

Figure 2. Rainfall-evapotranspiration balance for S. Gabriel da Cachoeira (Source: Bastos, 1972)

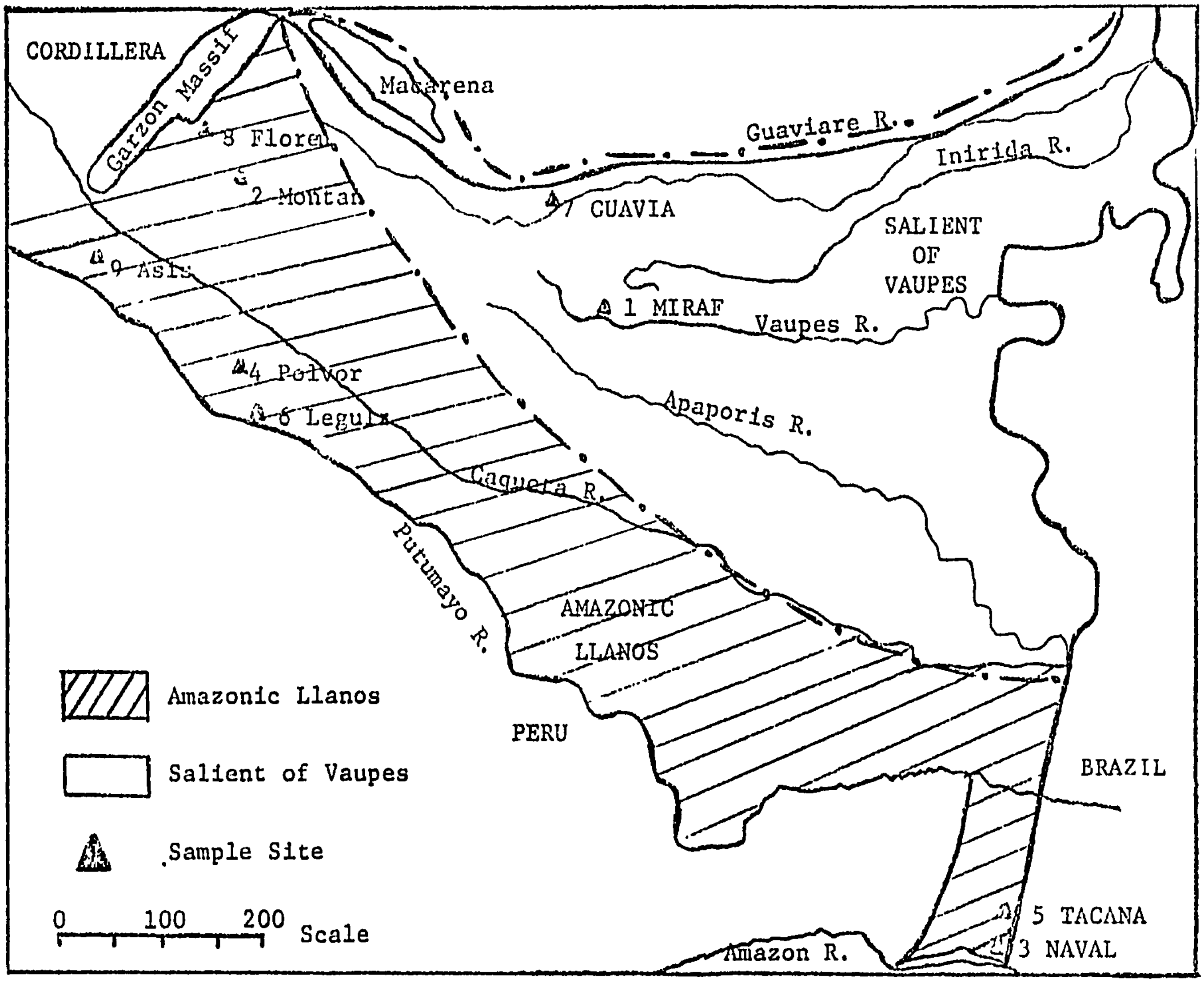

Figure 3. General geological provinces of Amazonia and location of the sample sites

The Salient of Vaupes unit is formed by precambrian rocks of the Guayana series as well as Paleozoic, Cretaceous and Cenozoic sediments.

At about 500 m elevation the eastern slopes of the Eastern Cordillera break and meet with the Amazonic Llanos. The Cordillera has had an important influence in the development of Amazonia, as a source of sediments, so the geology of the Eastern Cordillera deserves some attention.

Geology of the Eastern Cordillera

The Eastern Cordillera is an independent range of the Andean system, and is formed (a) by sedimentary rocks overlying a basement of Precambrian and Paleozoic igneous and metamorphic rocks and (b) by the Garzon massif, which is a simple horst outcrop considered to be the most westerly manifestation of the Guayana Shield (Hubach, 1954; Olsson, 1956; Campbell and Burgl, 1965; Julivert, 1970).

Starting from the summit of the interfluve (4000 m elevation) down to the Amazonia (500 m elevation), the following rock types are found (Radelli, 1962; Servicio Geologico Nacional, 1962; Cucalon and Camacho, 1966; Gutierrez, 1967):

(1) Migmatites formed by granitic rocks, gneisses and micaceous and sericitic schists. The minerals of these rocks are quartz, feldspars and micas. Their relative abundance varies from place to place.

(2) Anatexic granites, formed by partial fusion of metamorphic rocks, consisting mostly of light-colored (less than 30% dark minerals) and persilicic rocks (containing more than 60% SiO_2) with a faint schistose structure and mineralogical

composition of quartz, feldspars, some micas and amphibols. The anatexic granites are frequently intruded by gabbroic and dioritic rocks containing andesine-labradorite, green hornblende and some pyroxene.

(3) Cretaceous sedimentary rocks formed by friable quartz sandstones (Caballos formation), gray to black calcareous and non-calcareous shales (Villeta formation) and massive medium to coarse sandstones (Guadalupe formation). The Cretaceous rocks are distributed as narrow stripes east and south of the Garzon massif.

(4) Several Tertiary formations are present in the slopes of the Eastern Cordillera and some of them extend into the Amazonic Llanos. The Rumiyaco formation (Paleocene continental sediments) consists of red, brown and pink kaolinitic clays interstratified with sandstones. The Pepino formation (Eocene) is formed by red clays and gray sandstones over a conglomeratic stratum. The San Miguel formation (Pliocene) consists of red clays and fine to coarse sandstones.

The rocks of the Cordillera, and some of the Amazonic Llanos, contain some volcanic material, mainly ash, originated by the eruptions of the Galeras, Dona Juana, Patascoy and other nearby volcanoes existing along the Central Cordillera.

Geology of the Amazonic Llanos

The geology of the Amazonic Llanos is almost unknown. The fragmentary information available (Habach, 1954; Olsson, 1958; Campbell and Burgl, 1965; Cucalon and Camacho, 1966; Oliveira, 1956; Morales, 1959;

Harrington, 1962; Gibbs, 1967; Howard, 1965) indicates that Cretaceous and Tertiary sedimentary strata lie directly on the gneissic and crystalline basement of the Guayana Shield. The sedimentary beds become thicker westward, toward to Eastern Cordillera.

The Tertiary sediments are by far the most extensive. They were deposited under marine, brackish-fresh water and continental conditions. They are unconsolidated or weakly consolidated, vary in color, texture, and are mineralogically dominated by kaolin and quartz. Pleistocene terraces and Holocene deposits are also present and are relatively more extensive near the foothills.

Cucalon and Camacho (1966) identified and described several formations in the western Amazonic Llanos between the Putumayo and Caqueta Rivers. The Orito beds, deposited during Oligocene, in a brackish to fresh water environment, consist of clays, sandy clays, sandstones and are found mainly in the Caqueta platform. The Ospina formation deposited under a continental environment during the Miocene-Pliocene is composed of red to gray clays, sandy clays and sandstones and extend mainly north of the Putumayo River. The Pleistocene terraces are found along the Putumayo and Caqueta Rivers and some of them have a thickness from 30 to 150 m. Terraces consist mainly of sandy to sandy clay matrix with igneous, metamorphic fragments. The Holocene or recent alluvium occurs as belts along the rivers, and in marshes, swamps, and oxbow lakes.

Hubach (1954) has pointed out that the upland sediments of the Putumayo basin are probably younger than Pliocene and he assigned a Pleistocene age. Sarmiento (1952) described a thick bed of a yellowish red clay and assigned a Tertiary to Pleistocene age.

In the Leticia area among the Amazon, Putumayo and Javari Rivers, Oliveira (1958) has identified the Pebas (Oligocene-Miocene?) and Barreiras (Miocene-Pliocene) formations. Hubach (1954) also indicated the presence of Pebas beds in Leticia. Some soil studies have indicated that the Barreiras clay constitutes the parent material of many soils of the upper Amazon basin.

Geology of the Salient of Vaupes

All the available information of this unit is provided by Hubach (1954) and by Servicio Geologico Nacional (1962). The Salient has a shield shape, slightly arcuated and flexured that descends axially from the nucleus to the Macarena Sierra. It has a relative slope toward the Llanos Orientales and is practically without gradient toward the Amazonic Llanos.

Above the basement Palezoic to Terciary rocks are found, including the Vaupes sandstones, which are equivalent to the Roraima formation (Venezuela and Guyana). Cretaceous rocks, probably sandstones, outcrop in several locations. However, the most extensive rocks of the Salient are Tertiary sediments ranging in age from Oligocene to Pliocene. Hubach (1954) has indicated the existence of some Pleistocene eolian red sands deposits in the western part of the Salient.

Outcrops of the basement rocks are found in several locations (Caqueta-Yari confluence, Macarena, Puerto Arturo). Some of these rocks have been dated indicating ages of 1,200 and 445 million years (Pinson *et al.*, 1962; Hurley, 1960).

Historical Geology

The Guayana Shield is the remnant of a very ancient (Brazilian continent and has remained emerged since the mid Precambrian. It has been the source of sediments that later built the Eastern Cordillera and the lower strata of the Amazon basin.

During late Precambrian the Amazon basin was the site of a geosyncline of east-west direction. The region was down warped in Cambrian times and the geosynclinal trough was replaced by a large basin that had existed since that time and was and is actually the Amazon basin. It has undergone a long sedimentary-erosional history; was repeatedly invaded by the sea during Cambrian, Silurian, Devonian and Pennsylvanian times and was the site of continental deposition during Cretaceous and Late Tertiary (Harrington, 1962).

Orogenic movements during Triassic led to the uplift of the Central Cordillera and to the formation of the East Andean basin (present Eastern Cordillera). Continental sediments, coming from the Guayana Shield and the Central Condillera were deposited. During Cretaceous times a marine flooding was felt in the East Andean basin (Garzon massif and Macarena were surrounded by the sea). A thick series of sandstones, limestones and shales were deposited (Caballos, Villeta, Guadalupe formations). The Guayana Shield was the main source of sediments. The cyclic nature of the sedimentation indicates periodic uplift and erosion of the Guayana Shield (Campbell and Burgl, 1965).

During the Late Maestrichtian times a marked regression took place that led to a non-marine environment in which important parts of the sediments were deposited. By the Early Tertiary the Amazon basin became a plain draining into the Pacific Ocean via a river system flowing to the west and discharging in the Gulf of Guayaquil (Olsson, 1956). During Oligocene and Miocene the Andean Cordillera (Western and Central) start uplifting and probably during the Middle Miocene (20 million years ago) the outlet of the proto-Amazon River was closed and the dammed water formed an inmense lake. As the Cordillera continued rising, the waters of the lake forced a drainage toward the Atlantic Ocean and the river cut its bed throughout a lower part of the Guayano-Brazilian Shield (Oliveira, 1956).

Extensive continental deposits were accumulated during Miocene (Pebas formation) and during the Pliocene the beds were deposited in a lake environment (Barreiras formation). At the end of the Pliocene and during the upthrow of the Andes and Eastern Cordillera, the Belterra clay was laid down on the top of the Barreiras formation, according to Sombroek (1966). The existence of Belterra clay has not been properly established in Colombia.

The uplift of the Eastern Cordillera during the Pleistocene was strong, which implied the start of an intense erosion-sedimentation period. Consequently, some authorities think that large portions of Amazonia were blanketed with the Pleistocene sediments (Hubach, 1954; Sombroek, 1966).

Physiography and Relief

Amazonia is a plain lying at altitudes of 500 m near the mountains and 100 m along the Brazilian border. The Salient of Vaupes is slightly elevated with respect to Amazonic Llanos.

In the western margin, the Tertiary sediments have been gently folded and faulted; the relief there is rolling to hilly at the foothills and becomes more level toward the east. In the foothills, colluvio-alluvial deposits and some alluvial fans are found.

The relief and general slope of Amazonic Llanos are gentle with the exception of the bluffs along the major rivers. The height of these banks vary between 10 and 25 m and in many cases are present only on one side of the valley (asymmetrical valleys), as in Leguizama and Leticia, where a high bluff is only on the left margin of the rivers.

In the Salient of Vaupes the monotony of the low relief is interrupted by relatively high, elongated "sierras," "cuestas," "mesas," which in general have a gentle slope toward the west with high shear cliffs and fault scarps toward the east (Hubach, 1954). Some of the mesas have considerable local relief, reaching 850 m above the general level. These features are formed by the outcrops of the resistant Vaupes and Cretaceous sandstones.

In the plains of the Amazonic Llanos and the Salient, three main physiographic features are distinguished, uplands (tierra firme), terraces and active alluvial plains (Cucalon and Camacho, 1966).

The uplands may be considered as a great plain thoroughly dissected by a series of branching valleys, creeks, small canyons (canos) forming a dendritic pattern and giving to the general area a slightly undulating to rolling topography. The slopes are complex with gradients ranging from 3 to 12%. The drainage density and texture determine the topography of the divides or interfluves. In a dense dendritic pattern the uplands have a "short wave" undulating topography. In other situations the streams, canyons or valleys are relatively separated and the interfluves are slightly sloping with convex edges running to the streams.

Uplands are well drained, however, close to the depressions they become imperfectly to poorly drained.

The terraces are more frequent in the western Amazonia, where they may have 3 to 4 Km width. The relief of the terraces is flat to gently sloping and undulating to rolling in places where dissection has occurred.

The active flood plains occupy a small portion of the Amazonia. They occur along the rivers, as well as small streams. The sedimentation processes have formed several geomorphic features including natural levees, point bars, scrolls, oxbow lakes (Cochas), and backswamps in which water stands for long periods.

Different "groundsurfaces" or "geomorphic surfaces" formed by paleoclimatic oscillation may exist but nothing is actually known. During the glacial and interglacial periods changes in the climate and vegetation of the lowlands took place (Hammen, 1961). During the glacial times temperatures were at least 8-10°C lower than today in Guyana and in the Caribbean (Hammen, 1961; Emiliani, 1971).

Garner (1968) cited several reports which indicate past climatic changes in and adjacent to the Amazon basin. Bigarella and Andrade (1965) have related four geomorphic surfaces of northeastern Brazil, with four major climatic changes during the Pleistocene. Sombroek (1966) pointed out that the interglacials and interpluvials coincided in the Amazonia, but Hammen (1961) and others (cited by Emiliani, 1971) have established that the cold periods were dry periods.

Sombroek (1966) thinks that during parts of Tertiary and Pleistocene the forest was restricted to small areas, mainly in foothills, and expanded only during Late and Post-Pleistocene times.

The implications of the climatic and vegetation changes and the eustatic fluctuations of the sea level on the geomorphology and soils deserves special study because it may be helpful in the understanding of soil-landscape relationships and may facilitate the soil survey.

Vegetation

More than 95% of the Colombian Amazonia is covered by evergreen tropical forest. There are some areas with savanna and "catinga" vegetation.

Foresters and ecologists (Budosky, 1966) distinguish two types of forest vegetation, the upland and the flood plain forest.

The upland forest is characterized by a great number of tree species and reduced number of palms. Inventories done in Caqueta and Leticia (Espinal and Montenegro, 1963) indicate that the more frequent families found in the upland forest are Mimosaceae, Caesalpinaceae Bignoniaceae, Bombaceae, Rubiaceae and Poligonaceae.

In the flood plain forest there is a reduction in the number of families and species and an increase in palms. Trees adapted to periodic flooding and poorly drained soils are usually low crown trees and mark even the narrowest valleys (Howard, 1965).

The amount of timber (wood) produced by the Amazonian tropical forest is relatively low, in spite of the large amount of trees. A forest inventory done on a 10,000 Km^2 area near Leticia, for example, gave the following average values of wood in cubic meters per hectare (Planeacion Nacional, 1971):

	Upland forest	Flood plain forest
Species of commercial value	41 m^3	36 m^3
Species of potential value	96 m^3	91 m^3
Species of unknown value	34 m^3	35 m^3

In the area embraced by Caqueta and Yari Rivers (Salient of Vaupes), there are extensive, slightly undulating lands covered by savannas (Diaz Galindo, 1938). The existence of savannas in the forest ecological environment is probably due to the effect of the sandy nature of the soils as well as to the low fertility (Ramirez, 1958).

Schultes (1951, 1958) and Ferri (1959) have described the "catinga" vegetation of the Inirida and Negro Rivers. It is a meager forest of low trees and shrubs. This zeromorphic formation, under tropical rain forest conditions, is attributed to the effect of sandy soils or it may be the relic of a past vegetation that existed under different climatic conditions (Ferri, 1959).

Land Use

The few thousand natives get food from hunting, fishing and cropping of manioc, corn, rice, and platain.

Settlement began with the penetration of "conquistadores," missionairs, quinine and rubber collectors.

The "piedmont" belt stretching along the foothills is an active pioneer front, in which some towns have been established (Florencia, Puerto Asis, Belen, San Vicente). Actually, there are spontaneous settlers as well as state colonization directed by the Land Reform Institute.

The main crops grown in the colonization lands are corn, rice, manioc, platain, cacao, sugar cane and oil palm. Rubber plantations have been recently established. An important part of the cleared lands is being devoted to raising and fattening of livestock. Beyond the colonization front is the tropical forest with no economic agriculture. A few forestry products including rubber, timber, leathers, and animals are being exploited.

REVIEW OF LITERATURE

The existing information about the soils of Colombian Amaz extremely meager. After an extensive search, only two works were found. Information contained in several papers dealing with the Amazon soils of Ecuador, Peru, Bolivia and Brazil will also be presented.

Studies in Colombia

Ramirez (1958) made an exploratory study of an area located near the confluence of the Caqueta and Yari Rivers. Soils there have a variable texture from sandy to clayey. The soil profiles are characterized by a weak brown A1 horizon and a blocky or massive, yellow, reddish yellow or yellowish red B horizon. In all the profiles described, Ramirez found a clay increase with depth, but clay skins were not reported. The cation exchange capacity (CEC) by NH_4OAc, pH 7, varied between 10 and 15 meq/100 g in the B horizon. These values according to Ramirez are higher than expected for kaolinitic soils and he indicated that the high CEC may be due to the presence of vermiculite clay. The sandy profiles were classified as regosols and the loamy and clayey soils as "Yellow Lixivium," following the definition given by Miller and Coleman (1952).

Guerrero (1965) studied the descriptions and the analysis published by Ramirez (1958) and suggested that the soils could be classified as Psamments, Aqualfs, Aquults, Udox and Aquox. However, the apparent CEC of the clay in the "oxic" horizon of the proposed Udox and Aquox soils seems to be higher than 16 meq/100 g of clay and consequently must be excluded from the Oxisol order.

Blasco (1968) described 61 profiles in the Leticia-Tarapaca area, including upland and flood plain soils. He found that the upland soils had a brown to light brown A horizon and a yellow, reddish yellow and sometimes white B horizon. In general, clay content increases with depth, following the same trend indicated by Ramirez for the soils of Caqueta. The CEC of the B horizon varied between 9 and 16 meq/100 g and the apparent CEC of the clay varied between 22 and 45 meq/100 g, suggesting the presence of 2:1 clay minerals. Blasco classified the soils of Leticia as "Braunlehms" and "Podzolized Braunlehms," according to Kubiena's classification (1952).

Studies in Other Countries

The first studies of the Amazon soils were done by Marbut and Manifold (1926). They traveled for a year studying the nature and conditions of the soils in rubber-producing areas. They described the well drained upland soils as "mature" soils, deeply weathered with a relatively light-textured, brown to pale brown A1 horizon; a heavy textured, yellow, reddish yellow, yellowish red or red B horizon and an underlying horizon (deeper than 1.20 m) regarded as "parent geological material," with textures coarser or finer than the B horizon and variegated colors of gray with red and yellow spots and streaks. They indicated that the yellow and red blotches consisted of clay and concentrations of iron oxide which indurate where exposed at the surface.

Thorp and Baldwin (1940) point out that Marbut was the first, in the Western Hemisphere at least, to recognize that the "laterite" (plinthite) formation described as "parent geological material," owes its characteristics to the process of ground water podzolization, and he coined the name "Ground Water Laterite."

Another interesting observation made by Marbut and Manifold (1926) is that the morphological characteristics of many Amazonian soils and of the Piedmont soils of North Carolina are very similar and they concluded that the processes of soil development must be similar in the Amazon region and in North Carolina and Georgia.

Regarding the potential value of the Amazon soils, Marbut and Manifold (1926) pointed out that soils are unusually friable in spite of the high clay content, and have good physical proeprties. The topography is favorable for intensive agriculture, the fertility level is low and the soils require fertilization. They also noted that the chemical characteristics are comparable to those of many soils of southeastern United States.

In 1945, Hardy published a paper and a small scale map of the soils of South America. Hardy thought that, according to the genetic theory, in the Amazon basin "lateritic soils" must be expected; he over-emphasized the role of the "low relief" as a factor in the soil genesis and consequently classified and mapped the Amazon soils as a uniform formation of Ground Water Laterite.

Miller and Coleman (1952) studied the morphology and the mineralogy of some soils of Peru and Ecuador. They established soil groups based on color and temperature of the subsoil and darkness of the A1 horizon. In the Amazonian Llanos, two soil groups were established, Gray-Brown in the foothills and "Red-Yellow Lixivium" in the Amazonic Llanos. The clay minerals found in the Lixivium group were predominantly kaolinite and mica with minor amounts of 14 Å minerals. In spite of the acidity of the Lixivium soils, the CEC and the base saturation were high, indicating "intrazonal influences."

Storie (1953) made a preliminary study of the Bolivian soils. In the Amazonian region (Madeira, Beni, Mamore, Guapore Rivers), he described some dark soils underlain by a "lateritic hardpan" and some reddish brown lateritic soils, both of which were considered of low agricultural potential.

The Amazon forest ("selva") constitutes more than 60% of Peru. The Peruvian government has been trying to incorporate the selva into agriculture and livestock production. As a consequence, Peruvian soil scientists have been working in mapping, classification and management of the selva soils for a rather long time. The works of Platenius (1947), Drosdoff _et al._ (1960), Zavaleta and Arca (1963), Muro (1966), Zamora (1966, 1967, 1968), Estrada (1971), Sanchez and Buol (1971) give general information about the occurrence and characteristics of the localized areas.

Drosdoff _et al._ (1960) describe the Amazonian soils as deep highly weathered "latosols," well to poorly drained, with low natural fertility.

Zavaleta and Arca (1963) established several soil groups in the Amazon region. Humic Latosols were described in the "upper selva" and Brown Latosols, with prominent B2 horizon in Tingo Maria. Silicic Latosols were widely distributed in the Amazonia and consisted of highly leached, extremely acid, kaolinitic, with low CEC, red or yellow profiles having blocky structure in the B horizon. According to authors, the Silicic Latosols have a very low potential for agriculture and they recommended that they be kept in original forest or used in tree plantations (rubber, cacao).

Muro, who has been working in the Amazonia for many years, indicates (1966) that the soils are variable according to the parent material,

drainage, relief, vegetation and age. He classifie 'lood-
and extensive soil groups as Brown, Red, and Reddi ick
Red-Yellow Podzolic, Tropical Podzols, and Ground
estimates that more than 70% of Amazonia is covered
Podzolic soils and Latosols and 20% by Ground Water Laterite and Hum
Gley soils. From his extensive research in management and fertility he has concluded that the Red-Yellow Podzolic soils and the Latosols have good physical conditions for intensive agriculture. They have low natural fertility, high acidity and high P fixation capacity; however, they are very responsive to moderate liming, fertilization and green manure application, so an intensive agriculture is agronomically possible. Muro (1966) has observed that the continuous use of machinery for preparation and cultivation produced a decrease in yield of annual crops. The detrimental effect of the compaction was overcome by the application of green manures.

Zamora (1966, 1967) classified the soils of the Peruvian Amazonia as Red Ferralsols, Red Yellow Ferralsols, Yellow Ferralsols and Red-Yellow Podzolic, indicating that the latter group has been ignored for a long time and classified simply as a Ferralsol. Now, the Red-Yellow Podzolic soil has been divided into eutrophic and dystrophic phases according to its base status. A base saturation of more than 50% has been tentatively established as the criterion for separation of eutrophic subgroups.

The existence of Podzols in Pucallpa, Iquitos, and Yurimaquas has been reported in sandy and loamy sand materials (Zamora, 1968). The soils are characterized by a prominent, gray A2 horizon over a dark gray or yellowish red Bh horizon. Klinge (1965) also found Podzols on flood-deposited sandy materials, near Manaus (Brazil). They consist of a thick A2 horizon underlain by thin lamellae of Bh horizon. The associated soils in the uplands are Braunlehm (Kubiena, 1952) developed from materials of the Barreira formation.

Sanchez and Buol (1971) studied some soil profiles along the Yurimaguas-Tarapoto road in Peru. The well drained Yuramaguas and Shanusi series are red, deep, sandy loam to sandy clay loam A horizon underlain by an argillic horizon. Kaolinite is the dominant mineral in the clay fraction, with montmorillonite present in some profiles. Due to the presence of a very thick argillic horizon and a low degree of base saturation, the Yurimaguas and Shanusi soils are classified as Typic Paleudults. The Pucallpa series is a poorly drained soil with gley, mottled argillic B horizon or cambic B horizon. Montmorillonite was prevalent and even predominant in the clay fraction of some profiles. Three profiles of Pucallpa soil were classified as Tropaqualf, Paleudalf and Tropaquept.

Sanchez and Buol (1971) point out that the described soils are probably representative of large areas in the Upper Amazon basin and conclude that they have a low level of fertility, but not extremely low as it is usually believed, and do not require excessive applications of lime and fertilizers.

Estrada (1971) studied the mineralogical and chemical properties of several profiles representative of the Yurimaguas-Tarapoto area and classified them as follows:

Aeropuerto series	Trophumod
Tarapoto Amarillo	Hapludult
Shanusi	Hapludult
Yurimaguas	Rhodudult
Pucallpa series	Plintudult

The mineral composition of the sand and silt fractions in these soils is dominated by quartz, with some kaolinite and traces of micas. In the clay fraction of Aeropuerto and Tarapoto soils, kaolinite is predominant, with only traces of 2:1 minerals. In the clay of the Shanusi and Yurimaguas soils, kaolinite and 2:1 minerals are present in equal amounts. In the Pucallpa soil, 2:1 minerals are predominant and include mica, vermiculite, montmorillonite and hydroxy-Al-interlayered minerals. Estrada indicates that the content of amorphous materials in the clay fraction is high (SiO_2 = 12-25% and Al_2O_3 = 5-10%) and the free iron oxide associated with the clay is relatively low (5-8%). The pH dependent CEC is high and related to the amount of organic matter and 2:1-2:2 clay minerals. Due to high content of exchangeable Al, toxic effects are predicted. The P adsorption maxima is low in the Spodosol and high in the Ultisols. From his investigation Estrada concludes that the agricultural suitability of these Amazonian soils is limited by the amount of active Al and the extremely low levels of available P.

Brazilian soil scientists, more than any other group in South America, have contributed to the knowledge and the development of a classification system of the tropical soils.

The concept of Latosol in the Brazilian classification is linked to the concept of latosolic B horizon, which has been worked out through several approximations (Bennema _et al._, 1959; Lemos _et al._, 1960; Bennema, 1963, 1966; Beek and Bramao, 1969).

The two main diagnostic horizons of the Brazilian classification; i.e., latosolic B horizon and textural B horizon are more or less equivalent to the oxic and argillic horizons of the new U.S.A. Soil Taxonomy (Soil Survey Staff, 1970). An abbreviated definition of the latosolic B horizon extracted from Bennema (1966) is as follows:

The latosolic B horizon is a subsurface horizon of medium or clay texture (more than 15% clay) consisting of thoroughly weathered soil material; the clay fraction has a very low mobility; the cation exchange capacity is less than 13 meq/100 g clay, measured by the NH_4OAc method (after correcting for organic matter assuming a CEC for organic matter of 450 meq/100 g carbon) and less than 22 meq/100 g by the sum of extractable cations; i.e., the sum of Ca, Mg, K, Na extracted by 1 N pH 7 NH_4OAc and extractable acidity by $BaCl_2$-TEA pH 8.1. The latosolic B horizon can never include a textural B horizon. Distinct clay skins on peds and channels or bridges between sand grains are absent or nearly absent. The soil material consists of sesquioxides, kaolinite, quartz and other minerals highly resistant to weathering and only traces of micas and other 2:1 lattice clays. Gibbsite may be absent or predominant. The water-dispersible clay content is less than 2%. The typical structure is very fine granular with coherent granules that form a structureless and often very porous soil mass. Atypical structures may include weak to moderate blocky structure and a tendency toward a prismatic structure in the upper part of the horizon. Consistency, when moist, is very friable.

All the soils with latosolic B horizon are classified as Latosols. The general soils map of Brazil (Conselho de Geografia, 1960) shows the soils between Amazon and Caqueta Rivers (in the Colombian Brazilian border) as Red-Yellow Latosols, terrace phase (fase terraco), clayey texture, developed from Barreiras clay, with inclusions of Ground Water Laterite, Concretionary Red-Yellow Latosol and Red-Yellow Podzolic soils. The main characteristics of the Amazonian Red-Yellow Latosols (Beek and Bennema, 1966; Bennema, 1966) are moderate to weakly developed A horizons over a yellow to yellowish latosolic B horizon with medium to high iron content. The CEC of clay is below 6.5 meq/100 g clay.

Falesi (1972), in a recent paper about the actual knowledge of the Brazilian Amazonia, reports the existence of some exploratory and reconnaissance soil surveys in Benjamin Constant and Tefe, close to the Colombian border. From those reports Falesi indicates that the Yellow Latosol (with hues 10 YR and 7.5 YR, high chromas and values) are extensively distributed, in associations with Red Latosols (5 YR) and Red-Yellow Podzolic soils.

From the available information, Falesi (1972) concludes that the Amazonian Latosols have good physical conditions, permitting deep root penetration, low fertility but a high capacity for response to fertilizer application. Spectacular increases in yields have been obtained in oil palm, cacao, citrus and pepper.

Sombroek (1966) published a book on the Amazonian soils. Most of his observations come from reconnaissance surveys done in the Lower Amazon basin. He developed a classification blending concepts and definitions of the U.S.D.A. (1938, 1949) and the Brazilian systems.

The classification scheme consists of three categorical levels--great groups, subgroups, and phases.

The phases found in the Colombian Brazilian border are:

Kaolinitic Yellow Latosols of varying texture
Kaolinitic Yellow Latosols of very heavy texture
Red-Yellow Podzolic
Kaolinitic Latosolic sands

The Kaolinitic Yellow Latosols are strongly weathered, well drained soils. The profile has an ABC sequence, but the boundaries are diffuse or gradual. The B horizons meet the requirements of the Latosolic B horizon as defined by Bennema (1966), but with weak to moderate macro-structure.

The Red-Yellow Podzolic group is described as having a textural B horizon, heavy texture, blocky and prismatic structure with clay skins. The color is red or yellow in the upper part and redder in the lower part.

Regarding the agricultural capability of the Kaolinitic Latosols, Sombroek thinks that for agricultural development of the area fertilizers and organic matter must be applied. He feels that application of organic matter is of paramount importance to maintain an adequate CEC and to supply nitrogen and phosphorus to the plants. Sombroek strongly recommends the planting of perennial crops like rubber, cacao, and oil palm.

Recently several soil maps of South America have been published. A small scale map prepared by Beek and Bramao (1969) indicates the existence of Red-Yellow Podzolic soils in the foothills and Yellow Kaolinitic Latosols associated with Ground Water Laterite in the central part of the Colombian Amazonia.

The Soil Map of South America (scale 1:5.000.000) prepared and published by FAO-UNESCO (1971) maps the Colombian Amazonia in following soil units, with the approximate equivalent to the U. S. Soil Taxonomy:

Eutric Nitosols (Paleudults) in the foothills of Putumayo
Orthic Ferralsols (Acrorthox?) in Florencia-Montanita
Xanthic Ferralsols (Haplorthox) in the rest of the area
Dystric Gleysols (Aquepts, Aquents) along the Putumayo River

A small scale map adopted from maps prepared by the U. S. Soil Conservation Service was published by Aubert and Tavernier (1972) in which the Upper Amazon soils appear are included in two associations--Tropepts-Tropudults in the northwestern portion, near the foothills, and Orthox-Tropudults for the rest of Amazonia.

MATERIALS AND METHODS

Sampling Sites

Since little information was available concerning the soils in the Colombian portion of the Amazon basin, about 20 sites were preliminary selected to cover the foothills, Amazonic Llanos and Salient of Vaupes. Unfortunately it was not possible to visit all the selected sites due to difficulties in schedules and flying conditions. Nine profiles, representative of the "available population" (Griffith, 1968) of the upland, well drained to moderately well drained soils were described and sampled. In most of the cases the profiles were described in road cuts or existing pits. Samples were taken from freshly exposed profiles.

Information about location, drainage conditions and parent materials are briefly presented as follows:

	Soil	General location	Drainage	Parent material
1.	Miraf	Miraflores	Well drained	?Oligocene-Miocene sediments
2.	Montan	Montanita	Well drained	Oligocene sediments
3.	Naval	Leticia	Moderately well drained	?Pleistocene sediments
4.	Polvor	Leguizamo	Moderately well drained	?Pleistocene sediments
5.	Tacana	Leticia	Well drained	?Pleistocene sediments
6.	Leguiz	Leguizamo	Well drained	?Post-Pleistocene sediments
7.	Guavia	S. Jose Guaviare	Well drained	Mixed sediments
8.	Floren	Florencia	Well drained	Mixed materials
9.	Asis	Puerto Asis	Well drained	Mixed sediments

Figure 3 indicates the approximate location of the sites. The profile descriptions (Appendix A) were prepared using the Soil Survey

Manual (1951) terminology. It is important to note that some thick horizons were subdivided for sampling at intervals of 20 or 50 cm.

Sample Preparation

After air drying the samples were crushed with a wooden roller to pass a 2-mm mesh sieve. One portion of the samples was kept in the Soil Survey Laboratory, Instituto Geografico Bogota for further analysis and the remainder was sent to the Soils Department, North Carolina State University at Raleigh for other analysis.

Physical Methods

Particle Size Distribution

Particle size distribution was done by the pipette method as described by Kilmer and Alexander (1949). Soils were treated with H_2O_2 to destroy organic matter and dispersed with $NaPO_3$ (calgon 10%) in a malted milk stirrer. The sand was separated with a 300-mesh sieve, oven dried and fractionated by further sieving. Silt and clay were determined by pipetting 25 ml of suspension at appropriate times and depths and gravimetrically determining the amount of solids after drying at 105°C.

The clay fraction was also determined by the method of Vettori (1969) using 0.1 N NaOH as the dispersing agent. The clay was determined by the hydrometer method after separation of the sand fraction.

Water-Dispersible Clay

Samples of all horizons were shaken for 5 min with distilled water in a milk shaker and the percentage of clay determined by the pipette method, as proposed by Vettori (1969).

Water Retention at 15 Bars

Water-saturated samples were equilibrated at 15 bars tension in a pressure membrane apparatus. Water retained was calculated on an oven-dry basis (Richards, 1954). The clay content was estimated multiplying the 15-bar water percentage by 2.5 according to the Soil Survey Staff (1970).

Mineralogical Methods

Sample Preparation

Removal of organic matter and free iron oxide and fractionation of particles according to size was done by the Kittrick and Hope procedure (1963). Decantates of Na dithionite-citrate were collected for free iron oxide determination. By combination of centrifugation, decantation and sieving the clay, silt and sand fractions were separated for further mineralogical analysis.

Mineralogy of the Sand Fraction

Examinations with a petrographic microscope were conducted on the deferrated very fine sand fraction. A simple mounting was done using oil with a refractive index of 1.54. Grain identification and counting was done by the line method, counting individual grains encountered by the intersection of the cross hairs, along linear traverses spaced at equal distances along the slide (Galeshouse, 1971).

Mineralogy of Silt and Clay Fractions

X-ray Diffraction. Oriented slides were prepared by evaporating aliquots of suspension containing about 50 mg of clay or fine silt on a 75 x 25 mm glass slide. The coarse silts (20-50 μ) were mounted as dry powder using a double-coated transparent tape.

Diffraction patterns were obtained for the following standard treatments, according to Jackson (1956): Mg-saturation, Mg-saturation and glycerol solvation; K-saturated at room temperature, 350°C and 550°C. A General Electric XRD-5 X-ray diffractometer was used with Cu-Kα radiation ($\lambda = 1.5418$ Å), a nickel filter and a scanning rate of 2° 2θ per minute.

Differential Thermal Analysis (DTA). For DTA analysis, 20-mg sample of deferrated Mg-saturated clay, equilibrated in a desiccator with a slurry of $Mg(NO_3)_2$, was packed in small platinum capsule and heated at a rate of 20°C per minute in an air atmosphere, using a Dupont 200 differential thermal analyzer with Pt vs Pt-Rh thermocouples.

Estimation of Kaolinite and Gibbsite. Calibration curves for the estimation of gibbsite and kaolinite contents were obtained by mixing different proportions of standard kaolinite and gibbsite and running DTA analysis under the same conditions as used for the sample analysis. The percentages of gibbsite and kaolinite in soil clay were calculated by comparing the surface area under the sample peaks with the surface area of the standard peaks (Dixon, 1966).

Estimation of Mica. The content of mica in the clay fraction was estimated from the K_2O content. Clays were decomposed with HF + $HClO_4$ in platinum crucibles and K determined by flame photometry, as outlined by Jackson (1958). The percentage of mica in the clay was estimated assuming that 1% K_2O is equivalent to 10% mica (Jackson, 1956).

Estimation of Quartz. The content of quartz in the clay fraction was estimated by comparing X-ray diffraction peak heights of the sample with the peak heights of standards prepared by mixing different proportions of quartz (novaculite < 2 μ) and kaolinite according to the suggestion of Dr. S. B. Weed.[1]

Amorphous Alumino Silicates. The amorphous materials in the deferrated clays were determined by the selective dissolution analysis of boiling the sample in 0.5 N NaOH (Hashimoto and Jackson, 1960; Alexiades and Jackson, 1966). The dissolved Si was determined as molybdosilicate and the dissolved Al was determined colorimetrically with aluminon (Jackson, 1965a).

The Al_2O_3 contained in gibbsite, as determined by DTA, was subtracted from the dissolved Al_2O_3 content. The remainder of the dissolved alumina was added to the amorphous silica and a 21% weight of water was added to obtain the percentage of amorphous materials (Jackson, 1965; Moniz and Jackson, 1967).

Total SiO_2 and Al_2O_3 in Clays. One-hundred milligrams of clay were fused with Na_2CO_3 in a platinum crucible. Aluminum was determined by the aluminon method. Silicon was determined by the molybdosilicate method (Jackson, 1958).

Free Iron Oxide. Free iron oxide extracted from soils and clays by the dithionite-citrate-bicarbonate method (Kittrick and Hope, 1963) was determined by an orthrophenanthroline method (Jackson, 1965a).

CEC of the Clay. Cation exchange capacity of the deferrated clay was determined by a procedure outlined by Dr. M. G. Cook.[2] Clays were saturated with Mg by treating with $Mg(OAc)_2$, $MgCl_2$ and washing with

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[1] Weed, S. B., Professor of Soil Science, North Carolina State University at Raleigh

[2] Cook, M. G., Professor of Soil Science, North Carolina State University at Raleigh; cation exchange capacity of clays--Soil Mineralogy course

ethanol and acetone. One-hundred-milligram samples of the Mg-saturated clays were shaken with 1 N NH_4OAc pH 7 in a centrifuge tube, centrifuged and the supernatant collected. Magnesium extraction was repeated three more times. Magnesium was determined with EDTA.

To the NH_4-saturated clay, from the previous determination, NH_4Cl was added, then the excess of salt was leached with ethanol and the NH_4 displaced with NaCl. The NH_4^+ was determined by distillation and titration.

Chemical Methods

Soil pH

Soil pH was determined in water, 1:1 ratio; in 1 N KCl, 1:1 ratio; and in 0.01 M $CaCl_2$, 1:2, soil:solution ratio, as suggested by Schofield and Taylor (1955).

Exchangeable Acidity

Exchangeable acidity was extracted with unbuffered 1 N KCl and the leachate titrated with 0.1 N NaOH to a phenolphthalein end point. Exchangeable Al was determined by adding KF to the titrated leachate, and then evaluated with standard H_2SO_4 (Yuan, 1959; Soil Survey Investigations Report 1, 1967).

Extractable Acidity

Extractable acidity was extracted by $BaCl_2$-triethanolamine at pH 8.2. The amount of extractable acidity was determined by the difference in titration of a blank and the sample with 0.2 N HCl to pH 5.1 (pink end point of mixed indicator bromocresol green and methyl red (Peech, 1965; Soil Survey Investigation Report 1, 1967).

Mehlich Acidity Test[3]

Solution A. Dissolve 5 ml glacial acetic acid and 21 ml of 1:1 aqueous dilution of triethanolamine to 800 ml with deionized water. Then add 52 g NH_4Cl and 30 g sodium glycerophosphate beta and make up to 1 lit with water.

Solution B. Dissolve 50 g barium chloride ($BaCl_2 \cdot 2H_2O$) and make up to 1 liter with deionized water. Mix solutions A and B in equal proportions and adjust to pH 6.6 with acetic acid or triethanolamine.

To 10 cm^3 of soil add 10 ml of deionized water and allow 1 hr for equilibration; read the pH. Then add 10 ml of the pH 6.6 buffer solution. Allow 1 hr for equilibration and read the pH. The acidity in meq/100 cm^3 soil is calculated by the formula:

$$\text{Acidity} = \frac{6.6 - (\text{soil buffer pH})}{0.25}$$

Exchangeable Bases

Exchangeable Ca, Mg, K and Na were extracted with 1 N pH 7 NH_4OAc. The leachate was evaporated and the residue dissolved in HCl. Ca and Mg were titrated with EDTA. K and Na were determined by flame photometr

Ammonium Retention

Soils were saturated with 1 N NH_4Cl; the samples were washed free of chlorides with ethanol and the retained NH_4^+ displaced with NaCl and determined by distillation and titration (Soil Survey Staff, 1970).

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[3] Mehlich, A., Professor, Soil Testing Division, North Carolina Department of Agriculture, Raleigh; personal communication

Cation Exchange Capacity

1 N NH_4OAc at pH 7. To 25 g of soil, 50 ml of 1 N NH_4OAc at pH 7 were added, shaken and allowed to stand overnight; then filtered. The NH_4^+-saturated soils were washed with 95% ethanol until a negative test for chlorides was obtained. The retained NH_4^+ was displaced by acidified 10% NaCl, distilled into boric acid and titrated with standard acid (Soil Survey Investigation Report 1, 1967).

Effective Cation Exchange Capacity (ECEC). Effective cation exchange capacity is equal to the sum of bases extracted by 1 N pH 7 NH_4OAc plus exchangeable acidity, extracted by unbuffered 1 N KCl.

CEC by Sum of Cations. CEC by sum of cations is defined as the sum of bases extracted by 1 N pH 7 NH_4OAc plus "extractable acidity" determined by $BaCl_2$-TEA pH 8.2 (Soil Survey Staff, 1960; Soil Survey Investigation Report 1, 1967).

Organic Carbon

Organic carbon was determined by the Walkley-Black procedure as outlined in the Soil Survey Investigation Report 1 (1967) and by dry-combustion method using a Leco Carbon Analizer.[4]

Total Nitrogen

Total nitrogen was determined according to the Kjeldahl method (Soil Survey Investigation Report 1, 1967).

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[4] Analysis done at the Soil Research Laboratory, Michigan State University, East Lansing

Indigenous Fixed Ammonium

The indigenous fixed ammonium was determined following the method proposed by Bremner (1965a). The soil samples were treated with alkaline potassium hypobromite solution to remove exchangeable NH_4^+ and organic nitrogen compounds. The residues were washed with 0.5 N KCl and then shaken with 5 N HF + 1 N HCl solution for 24 hr to decompose the minerals containing the nonexchangeable NH_4^+; then distilled and titrated.

Nitrogen Mineralization

Aerobic incubation was done according to the Bremner procedure (1965b). The mineralized NO_3^- was calculated subtracting the initial NO_3^- content (times zero) from the final NO_3^- content (after 14 days of incubation at constant temperature). The anaerobic incubation was done following the Waring-Bremner procedure (1964). Soils were incubated under waterlogged conditions during 7 days. Mineralized NH_4^+ is equal to final content less initial NH_4^+ concentrations.

Total and Organic Phosphorus

Total phosphorus was determined by Na_2CO_3 fusion and molybdate colorimetric method (Jackson, 1958).

Organic phosphorus was determined by a procedure developed in Colombia by Lopez (1960). One gram of soil was calcined at 550°C for 6 hr; 150 ml of 0.8 N H_2SO_4 were then added and the suspension shaken for 6 hr. The P was determined in an aliquot. The same extraction procedure was done in a non-calcined sample. The difference between the phosphorus extracted from calcined and non-calcined samples was taken as the organic phosphorus.

Available Phosphorus

Available phosphorus was extracted with three different solutions:

(1) Bray II (0.03 N NH_4F + 0.1 N HCl)

(2) North Carolina (0.05 N HCl + 0.025 N H_2SO_4)

(3) Olsen modified by Hunter (0.5 N $NaHCO_3$ + 0.01 M EDTA + 0.15 g superflock/liter (Hunter, 1972)

Phosphorus was determined colorimetrically as phospho-molybdate.

Extractable Copper, Zinc and Manganese

Copper, zinc and manganese were extracted with North Carolina and Modified Olsen solutions and determined in a Perkin-Elmer Atomic Absorption Spectrophotometer.[5]

Thin Sections

Undisturbed samples were oven-dried (110°C) and impregnated under vacuum with castolite-styrene mixture, following the procedure of Buol and Fadness (1961). In some samples the impregnation with castolite was not satisfactory, due to the lack of resin penetration. In these samples impregnation was made with carbowax (Polyethylene Glycol). Melted carbowax (melting point 60°C) was poured to cover the dry peds and kept at 60°C for 8 days, then allowed to solidify at room temperature. Cutting and grinding was done in kerosene, because the carbowax is soluble in water.

The impregnated samples were mounted on glass slides and ground to a thickness of about 30 μ. Descriptions of the micromorphological features were made following the Brewer terminology (1964).

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[5] Appreciation is expressed to Dr. A. H. Hunter, Professor, Department of Soil Science, North Carolina State University at Raleigh for his assistance in the micronutrient determinations

RESULTS AND DISCUSSION

Texture and Morphology

Contents of total and water-dispersible clay are shown in Table 3. Particle size distribution and silt/clay ratios are presented in Tables 4 and 5.

According to the very extended concept that huge areas in South America are occupied by Oxisols and Ultisols (Soil Survey Staff, 1970), the initial (working) hypothesis was to assume that the soils used in the present study had oxic or argillic horizons. A reliable determination of the amount of clay is essential in both cases, for estimating the CEC of the clay in oxic horizon and for determining the increase in clay with depth in the argillic horizon. The clay content was determined by the pipette method using $NaPO_3$ as a dispersing agent and also calculated by multiplying the 15-bar water percent by 2.5; this calculation seems to give a reliable estimate of the clay percent in soils difficult to disperse (Soil Survey Staff, 1967). For comparison, the clay was also determined with NaOH as a dispersant, a procedure usually employed in the Brazilian laboratories (Vettori, 1969).

The results obtained by the use of $NaPO_3$ and NaOH dispersants are in good agreement, indicating that both treatments are equally effective. A maximum difference of 4% clay was found in a few samples. In 49 samples, 71% of the total, NaOH-dispersed, clay content is higher than $NaPO_3$-dispersed clay

In profiles 1, 2, and 7, the amount of clay obtained by the $NaPO_3$-pipette method is higher than the calculated clay (15-bar water % x 2.5). and in profiles 3, 4, 5, 6, 8 and 9 the reverse is true. In the majorit

Table 3. Fifteen-bar water percent; water-dispersible clay; total clay content determined by three procedures and 15-bar water percent/$NaPO_4$-clay percent ratio

Sample	Horizon	Depth from surface	15-bar H_2O	Water-dispersible clay	Clay: $NaPO_3$[a]	Clay: NaOH[b]	Clay: 15-bar H_2O % x 2.5	15-bar H_2O % / $NaPO_3$-clay %
		cm	%	%	%	%	%	Ratio
				Profile 1 - Miraf				
21	A1	0-21	25.6	48.8	69.7	67.6	64.0	0.367
22	B1	21-38	27.0	42.8	72.0	70.6	67.5	0.375
23	B21	38-60	27.0	53.8	71.6	74.2	67.5	0.377
24		60-80	27.4	32.6	73.3	73.7	68.5	0.374
25		80-100	27.7	14.7	72.2	73.7	69.3	0.384
26	B22	100-150	27.8	4.2	72.4	78.3	69.5	0.385
27	B23	150-200	28.6	3.1	73.8	76.8	71.5	0.388
28		200-250	28.7	2.0	74.8	76.4	71.8	0.383
29		250-300	29.2	1.0	75.3	75.6	73.0	0.387
30		300-350	27.7	0.0	73.1	77.0	69.3	0.379
				Profile 2 - Montan				
44	A1	0-17	26.0	52.5	69.8	67.8	65.0	0.372
45	B1	17-37	24.9	55.4	72.2	73.1	62.3	0.345
46		37-64	25.4	48.3	75.6	74.7	63.5	0.336
47	B21	64-84	25.6	44.7	77.4	78.3	64.0	0.331
48		84-104	25.5	28.9	77.5	75.6	63.8	0.329
49		104-124	26.1	6.8	78.9	77.5	65.3	0.331
50		124-153	26.2	6.4	79.0	77.3	65.5	0.332
51	B22	153-173	27.0	2.2	78.9	77.3	67.5	0.342
52		173-200	27.6	2.0	77.8	82.3	69.0	0.355
53		200-227	27.7	2.0	77.2	76.6	69.3	0.359
54	C1	227-310	27.1	2.0	71.0	72.7	67.8	0.382
55	C2	310-350	28.3	2.0	78.8	80.9	70.8	0.359

Table 3 (Continued)

Sample	Horizon	Depth from surface	15-bar H_2O	Water-dispersible clay	Clay			15-bar H_2O % / $NaPO_3$-clay %
					$NaPO_3$[a]	NaOH[b]	15-bar H_2O % x 2.5	
		cm	%	%	%	%	%	Ratio
Profile 3 - Naval								
8	A1	0-13	11.8	13.7	23.5	25.2	29.5	0.502
9	B21	13-33	10.1	3.0	22.0	22.4	25.3	0.459
10		33-52	11.7	1.5	25.2	29.5	29.3	0.464
11	B22	52-72	16.6	0.4	35.7	38.9	41.5	0.465
12		72-105	20.9	0.5	46.1	50.0	52.3	0.453
13	B23	105-142	21.2	0.0	46.3	47.0	53.0	0.584
14	B24	142-200	20.1	0.0	44.4	48.0	50.3	0.453
15		200-250	15.2	0.0	32.8	36.0	38.0	0.463
Profile 4 - Polvor								
31	A1	0-17	14.6	25.9	35.7	34.2	36.5	0.409
32	B1	17-47	14.4	14.5	33.8	32.8	36.0	0.426
33	B21	47-80	19.7	6.2	46.6	45.5	49.3	0.423
34	B22	80-120	22.8	7.3	54.6	56.2	57.0	0.418
35		120-157	22.9	4.2	56.5	58.5	57.3	0.405
36	C1	157-210	22.7	4.6	54.3	57.5	56.6	0.418
Profile 5 - Tacana								
1	A1	0-10	17.9	15.5	39.7	36.2	44.8	0.451
2	B21	10-30	18.7	5.2	41.3	38.7	46.7	0.453
3		30-50	18.9	2.0	42.8	41.4	47.3	0.441
4		50-70	20.1	1.0	45.3	43.7	50.2	0.444
5		70-83	21.1	2.1	47.7	45.5	52.8	0.443
6	B22	83-140	20.6	1.0	46.6	49.2	51.5	0.442
7	B23cn	140-200	16.3	2.1	36.1	39.5	40.8	0.452

Table 3 (Continued)

Sample	Horizon	Depth from surface	15-bar H_2O	Water-dispersible clay	Clay $NaPO_3$[a]	Clay $NaOH$[b]	Clay 15-bar H_2O % x 2.5	$\frac{\text{15-bar } H_2O\ \%}{NaPO_3\text{-clay } \%}$
		cm	%	%	%	%	%	Ratio
				Profile 6 - Leguiz				
37	A1	0-20	10.3	14.6	23.7	24.5	25.8	0.435
38	B21	20-80	20.8	9.4	48.6	46.8	25.0	0.428
39	B22	80-133	20.0	5.2	43.5	44.0	50.0	0.460
40	IIB23	133-173	17.7	4.2	38.2	37.9	44.3	0.463
41	IIC1	173-215	12.1	4.2	25.1	27.1	30.3	0.482
42	IIC2	215-243	14.1	4.3	31.0	32.2	35.3	0.455
43	IIIC3	243-265	9.8	4.1	19.0	20.6	24.5	0.516
				Profile 7 - Guavia				
16	A11	0-25	9.4	14.4	22.4	22.6	23.5	0.420
17	A12	25-47	9.8	6.1	25.0	26.5	24.5	0.392
18	B21	47-75	11.1	0.0	29.9	32.8	27.8	0.372
19	B22cn	75-97	14.4	0.0	39.0	36.9	36.0	0.369
20	IIC	124-240	21.8	0.0	59.0	60.1	54.5	0.369
				Profile 8 - Floren				
56	A1	0-16	19.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	B21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]					

Table 3 (Continued)

Sample	Horizon	Depth from surface	15-bar H_2O	Water-dispersible clay	Clay			$\frac{\text{15-bar } H_2O \text{ \%}}{NaPO_3\text{-clay \%}}$
					$NaPO_3$[a]	NaOH[b]	15-bar H_2O % x 2.5	
		cm	%	%	%	%	%	Ratio
				Profile 9 - Asis				
63	A1	0-12	17.2	20.0	31.1	35.0	43.0	0.553
64	B2	12-86	20.0	2.5	45.9	47.0	50.0	0.436
65	IIC1	86-138	16.4	2.1	32.1	35.6	41.0	0.511
66	IIC2	138-214	19.6	2.0	45.9	50.1	49.0	0.427
67	IIC3	214-296	17.2	2.0	38.0	40.0	43.0	0.453
68	IIIC4	296-350	11.8	2.0	24.9	26.0	29.5	0.474

[a] Clay by $NaPO_3$-pipette

[b] Clay by NaOH-hydrometer

Table 4. Particle size distribution

Sample	Horizon	Depth from surface	Sand					Silt		Clay
			V.C.S.[a]	C.S.	M.S.	F.S.	V.F.S.	C.Si	M & F Si	
		cm	%	%	%	%	%	%	%	%
			Profile 1 - Miraf							
21	A1	0-21	0.0	0.2	0.4	3.6	10.0	8.4	7.6	69.7
22	B1	21-38	0.0	0.3	0.3	3.2	9.7	7.6	6.8	72.0
23	B21	38-60	0.1	0.2	0.3	3.1	9.8	8.2	6.5	71.6
24		60-80	0.1	0.2	0.4	3.4	10.3	5.2	6.9	73.3
25		80-100	0.2	0.3	0.4	3.5	9.8	6.5	7.0	72.2
26	B22	100-150	0.2	0.3	0.4	2.9	9.4	7.3	6.7	72.4
27	B23	150-200	0.3	0.4	0.6	3.1	8.6	7.2	5.9	73.8
28		200-250	0.3	0.4	0.5	3.1	8.8	6.6	5.3	74.8
29		250-300	0.1	0.3	0.3	2.9	7.7	6.9	6.5	75.3
30		300-350	0.1	0.1	0.2	1.5	6.1	7.8	11.0	73.1
			Profile 2 - Montan							
44	A1	0-17	0.6	2.6	4.7	3.0	1.9	2.7	14.7	69.8
45	B1	17-37	0.5	1.8	4.4	2.7	1.5	2.0	15.0	72.2
46		37-64	0.3	1.5	3.5	2.4	1.3	1.6	13.8	75.6
47	B21	64-84	0.3	1.5	3.3	2.2	1.2	1.5	12.6	77.4
48		84-104	0.5	1.5	3.5	2.3	1.2	1.0	12.6	77.5
49		104-124	0.3	1.4	3.1	2.0	1.1	2.4	11.0	78.9
50		124-153	0.4	1.4	2.8	2.0	1.1	1.7	11.5	79.0
51	B22	153-173	0.4	1.5	2.9	2.1	1.1	2.5	10.6	78.9
52		173-200	0.4	1.7	2.7	2.0	1.1	1.8	12.4	77.8
53		200-227	0.4	1.3	2.4	1.9	1.2	2.0	13.7	77.2
54	C1	227-310	0.3	1.2	1.9	1.9	2.4	4.1	16.9	71.0
55	C2	310-350	0.1	0.3	0.6	1.0	1.4	1.8	16.0	78.8

Table 4 (Continued)

Sample	Horizon	Depth from surface	Sand					Silt		Clay
			V.C.S.[a]	C.S.	M.S.	F.S.	V.F.S.	C.Si	M & F Si	
		cm	%	%	%	%	%	%	%	%
			Profile 3 - Naval							
8	A1	0-13	0.0	0.0	0.0	3.2	34.7	18.1	20.4	23.5
9	B21	13-33	0.0	0.0	0.0	2.5	36.9	18.5	20.0	22.0
10		33-52	0.0	0.0	0.0	2.3	35.4	12.8	24.1	25.2
11	B22	52-72	0.0	0.0	0.0	1.1	30.7	15.6	16.9	35.7
12		72-105	0.0	0.0	0.0	0.6	22.4	13.6	17.3	46.1
13	B23	105-142	0.0	0.0	0.0	0.6	20.4	11.0	21.5	46.3
14	B24	142-200	0.0	0.0	0.0	0.3	12.7	12.7	29.8	44.4
15		200-250	0.0	0.0	0.0	0.9	18.5	18.5	29.2	32.8
			Profile 4 - Polvor							
31	A1	0-17	0.2	0.3	0.3	2.0	14.5	16.1	32.0	35.7
32	B1	17-47	0.2	0.3	0.2	1.5	14.3	17.7	31.9	33.8
33	B21	47-80	0.2	0.3	0.1	1.1	10.8	12.6	28.3	46.6
34	B22	80-120	0.0	0.1	0.1	0.9	8.5	11.8	23.9	54.6
35		120-157	0.0	0.2	0.1	1.0	7.8	12.1	22.3	56.5
36	C1	157-210	0.0	0.2	0.2	1.5	10.7	8.6	24.5	54.3
			Profile 5 - Tacana							
1	A1	0-10	0.0	0.0	0.0	6.6	25.2	15.0	13.4	39.7
2	B21	10-30	0.0	0.1	0.1	5.5	25.2	14.1	13.8	41.3
3		30-50	0.0	0.1	0.2	4.1	26.1	12.7	14.0	42.8
4		50-70	0.0	0.1	0.2	4.1	22.4	14.3	13.3	45.3
5		70-83	0.1	0.1	0.2	4.2	22.0	13.3	12.2	47.7
6	B22	83-140	0.8	1.0	0.5	2.7	17.6	9.9	21.4	46.6
7	B23cn	140-200	0.9	1.3	0.9	4.4	21.8	9.1	25.5	36.1

Table 4 (Continued)

Sample	Horizon	Depth from surface	Sand					Silt		Clay
			V.C.S.[a]	C.S.	M.S.	F.S.	V.F.S.	C.Si	M & F Si	
		cm	%	%	%	%	%	%	%	%
			Profile 6 - Leguiz							
37	A1	0-20	0.0	0.1	0.5	29.6	21.5	9.1	15.5	23.7
38	B21	20-80	0.1	0.3	0.3	22.9	11.7	4.4	11.8	48.6
39	B22	80-133	0.1	0.3	0.3	24.5	11.1	4.4	15.8	43.5
40	IIB23	133-173	0.0	0.0	0.2	29.5	13.5	3.4	15.2	38.2
41	IIC1	173-215	0.0	0.0	0.6	42.1	9.7	4.2	18.3	25.1
42	IIC2	215-243	0.0	0.4	0.9	36.3	11.7	4.5	15.0	31.0
43	IIIC2	243-265	0.0	0.0	0.4	51.0	6.7	4.1	18.6	19.0
			Profile 7 - Guavia							
16	A11	0-25	0.9	2.4	11.2	33.4	16.4	7.4	5.9	22.4
17	A12	25-47	1.2	2.2	10.2	31.0	16.5	7.2	6.6	25.0
18	B21	47-75	1.5	2.1	8.3	27.4	16.4	7.5	6.7	29.9
19	B22cn	75-97	1.3	1.1	8.6	22.1	13.3	6.6	8.0	39.0
20	IIC1	124-240	0.2	1.2	1.8	3.4	2.7	3.2	28.4	59.0
			Profile 8 - Floren							
56	A1	0-16	4.6	14.2	12.8	9.4	5.3	3.7	12.9	37.0
57	B21	16-85	2.8	7.8	7.8	6.7	4.7	3.8	13.9	52.3
58	B22	85-173	3.4	8.2	7.0	6.6	4.4	4.4	17.0	49.0
59	B3	173-208	6.1	10.5	9.5	7.7	7.0	6.0	24.6	28.4
60	C1	208-228	9.8	16.3	12.9	10.1	7.1	5.9	17.7	20.2
61	C2	228-247	2.3	6.4	7.6	8.3	8.5	7.7	31.3	28.0
62	C3	247-350	2.8	8.1	9.6	8.8	9.2	8.4	31.6	21.4

Table 4 (Continued)

Sample	Horizon	Depth from surface	Sand					Silt		Sand
			V.C.S.[a]	C.S.	M.S.	F.S.	V.F.S.	C.Si	M & F Si	
		cm	%	%	%	%	%	%	%	%
			Profile 9 - Asis							
63	A1	0-12	0.5	3.3	11.1	18.4	11.9	7.3	16.2	31.1
64	B2	12-86	0.4	1.7	4.8	11.4	9.3	6.6	19.8	45.9
65	IIC1	86-138	0.2	1.4	3.1	6.3	10.7	10.8	35.3	32.1
66	IIC2	138-214	0.7	3.2	4.5	3.3	6.1	9.8	26.0	45.9
67	IIC3	214-296	0.6	3.1	3.6	2.7	7.1	11.3	33.6	38.0
68	IIIC4	296-350	1.8	11.6	17.3	11.2	9.0	9.5	14.7	24.9

[a] V.C.S. = very coarse sand 2-1 mm
C.S. = coarse sand 1-0.5 mm
M.S. = medium sand 0.5-0.25 mm
F.S. = fine sand 0.25-0.10 mm
V.F.S. = very fine sand 0.10-0.05 mm
C.Si = coarse silt 50-20 μ
M F Si = medium & fine silt 20-2 μ
Clay < 2 μ by $NaPO_3$-pipette method

Table 5. Textural classes; silt to clay ratios

Sample	Horizon	Depth from surface	Sand 2000-50 μ	Silt 50-2 μ	Clay <2 μ	Textural class U.S.D.A.	Total silt % / Clay %	Medium & fine silt % / Clay %
		cm	%	%	%		Ratio	Ratio
				Profile 1 - Miraf				
21	A1	0-21	14.2	16.0	69.7	clay	0.23	0.11
22	B1	21-38	13.5	14.4	72.0	clay	0.20	0.09
23	B21	38-60	13.5	14.7	71.6	clay	0.20	0.09
24		60-80	14.4	12.1	73.3	clay	0.16	0.09
25		80-100	14.2	13.5	72.2	clay	0.18	0.09
26	B22	100-150	13.2	14.0	72.4	clay	0.19	0.09
27	B23	150-200	13.0	13.1	73.8	clay	0.18	0.08
28		200-250	12.9	11.9	74.8	clay	0.16	0.07
29		250-300	11.3	13.4	75.3	clay	0.17	0.09
30		300-350	8.0	18.8	73.0	clay	0.25	0.15
				Profile 2 - Montan				
44	A1	0-17	12.8	17.4	69.8	clay	0.25	0.21
45	B1	17-37	10.9	17.0	72.2	clay	0.23	0.20
46		37-64	8.7	15.4	75.6	clay	0.20	0.18
47	B21	64-84	8.5	14.1	77.4	clay	0.18	0.16
48		84-104	9.0	13.1	77.5	clay	0.16	0.16
49		104-124	6.5	13.4	78.9	clay	0.16	0.14
50		124-153	7.7	13.2	79.0	clay	0.16	0.14
51	B22	153-173	8.0	13.1	78.9	clay	0.16	0.13
52		173-200	7.9	14.2	77.8	clay	0.20	0.17
53		200-227	7.2	15.7	77.2	clay	0.20	0.18
54	C1	227-310	7.7	21.0	71.0	clay	0.29	0.23
55	C2	310-350	3.4	17.8	78.0	clay	0.23	0.20

Table 5 (Continued)

Sample	Horizon	Depth from surface	Sand 2000-50 μ	Silt 50-2 μ	Clay <2 μ	Textural class U.S.D.A.	Total silt % / Clay %	Medium & fine silt % / Clay %
		cm	%	%	%		Ratio	Ratio
				Profile 3 - Naval				
8	A1	0-13	37.9	38.5	23.5	loam	1.63	0.87
9	B21	13-33	40.4	38.5	22.0	loam	1.75	0.91
10		33-52	37.7	36.9	22.5	loam	1.46	0.96
11	B22	52-72	31.8	32.5	35.7	clay loam	0.91	0.47
12		72-105	23.0	30.9	46.1	clay	0.67	0.38
13	B23	105-142	21.0	32.5	46.1	clay	0.70	0.46
14	B24	142-200	13.0	42.5	44.4	silty clay	0.96	0.67
15		200-250	19.4	47.7	32.8	silty clay loam	1.45	0.89
				Profile 4 - Polvor				
31	A1	0-17	15.5	48.1	35.7	silty clay loam	1.35	0.90
32	B1	17-47	16.5	49.6	33.8	silty clay loam	1.47	0.94
33	B21	47-80	12.5	40.9	46.6	silty clay	0.88	0.61
34	B22	80-120	9.6	35.7	54.6	clay	0.65	0.44
35		120-157	9.1	34.4	56.5	clay	0.61	0.39
36	C1	157-210	12.6	33.1	54.3	clay	0.61	0.45
				Profile 5 - Tacana				
1	A1	0-10	31.8	28.4	39.7	clay loam	0.72	0.34
2	B21	10-30	30.9	27.9	41.3	clay	0.68	0.33
3		30-50	30.5	26.7	42.8	clay	0.62	0.33
4		50-70	26.8	27.6	45.3	clay	0.61	0.29
5		70-83	26.6	25.5	47.7	clay	0.53	0.26
6	B22	83-140	22.1	31.3	46.6	clay	0.67	0.46
7	B23cn	140-200	29.3	34.6	36.1	clay loam	0.96	0.71

Table 5 (Continued)

Sample	Horizon	Depth from surface	Sand 2000-50 µ	Silt 50-2 µ	Clay <2 µ	Textural class U.S.D.A.	$\frac{\text{Total silt \%}}{\text{Clay \%}}$	$\frac{\text{Medium \& fine silt \%}}{\text{Clay \%}}$
		cm	%	%	%		Ratio	Ratio
				Profile 6 - Leguiz				
37	A1	0-20	51.7	24.6	23.7	sandy clay loam	1.04	0.65
38	B21	20-80	35.3	16.2	48.6	clay	0.33	0.25
39	B22	80-133	36.3	20.2	43.5	clay	0.46	0.45
40	IIB23	133-173	43.2	18.6	38.2	clay loam	0.49	0.40
41	IIC1	173-215	52.4	22.5	25.1	sandy clay loam	0.89	0.73
42	IIC2	215-243	49.3	19.5	31.0	sandy clay loam	0.63	0.48
43	IIIC3	243-265	58.1	22.7	19.0	sandy clay loam	1.19	0.98
				Profile 7 - Guavia				
16	A11	0-25	64.3	13.3	22.4	sandy clay loam	0.59	0.26
17	A12	25-47	61.1	13.8	25.0	sandy clay loam	0.55	0.26
18	B21	47-75	55.7	14.2	29.9	sandy clay loam	0.47	0.22
19	B22cn	75-97	46.4	14.6	39.0	sandy clay	0.47	0.21
20	IIC1	124-240	9.3	31.6	59.0	clay	0.54	0.48
				Profile 8 - Floren				
56	A1	0-16	46.8	16.6	37.0	sandy clay	0.45	0.35
57	B21	16-85	29.8	17.7	52.3	clay	0.34	0.27
58	B22	85-173	29.6	21.4	49.0	clay	0.44	0.35
59	B3	173-208	40.8	30.6	28.4	clay loam	1.08	0.87
60	C1	208-228	56.2	23.6	20.2	sandy clay loam	1.17	0.88
61	C2	228-247	33.1	39.0	28.0	clay loam	1.39	1.12
62	C3	247-350	38.5	40.0	21.4	loam	1.87	1.48

Table 5 (Continued)

Sample	Horizon	Depth from surface	Sand 2000-50 μ	Silt 50-2 μ	Clay <2 μ	Textural class U.S.D.A.	Total silt % / Clay %	Medium & fine silt % / Clay %
		cm	%	%	%		Ratio	Ratio
				Profile 9 - Asis				
63	A1	0-12	45.2	23.5	31.1	sandy clay loam	0.76	0.52
64	B2	12-86	27.6	26.4	45.9	clay	0.58	0.43
65	IIC1	86-138	21.7	46.1	32.1	clay loam	1.44	1.10
66	IIC2	138-214	17.8	35.8	45.9	clay	0.78	0.57
67	IIC3	214-296	17.1	44.9	38.0	silty clay loam	1.18	0.88
68	IIIC4	296-350	50.9	24.2	24.9	sandy clay loam	0.97	0.59

of the samples the difference in clay content ranges from 1 to 4%. The maximum discrepancies (13%) are found in profile 2. For calculating the CEC of the clay, the higher value of the two methods must be used (Soil Survey Staff, 1967).

$NaPO_3$ is considered the best overall dispersing agent (Ingram, 1971). It complexes Ca, furnishes a Na-saturated soil and provides colloidal protection (Jackson, 1964). Van Wambeke (1959) pointed out that the use of $NaPO_3$ dispersant for measuring the amounts of clay and silt in tropical soils of the Congo is very satisfactory. On these grounds, it seems to be sound to assumethat the $NaPO_3$-pipette clay is close to the true clay.

The ratio of 15-bar water content to the clay, as determined by $NaPO_3$-pipette, gives an indication of the "activity" of the clay fraction and the surface area available to retain water against 15-bar tension. Comerma (1968) has related this ratio to the degree of weathering of some soils in tropical areas. He found values below 0.3 for soils considered older and more highly weathered; values between 0.3 and 0.4 for less weathered soils and above 0.5 for the recent alluvial soils. Similar values have been reported by Jahn for red soils of northern Venezuela (cited by Comerma, 1968). In soils 1, 2, and 7, which are considered more weathered, as will be discussed later, the ratio is below 0.38; in soils 3, 4, 6 and 9, which are considered less weathered, the ratio varies between 0.42 and 0.56. In general, there is agreement between the data presented here and those found by Comerma (1968).

Water-dispersible clay (natural clay in the Brazilian terminology) is significant in the definition of the upper boundary of the oxic horizon. Water-dispersible clay must be less than 5% (Soil Survey Staff,

1970) or less than 2% (Bennema, 1966). However, it must be noted that low amounts of water-dispersible clay is not an exclusive characteristic of oxic horizon.

In profiles 1 and 2 the water-dispersible clay (Table 3) decreases rather abruptly at 100 cm in profile 1 and at 153 cm in profile 2. In all other profiles the amount of water-dispersible clay decreases drastically around the boundary between the A and B horizons.

The failure of clay to disperse in water is usually attributed to the binding effect of iron oxides and of amorphous material and to the low electrostatic repulsion due to "low activity of the clay" (Soil Survey Staff, 1970). The reason for the decrease in water-dispersible clay with depth is not known. There is no relation between the water-dispersible clay and either the amounts of free iron oxide or the amorphous materials associated with the clay fraction (Table 9). The distribution trend suggests that organic matter may influence in some way (physical and/or physico-chemical) the clay dispersibility, which seems to be contrary to what is commonly accepted; *i.e.*, that organic matter has a binding effect.

Soils 1 and 2 from north of the Caqueta River have very fine clayey textures from top to bottom, with no clear evidence of textural gradient or clay translocation. The high clay content with only minor amounts of fine silt and medium to very fine sand suggest that the materials were laid down in a tranquile, low energy water body (Selley, 1972). This observation supports the findings of Cucalon and Camacho (1966) who established that the Orito formation (on which the profile 2 was described) was deposited in a fresh to brackish water body. This profile has at depth of 3.5 m a laminar structure (rock fabric) with joint plane cutans.

Soil 7, located in San Jose de Guaviare, has the highest amounts of sand, mainly fine and very fine sand, reflecting the influence of parent material, constituted by the Puerto Arturo sandstone. Underlying the B22 horizon is a lithologic discontinuity formed by a concretionary layer over a clayey horizon.

The moderately well drained soils 3 and 4 show an increase in clay content with depth. In profile 3 there is an increase of 13% in a 20-cm vertical distance and in profile 4 there is an increase of 13% in 30-cm vertical distance. In the field thin, discontinuous argillans in root channel walls and ped faces were observed, in the B2 horizon of both profiles. In the thin sections the existence of oriented clay films was confirmed (Appendix B). In the B horizon of profile 3, thin ped and vugh argillans and ferri-argillans, with sharp to diffuse separation were found. The estimated volume occupied by cutans is less than 1%. In the B horizon of soil 4, sparse to common (but <1%) thin, ped, vugh, channel and skew plane argillans, and ferri-argillans were observed.

The presence of oriented clay films and coatings on pores, root channel walls and on ped faces is taken as an evidence of clay illuviation (Cady, 1960; Hendricks _et_ _al_., 1968; Soil Survey Staff, 1970).

The presence of argillans in the B horizon of profiles 3 and 4 may indicate that lessivage has taken place or is taking place and the clay enriched horizons may be defined as argillic horizons. The relatively small volume of argillans may suggest that the clay cutans formed in the past are being destroyed by (a) the intensive weathering environment, as suggested by Sys (1959) for soils of the Congo and by McCracken et al. (1971) for some Ultisols of southeastern United States or (b) by intense faunal and floral pedoturbation (Soil Survey Staff, 1970; Buol et al., 1972). An alternative explanation for the relative scarcity of argillans in soils 3 and 4 may be that clay movement has not taken place to a significant extent in these soils. In this case the clay enrichment of the B horizons may be due, at least in part, to other causes. For example, Folster and Ladeine (1967) have indicated that the vertical differences in texture of Nigerian soils are due to stratified pedisedimentation and mainly to faunal activity combined with loss of clay by surface wash. Brewer (1968) has proposed a "differential weathering" mechanism between A and B horizons, as suggested by Simonson (1949) for the Red-Yellow Podzolic soils, and later rejected by McCaleb (1959) in favor of the lessivage theory. In the present case, it is not actually possible to determine if some of these processes have taken place. Further studies are needed. For classification purposes it is considered that the B horizons of soils 3 and 4 meet the definition of argillic horizons.

In soil 5, a small increase in clay content with depth is found and there is a noticeable decrease in clay content at the bottom of the profile.

The particle size distribution of soil 6 reflects a stratified profile formed by sediments probably transported and deposited by the Putumayo River.

Profiles 8 and 9, sampled in the foothills, show a variable particle size distribution with depth; lithological discontinuities may be due to colluviation and incorporation of pyroclastic materials.

European soil scientists (Sys, 1959; Van Wambeke, 1959, 1962; Webster, 1965; Buringh, 1970) have been using the silt/clay ratio for judging the weathering stage of African soils and parent materials. Van Wambeke (1959, 1962) found that parent materials of recent origin have silt/clay ratios in the order of 0.36 to 1.03; for Pleistocene materials between 0.17 and 0.32 and for Pre-Pleistocene materials between 0.08 and 0.12. He proposed a critical value of less than 0.15 for older and advanced weathered materials.

Comerma (1968) used the silt/clay ratio in Venezuela and found that for recent alluvial soils the ratio is greater than 1.5; for the hydromorphic soils of medium age, between 0.5 and 1.5 and for older, well drained soils between 0.2 and 0.4. Guerrero (1971) found values greater than 0.3 for the Llanos Orientales soils of Colombia.

The silt/clay ratios in the B horizon of soils 1 and 2, on tertiary clays, are less than 0.2 and the fine silt/clay ratio is less than 0.09 for soil 1 and less than 0.18 for soil 2. According to the French classification system (Buringh, 1970), the "sols ferrallitiques" (Oxisols) must have a fine silt/clay <0.15.

The other soils have higher silt/clay ratios, thus suggesting that they are from parent material younger than Tertiary. This finding supports the ideas of Hubach (1954) who believes that the Putumayo-Amazon areas may be covered by Pleistocene materials.

Mineralogy of the Sand

The mineralogy of the very fine sand fraction was studied with a petrographic microscope using the point-counting technique.

Around 600 grains were counted on each slide. Many investigators (Galehouse, 1971) indicate that for general purposes 300 grains are sufficient to get reasonable accuracy with minimum investment of time.

Table 6 contains the results of microscopic examination of the very fine sand. The amounts of the different minerals are expressed in percentage of grains counted. When a mineral is present in less than 1%, it is reported as trace (tr).

Subrounded and subangular quartz is the principal mineral in the very fine sand of soil 1. There are different types of quartz--clear quartz with almost no inclusions, some grains with bubbles and bubble trains, as well as some mosaics or aggregates with small zircon and rutile inclusions. The variation in quartz type may suggest different sources of sediments. The degree of roundness may be due to transportation and a reworked condition.

The heavy minerals are rutile and zircon, many of which are of small size. The opaques are usually rounded masses, red to yellowish red in reflected light, probably hematite. The rock fragments are probably of metamorphic origin. Traces of chert are present in all horizons. No feldspars or micas are found. However, some of the rock fragments have inclusions of sericite. In general, there is not any significant trend in the vertical distribution of the minerals.

In soil 2 quartz is predominant, with a variable degree of roundness, subangular and subrounded, and some angular grains are present. Cherts are rounded and uniformly distributed through the profile. The heavy minerals are usually small crystals of rutile and zircon. The opaques have a variable size and shape (rounded to irregular) and red in

Table 6. Mineralogy of the very fine sand (0.05-0.10 mm) by the grain counting method with petrographic microscope[a]

Sample	Horizon	Depth from surface	Total grains counted	Quartz	Chert	Micas	Feldspars	Heavies	Opaques	Isotropics		Rock fragments
										Glass	Opal	
		cm		%	%	%	%	%	%	%	%	%
					Profile 1 - Miraf							
21	A1	0-21	550	93	1	0	0	3	1	0	0	2
22	B1	21-38	555	92	Tr	0	0	3	2	0	0	2
23	B21	38-60	581	92	Tr	0	0	4	2	0	0	1
24		60-80	579	93	Tr	0	0	4	1	0	0	1
25		80-100	583	95	Tr	0	0	2	1	0	0	2
26	B22	100-150	558	95	Tr	0	0	1	2	0	0	2
27	B23	150-200	546	95	Tr	0	0	1	1	0	0	2
28		200-250	549	95	Tr	0	0	2	1	0	0	2
29		250-300	559	94	Tr	0	0	2	2	0	0	2
30		300-350	550	95	Tr	0	0	2	1	0	0	2
					Profile 2 - Montan							
44	A1	0-17	600	89	2	0	0	1	6	0	Tr	2
45	B1	17-37	577	88	1	0	0	1	6	0	Tr	2
46		37-64	605	90	Tr	0	0	1	6	0	0	2
47	B21	64-84	558	93	Tr	0	0	2	2	0	0	2
48		84-104	604	91	1	0	0	2	3	0	0	2
49		104-124	602	91	1	0	0	2	5	0	0	1
50		124-153	581	92	1	0	0	2	3	0	0	1
51	B22	153-173	585	92	1	0	0	1	4	0	0	1
52		173-200	582	93	1	0	0	2	3	0	0	2
53		200-227	589	94	1	0	0	1	3	0	0	1
54	C1	227-310	558	71	1	0	0	2	23	0	0	3
55	C2	310-350	611	81	2	0	0	2	7	0	0	8

Table 6 (Continued)

Sample	Horizon	Depth from surface	Total grains counted	Quartz	Chert	Micas	Feldspars	Heavies	Opaques	Isotropics Glass	Isotropics Opal	Rock fragments
		cm		%	%	%	%	%	%	%	%	%
						Profile 3 - Naval						
8	A1	0-13	594	94	0	Tr	0	2	1	0	2	1
9	B21	13-33	563	95	0	Tr	0	2	1	0	Tr	2
10		33-52	556	95	1	Tr	0	2	1	0	Tr	1
11	B22	52-72	569	95	1	1	0	1	Tr	0	0	2
12		72-105	565	93	1	2	0	2	Tr	0	0	2
13	B23	105-142	581	86	3	5	0	2	Tr	0	0	4
14		142-200	630	79	8	5	0	2	1	0	0	5
15	B24	200-250	611	83	4	7	Tr	1	1	0	0	4
						Profile 4 - Polvor						
31	A1	0-17	589	89	4	0	0	3	1	0	1	2
32	B1	17-47	584	88	3	0	0	4	1	0	Tr	3
33	B21	47-80	627	87	5	0	0	3	2	0	Tr	3
34	B22	80-120	648	88	4	Tr	0	4	1	0	0	3
35		120-157	597	90	3	Tr	0	4	1	0	0	2
36	C1	157-210	622	85	3	Tr	0	3	5	0	0	3
						Profile 5 - Tacana						
1	A1	0-10	584	92	0	0	0	2	Tr	0	[illegible]	3
2	B21	10-30	555	93	1	0	0	2	Tr	0	1	2
3		30-50	603	92	Tr	Tr	0	2	1	0	1	3
4		50-70	570	93	0	Tr	0	2	1	0	0	3
5		70-83	604	91	1	1	0	2	1	0	0	4
6	B22	83-140	593	86	4	2	0	1	1	0	0	7
7	B23cn	140-200	612	81	3	3	0	1	3	0	0	9

Table 6 (Continued)

Sample	Horizon	Depth from surface	Total grains counted	Quartz	Chert	Micas	Feldspars	Heavies	Opaques	Isotropics Glass	Isotropics Opal	Rock fragments
		cm		%	%	%	%	%	%	%	%	%
					Profile 6 - Leguiz							
37	A1	0-20	618	89	4	Tr	0	2	Tr	Tr	Tr	3
38	B21	20-80	597	88	3	1	0	1	2	2	0	3
39	B22	80-133	659	85	2	Tr	Tr	1	3	2	0	6
40	IIB23	133-173	628	81	2	1	Tr	1	2	3	0	9
41	IIC1	173-215	604	69	3	5	Tr	1	3	8	0	11
42	IIC2	215-243	608	76	2	3	Tr	Tr	3	6	0	10
43	IIIC3	243-[illegible]	[illegible]	74	1	6	Tr	1	2	6	0	10
					Profile 7 - Guavia							
16	A11	0-25	556	96	0	0	0	1	1	0	1	1
17	A12	25-47	562	96	0	0	0	1	1	0	Tr	1
18	B21	47-75	578	95	0	Tr	0	1	3	0	Tr	1
19	B22cn	75-97	567	95	0	Tr	0	1	3	0	0	1
20	IIC	124-240	623	82	2	Tr	0	2	9	0	0	6
					Profile 8 - Floren							
56	A1	0-16	651	79	5	2	0	1	3	2	3	4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Tr	[illegible]	[illegible]	2	0	7

Table 6 (Continued)

Sample	Horizon	Depth from surface	Total grains counted	Quartz	Chert	Micas	Feldspars	Heavies	Opaques	Isotropics Glass	Isotropics Opal	Rock fragments
		cm		%	%	%	%	%	%	%	%	%
					Profile 9 - Asis							
63	A1	0-12	608	86	5	0	0	2	3	2	0	2
64	B2	12-86	603	85	4	2	0	1	3	2	0	3
65	IIC1	86-138	668	69	6	2	Tr	1	3	2	0	16
66	IIC2	138-214	627	83	3	2	0	2	1	2	0	7
67	IIC3	214-296	641	84	2	2	Tr	1	1	2	0	7
68	IIIC4	296-350	611	83	3	3	0	2	1	1	0	7

[a] When a mineral is present in less than 1%, it is reported as traces (Tr)

reflected light. In the lower portion of the profile some black opaques are present, probably magnetite. Sample 54 has a relatively high content of red to reddish brown particles of iron oxide. In the field this subhorizon shows the presence of sesquioxidic nodules with concentric fabric. The rock fragments are uniformly distributed in the solum with a noticeable increase in C2 horizon. The rock fragments are of metamorphic origin. In the A1 and B1 horizons, and occasionally deeper, opal phytoliths are found. They are isotropic and have square or rectangular shape with "serrated" or straight edges.

The opal phytoliths are released from grasses and trees and incorporated into the soils during decomposition of the litter or sometimes via the dung of animals (Verma and Rust, 1969). Opal phytoliths are ubiquitous and have been identified in atmospheric dust, soils, paleosoils, Pleistocene loess and other ancient sediments (Twiss _et al._, 1969). Parfenova and Yarilova (1965) point out that the vegetation of tropical regions, mainly plants of topographical depressions, is very rich in silica (for example, the ash of bamboo contains 52% SiO_2) and produces abundant opal phytoliths. Riquier (1960) has found that in certain tropical soils the phytoliths form thick horizons under bamboo and acacia vegetation. The existence of opal phytoliths in several soils of Colombia has been reported (Luna, 1969; Calhoun _et al._, 1972).

Opal phytoliths undergo transformations in soils. They are relatively soluble (unstable) and constitute one source of soil solution silica. On the other hand, they tend to lose structural water and in geologic time are converted into chert or flint as it has been postulated by Smithson (1956).

The mineralogical composition of the very fine sand of profiles 1 and 2 is dominated by resistant minerals, with no weatherable minerals, indicating an advanced weathering stage.

In soil 3 the amount of quartz tends to decrease in the lower part of the profile, due to an increase in chert, micas and rock fragments. Quartz is predominantly subrounded, however, some angular and rounded grains are found. Bubbles and bubble trains are abundant and inclusion of heavy minerals (zircon and rutile) are present. Opal phytoliths of rectangular and irregular form are present in the upper part of the profile. The mica content increases with depth and is relatively abundant below the B23 horizon. The mica is in the form of small flakes of muscovite. The rock fragments are probably of metamorphic origins and in several cases they contain some mica. The heavy and opaque minerals are zircon, rutile and hematite. A K-feldspar grain was found in the last horizon.

In profile 4 the quartz is subrounded to subangular. There are clean grains as well as grains with bubbles and heavy mineral inclusions. There are some recrystallized and stretched and crenulated quartz grains. Micas are present in small amounts in the lower part of the profile. A few feldspar grains are found. Heavies are mainly small crystals of zircon. Rock fragments are mostly metamorphic in character. The phytoliths have rectangular and elongated shape with serrated edges.

The mineralogy of profiles 3 and 4 indicates a less weathered stage in relation to profiles 1 and 2, because of the presence of mica and some remnants of feldspars. The less extensive weathering may be due, in part, to the impeded drainage conditions prevalent in the lower portion of profiles 3 and 4.

In soil 5 the chert, mica and rock fragment content tends to increase at the expense of the quartz. The quartz consists of subrounded to subangular grains with bubbles, rutile and zircon inclusions. There are also minor amounts of composite stretched quartz. In the B22 horizon some relatively large muscovite flakes with frayed edges are present. Opal phytoliths are present in the upper part of the profile; they have rectangular, squared, elongated and sometimes triangular shape. Heavy minerals are usually small needles of rutile and small zircon crystals.

In the lower part of the profile some rock fragments seem to have volcanic origin, because of the concave, concoidal surfaces and "eyes" . formed or developed when gas bubbles left the solid (frothing effect). Probably the volcanic rock material has been carried to the area by rivers coming from the Andes. The direct deposition as showers seem to be less probable, since the distance between the site and the source is more than 800 Km.

In soil 6 subangular and subrounded quartz is dominant. Quartz grains with bubbles and microlites are common. Some well defined volcanic quartz grains and some metamorphic aggregated grains are present. The mica content increases with depth and consists of muscovite flakes and sericite aggregates. A very few feldspar fragments are found. The heavy and opaque minerals are zircon, rutile and hematite. The rock fragments are predominantly of volcanic nature. Some opal phytoliths are found in the surface horizon. Volcanic glasses, characterized by irregular, arcuate shard forms and isotropic nature are found in all horizons of profile 6, indicating an influence of pyroclastic materials. The glasses have an index of refraction around 1.54, and some of them start to show an anisotropic character due to incipient crystallization (Cavaroc)[1]. The soil site is about 300 Km from the Andean volcanoes and probably the pyroclastic materials were transported and mixed with other sediments by the Putumayo River which originates in the volcanic zone of the Andes.

In profile 7 quartz is dominant, with subangular, subrounded shapes and abundant bubbles and bubble trains. In the IIC horizon there is some metamorphic quartz. Chert is absent in the horizons above the concretionary layer but is present in the IIC horizon, confirming the lithologic discontinuity. The parent material of the profile 7 is a sediment deposited over the ironstone and derived from the erosion of the Puerto Arturo sandstone, which does not have chert. The heavy minerals are zircon and rutile. Opaques are irregular to subrounded and red in reflected light (hematite). Mica is found in the lower part of the profile.

Profile 8 is in the foothills of the Eastern Cordillera in the contact area between the Garzon Massif and the Orito formation. At the bottom of the profile an extremely altered rock with a gneissic fabric is found. In some horizons a smoky, dark chert (flint) forms up to 5% the volume of the horizon. The mineralogical examination of the very fine sand indicates that quartz is predominant in A and B

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[1] Cavaroc, V. V., Assistant Professor of Geosciences, North Carolina State University at Raleigh; personal communication

horizons and rock fragments are predominant in the C horizon. Chert is present in all horizons.

The quartz is mainly subangular with some bubble inclusions. The rock fragments are of volcanic origin. Some are banded showing lava flow lines (Cavaroc)[2]. Volcanic glass with yellowish and bluish gray tinges are present in all horizons. The index of refraction is less than 1.54. The micas are in the form of small flakes. Opaques are red and black under reflected light (hematite and magnetite). Zircon and rutile contents are less abundant than the opaques. The opal phytoliths in the A horizon have rectangular, squad, elongated, trapezoidal, crescent, and ribbon-like shapes, indicating a variety of vegetative sources. A few microcline grains are present. The materials of the soil 8 are probably of a layered nature, derived from colluvial, pyroclastic, igneous and metamorphic sources.

Profile 9 was sampled in the foothills of the Andex north of Puerto Asis. Quartz is the dominant mineral. It has subangular to subrounded shape; some volcanic quartz is found. Chert contents tend to decrease with depth. Small mica flakes are uniformly distributed throughout the profile, except in the A1 horizon. Traces of feldspars are found in some horizons. The heavy minerals are abundant; the opaques tend to decrease with depth. No opal phytoliths are apparent in the profile. Volcanic glass and volcanic rock fragments are present in all horizons. There is an increase in rock fragment content in the top of the C horizon suggesting a stratification and lithologic discontinuity.

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[2] Cavaroc, V. V., Assistant Professor of Geosciences, North Carolina State University at Raleigh; personal communication

The mineralogy of the sand indicates that the materials in soils 8 and 9 contain considerably pyroclastic material, which is expected since volcanoes are quite close to these sites.

Mineralogy of the Silt

The minerals present in the silt of selected horizons were identified from X-ray diffractograms of deferrated samples. An estimation of the relative abundance of the minerals was done measuring the height of the diagnostic peaks of the 2:1 minerals (14 Å), mica (10 Å), kaolinite (7 Å) and quartz (4.26 Å). The sum of the heights was set equal to 100% and the height of each diagnostic peak was expressed as percent. The results are presented in Table 7. The percent values give only an indication of the relative abundance and by no means the actual amounts, because the intensity of the peaks depends on many factors (polarization, mass absorption, Lorentz factor, crystallinity) and consequently a direct comparison of the amounts of a mineral in a mixture as presented by peak intensities is not possible.

In soil 1 the coarse silt contained quartz with traces of hematite. The medium silt contained quartz and anatase; in the B23 horizon some kaolinite and mica were present. The fine silt (2-5 μ) showed a decrease in quartz content with depth and a concomitant increase in kaolinite and mica. In the B21 horizon (sample 24) traces of vermiculite are present.

The silt fraction of profile 2 was predominantly quartz with subordinate amounts of kaolinite and some micas. Kaolinite was found mainly in the fine and medium silt; mica in the medium silt. In the fine silt of the B22 horizon there was a small amount of intergradient 2:1-2:2 mineral; in the medium silt of the B21 horizon traces of gibbsite (4.87 Å)

Table 7. Mineralogy of the silt by X-ray diffraction of magnesium-saturated specimens[a]

Sample	Horizon	Depth from surface	Basal spacings and relative % intensity of the diagnostic peaks											
			14 Å			10 Å micas			7 Å kaolinite			4.26 Å quartz		
			2-5μ	5-20μ	20-50μ	2-5μ	5-20μ	20-50μ	2-5μ	5-20μ	20-50μ	2-5μ	5-20μ	20-50μ
		cm		%			%			%			%	
						Profile 1 - Miraf								
24	B21	60-80	Tr	0	0	5	0	0	10	0	0	85	100	100
26	B22	100-150	0	0	0	14	0	0	12	0	0	75	100	100
30	B23	300-350	0	0	0	31	22	0	27	15	0	42	63	100
						Profile 2 - Montan								
47	B21	64-84	0	0	0	0	5	0	10	10	0	90	85	100
49	B21	104-124	0	0	0	0	12	0	14	19	0	86	69	100
52	B22	173-200	4	0	0	6	22	0	30	22	3	60	56	97
55	C2	310-350	0	0	0	6	5	0	25	6	21	69	89	79
						Profile 3 - Naval								
10	B21	33-52	3	0	0	14	6	0	7	0	0	76	94	100
12	B22	72-105	5	0	0	19	16	0	14	8	0	62	76	100
13	B23	105-142	6	0	0	21	19	3	19	9	2	54	72	95
14	B24	142-200	5	0	0	28	18	4	20	8	0	47	74	96
						Profile 4 - Polvor								
33	B21	47-80	0	0	0	0	0	0	0	0	0	100	100	100
35	B22	120-157	0	0	0	0	0	0	5	0	0	95	100	100
36	C1	157-210	0	0	0	10	4	0	22	4	0	68	92	100
						Profile 5 - Tacana								
5	B21	70-83	0	0	0	6	0	4	6	0	3	88	100	93
6	B22	83-140	0	0	0	22	9	4	34	15	4	44	76	92
7	B23cn	140-200	9	0	0	23	10	6	35	12	6	33	78	88

Table 7 (Continued)

Sample	Horizon	Depth from surface	Basal spacings and relative % intensity of the diagnostic peaks											
			14 Å			10 Å micas			7 Å kaolinite			4.26 Å quartz		
			2-5µ	5-20µ	20-50µ	2-5µ	5-20µ	20-50µ	2-5µ	5-20µ	20-50µ	2-5µ	5-20µ	20-50µ
		cm		%			%			%			%	
						Profile 6 - Leguiz								
38	B21	20-80	0	0	0	5	5	3	10	16	0	85	79	97
39	B22	80-133	9	0	0	8	8	3	0	35	5	45	57	92
42	IIC2	215-243	25	0	0	5	13	3	0	24	5	40	63	92
						Profile 7 - Guavia								
18	B21	47-75	0	0	0	10	3	0	12	0	0	78	97	100
19	B22	75-97	0	0	0	24	6	0	24	4	0	52	90	100
20	IIC	124-240	0	0	0	32	14	0	24	10	0	44	76	100
						Profile 8 - Floren								
58	B22	85-173	0	0	0	23	0	0	40	6	0	37	94	100
60	C1	208-228	0	0	0	34	4	13	30	13	11	36	83	76
62	C3	247-350	0	0	0	24	6	0	49	26	43	27	68	57
						Profile 9 - Asis								
64	B2	12-86	18	10	0	10	8	0	12	10	0	60	70	100
65	IIC1	86-138	17	13	0	10	10	0	24	17	0	49	60	100
68	IIIC4	296-350	13	5	0	9	6	0	10	6	0	68	83	100

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[a] Relative intensity of the diagnostic peaks in percentage calculated from peak heights

were found. However, no indication of gibbsite was found in the fine silt or the clay (by DTA). Traces of hematite were noticed in the coarse silt.

The relative amount of quartz in the silt fraction of profile 3 decreased with depth, and the relative amounts of micas and kaolinite increased with depth. Micas were relatively abundant; mainly in the fine silt there were also 2:1 minerals, vermiculite and montmorillonite. Traces of anatase (3.51 Å) and zircon (4.43 Å) were noticed.

In soil 4 the silt fraction contained quartz, some kaolinite, mica and traces of anatase. The micas were present near the bottom of the profile.

In soil 5 the relative amounts of mica and kaolinite in the silt increased with depth at the expense of the quartz. Mica and kaolinite were found mainly in fine silt. Some vermiculite and 2:1-2:2 mineral were present in the B23 horizon. Traces of anatase, zircon and hematite were found mainly in the medium and coarse silt.

In the silt of profile 6, quartz, kaolinite, mica, montmorillonite and vermiculite were found. Kaolinite was mainly present in the medium silt and micas in the medium and fine silt. Their presence tends to increase with depth. The 14 Å minerals were found only in the fine silt fraction and their contents increase with depth. Traces of anatase and zircon were found in the coarse silt.

The coarse silt fraction of soil 7 was composed of quartz; the medium silt consists of quartz, some mica and some kaolinite. In the fine silt the quartz content decreased with depth with a corresponding increase in the content of mica and kaolinite.

In the fine silt of profile 8, kaolinite (with a very broad peak) was relatively abundant and became dominant in the C3 horizon. Mica was also relatively abundant. Traces of magnetite (4.87 Å) were found. The medium silt was dominated by quartz with subordinate amounts of kaolinite and small amounts of mica. Both kaolinite and mica increase with depth. The kaolinite content of the coarse silt fraction increased with depth and became the dominant mineral in the C3 horizon.

The coarse silt of soil 9 was composed of quartz with traces of zircon. The medium silt consisted of quartz, kaolinite, micas and some amounts of montmorillonite-vermiculite. The fine silt showed the same mineralogical composition but with somewhat more montmorillonite-vermiculite and traces of pyrophyllite or talc.

The mineralogical picture of the sand and silt fractions indicates that the soils of the present study have undergone chemical weathering strong enough to decompose the weatherable minerals less table than muscovite. Similar mineralogical composition has been reported by Pratt _et al._ (1969) for soils of Brazil, by Estrada (1971) for soils of Amazonia of Peru, and by Guerreno (1971) for the eastern plain soils of Colombia.

Mineralogy of the Clay

McCracken (1968) has pointed out the urgent need to obtain complete mineralogical information for tropical soils, as clay mineral suites in some of these soils may differ from those of temperate regions and such differences may cause problems in the transfer of agronomic technology to developing countries.

The objective of this part of the study was to characterize the minerals present in the clay fraction and to estimate their amounts and their distribution through the soil profiles. A combination of methods was used including X-ray diffraction, differential thermal, selective dissolution and total elemental analysis.

Table 8 contains a summary of the interpretation of the X-ray patterns which includes the identification of minerals as well as an estimation of their relative abundance.

Table 9 shows the quantitative estimate of the minerals in the clay fraction. The total analysis of clay, including silica, alumina, potassium, and the cation exchange capacity of the deferrated clay are presented in Table 10. Table 11 shows the amorphous silica and alumina extracted according to the Hashimoto and Jackson (1960) procedure. It is important to notice that using this procedure some crystalline minerals are dissolved; therefore, the reported values in Table 11 are somewhat higher than the true amorphous minerals.

Mica is present in all soils in amounts varying between 7 and 45%. The primary sources of micas of the Amazon soils are the rocks of the Eastern Cordillera. Gibbs (1967) has found that the mica in the sediments of the Amazon River is derived directly from the Andean mountains. Jackson (1965b) has stated that micas can be inherited from minerals of Quaternary, Tertiary or even older formations.

The presence of vermiculites, montmorillonites and 2:1-2:2 minerals in the Amazonian soils may indicate that the micas have suffered a pedochemical weathering consisting in depotassication, opening of the interlayers and further precipitation of hydroxy-Al and/or hydroxy-Fe compounds in the interlayers.

Table 8. Mineralogy of the clay (<2 μ); estimation of the relative abundance based on the intensity of the diagnostic peaks in the X-ray diffractograms

Sample	Horizon	Depth	Relative abundance of minerals in clay fraction[a]
		cm	
		Profile 1 - Miraf	
21	A1	0-21	K4 V2 G1 V/C1
24	B21	60-80	K4 V2 G1 V/C1
26	B22	100-150	K4 V2 V/C1 G1 Mi1
27	B23	150-200	K4 V1 G1 V/C1 Mi1
30	B23	300-350	K4 Mi2 V1 G1
		Profile 2 - Montan	
44	A1	0-17	K4 V1 M1 V/C1 Q1
46	B1	37-64	K4 V1 M1 V/C1 Q1
49	B21	104-124	K4 V1 M1 V/C1 Q1
52	B22	173-200	K4 V1 M1 V/C1 Mi1 Q1
54	C1	227-310	K4 V1 M1 V/C1 Mi1 Q1
55	C2	310-350	K4 V1 M1 V/C1 Q1 Mi1
		Profile 3 - Naval	
8	A1	0-13	K3 Mi3 M1 V1 Q1 P1
10	B21	33-52	K4 Mi3 M1 V1 V/C1 Q1
12	B22	72-105	K4 Mi3 M1 V1 V/C1
13	B23	105-142	K3 Mi3 M1 V1 V/C1
14	B24	142-200	K3 Mi3 M1 V1 V/C1
15	B24	200-250	K3 Mi3 M2 V1 Q1
		Profile 4 - Polvor	
31	A1	0-17	K4 V2 Mi1 M1 V/C1 Q1
33	B21	47-80	K3 Mi2 V1 M1 V/C1 Q1
35	B22	120-157	K4 Mi2 V1 M1 V/C1 P1 Q1
36	C1	157-210	K3 M2 Mi2 V1 V/C1 Q1
		Profile 5 - Tacana	
1	A1	0-10	K4 V2 V/C2 Mi1 Q1 G1
3	B21	30-50	K4 V2 V/C2 Mi1 Q1 G1 P1
5		70-83	K3 V2 V/C2 Q2 Mi1 G1 P1
6	B22	83-140	K4 V2 V/C2 Mi1 Q1 G1
7	B23cn	140-200	K4 V2 V/C2 Mi2 Q1
		Profile 6 - Leguiz	
37	A1	0-20	K4 Mi2 M1 V1 V/C1 Q1 P1
38	B21	20-80	K4 M2 V1 V/C1 Mi1
39	B22	80-133	K4 M2 Mi2 V1 V/C1 Q1
40	IIB23	133-173	K3 M2 Mi2 V1 V/C1 Q1
42	IIC2	215-243	K3 M3 V1 V/C1 Mi1
43	IIIC3	243-265	K4 M2 Mi2 V1 V/C1

Table 8 (Continued)

Sample	Horizon	Depth	Relative abundance of minerals in clay fraction[a]
		cm	
		Profile 7 - Guavia	
16	A11	0-25	K3 V2 V/C2 Mi1
17	A12	25-47	K4 V2 V/C2 Mi1
18	B21	47-75	K4 V2 V/C2 Mi1
19	B22cn	75-97	K4 V2 Mi1 V/C1 G1
20	IIC	124-240	K4 Mi3 V1
		Profile 8 - Floren	
56	A1	0-16	K4 Mi2 V1 V/C1 G1
57	B21	16-85	K4 Mi2 V1 V/C1 G1
58	B22	85-173	K4 Mi2 V1 V/C1 G1
59	B3	173-208	K4 Mi3 V1 M1 V/C1 G1
61	C2	228-247	K4 Mi2 V1 M1 V/C1 G1
		Profile 9 - Asis	
63	A1	0-12	K3 V2 Mi2 M1 V/C1 G1
64	B2	12-86	K3 V2 V/C2 Mi2 M1 G1
65	IIC1	86-138	K3 Mi3 V2 V/C2 M1 Q1
68	IIIC4	296-350	K3 Mi2 M2 V1 V/C1 Q1

[a] Code:

K = kaolinite
Mi = mica
M = montmorillonite
V = vermiculite
Q = quartz
P = pyrophyllite
C = chlorite
V/C = 2:1-2:2 intergrade, partially hydroxy aluminum interlayered

Relative abundance:

1 < 10%
2 = 10-25%
3 = 25-50%
4 > 50%

Table 9. Quantification of the minerals in the deferrated clay; free iron oxide in clay and soil[a]

Sample	Horizon	Depth	Amorphous minerals	Quartz	Gibbsite	Kaolinite	Mica	Free Fe_2O_3 Clay	Free Fe_2O_3 Soil
		cm	%	%	%	%	%	%	%
				Profile 1 - Miraf					
21	A1	0-21	10	0	7	57	8	13.7	10.4
22	B1	21-38	8	0	9	62	8	12.6	11.1
23	B21	38-60	9	0	8	55	8	12.9	11.1
24		60-80	9	0	9	44	7	12.6	10.8
25		80-100	6	0	10	48	7	12.6	10.4
26	B22	100-150	7	0	11	45	8	13.7	11.1
27	B23	150-200	6	0	10	53	9	13.7	11.4
28		200-250	9	0	8	49	10	13.7	12.2
29		250-300	7	0	5	49	13	13.7	11.4
30		300-350	6	0	2	49	22	13.8	11.1
				Profile 2 - Montan					
44	A1	0-17	7	2	0	55	9	5.7	6.6
45	B1	17-37	7	3	0	60	8	7.0	5.7
46		37-64	6	3	0	60	8	7.7	6.9
47	B21	64-84	7	3	0	65	8	8.4	6.2
48		84-104	7	3	0	57	9	7.1	7.2
49		104-124	8	3	0	54	8	7.9	7.3
50		124-153	9	2	0	57	7	7.1	7.3
51	B22	153-173	8	2	0	57	9	7.1	7.8
52		173-200	7	3	0	63	10	7.2	7.
53		200-227	6	2	0	51	11	7.1	7.
54	C1	227-310	6	2	0	58	16	7.1	9.
55	C2	310-350	5	5	0	77	18	4.0	5

Table 9 (Continued)

Sample	Horizon	Depth	Amorphous minerals	Quartz	Gibbsite	Kaolinite	Mica	Free Fe_2O_3	
								Clay	Soil
		cm	%	%	%	%	%	%	%
				Profile 3 - Naval					
8	A1	0-13	8	4	0	35	45	1.0	0.2
9	B21	13-33	7	4	0	41	32	1.4	0.3
10		33-52	8	0	0	43	29	1.4	0.4
11	B22	52-72	7	0	0	49	27	1.2	0.6
12		72-105	6	0	0	46	25	1.8	1.1
13	B23	105-142	7	0	0	41	26	1.9	1.1
14	B24	142-200	9	0	0	40	27	2.2	1.5
15		200-250	8	7	0	32	28	2.2	1.3
				Profile 4 - Polvor					
31	A1	0-17	7	5	0	42	17	4.1	1.7
32	B1	17-47	7	4	0	48	18	4.2	1.8
33	B21	47-80	8	8	0	36	19	4.1	2.2
34	B22	80-120	6	16	0	41	16	4.1	3.2
35		120-157	5	11	0	45	17	4.1	3.0
36	C1	157-210	6	3	0	39	18	2.9	[illegible]
				Profile 5 - Tacana					
1	A1	0-10	10	6	2	50	19	5.	
2	B21	10-30	8	4	3	41	17	5	
3		30-50	9	8	3	46	18	5	
4		50-70	10	5	3	41	18		
5		70-83	11	10	3	39	14		
6	B22	83-140	8	4	4	53	17		
7	B23cn	140-200	11	5	2	55	18		

Table 9 (Continued)

Sample	Horizon	Depth	Amorphous minerals	Quartz	Gibbsite	Kaolinite	Mica	Free Fe_2O_3	
								Clay	Soil
		cm	%	%	%	%	%	%	%
				Profile 6 - Leguiz					
37	A1	0-20	5	9	0	39	19	1.8	1.7
38	B21	20-80	6	0	0	47	14	6.0	5.1
39	B22	80-133	8	6	0	48	16	7.6	4.9
40	IIB23	133-173	6	0	0	38	14	4.7	3.0
41	IIC1	173-215	9	0	0	38	14	5.6	2.7
42	IIC2	215-243	9	0	0	28	16	4.2	3.0
43	IIIC3	243-265	7	0	0	43	14	4.5	1.4
				Profile 7 - Guavia					
16	A11	0-25	8	0	2	38	18	5.1	1.6
17	A12	25-47	8	0	1	46	19	5.8	2.0
18	B21	47-75	8	0	1	44	19	5.1	2.2
19	B22cn	75-97	7	0	2	50	25	5.7	3.3
20	IIC	124-140	4	0	0	50	37	4.2	5.7
				Profile 8 - Floren					
56	A1	0-16	10	0	2	45	22	7.2	3.9
57	B21	16-85	10	0	3	59	23	7.4	5.9
58	B22	85-173	9	0	3	61	20	7.1	6.1
59	B3	173-208	9	0	2	62	27	6.9	3.2
60	C1	208-228	9	0	2	50	38	5.6	1.7
61	C2	228-247	10	0	1	55	20	7.0	5.9
62	C3	247-350	13	0	1	59	21	4.9	2.8

Table 9 (Continued)

Sample	Horizon	Depth	Amorphous minerals	Quartz	Gibbsite	Kaolinite	Mica	Free Fe_2O_3 Clay	Free Fe_2O_3 Soil
		cm	%	%	%	%	%	%	%
				Profile 9 - Asis					
63	A1	0-12	9	4	0	31	18	4.3	2.0
64	B2	12-86	8	5	0	29	18	5.6	3.6
65	IIC1	86-138	7	10	0	32	26	5.4	4.2
66	IIC2	138-214	4	18	0	24	26	5.4	3.8
67	IIC3	214-296	5	14	0	30	26	5.0	4.2
68	IIC4	296-350	[illegible]	14	0	29	21	3.4	1.6

*Minerals in percentage of the deferrated clay; amorphous minerals by Hashimoto and Jackson (1960), quartz by X ray diffraction, gibbsite and kaolinite by DTA, mica by K_2O % x 10

Table 10. Analysis of the clay; silica, alumina, their molar ratio; cation exchange capacity of the deferrated clay

Sample	Horizon	Depth	SiO_2	Al_2O_3	SiO_2/Al_2O_3	K_2O	CEC $Mg(OAc)_2$	CEC NH_4OAc
		cm	%	%	Molar ratio	%	meq/100 g clay	
				Profile 1 - Miraf				
21	A1	0-21	42.78	30.62	2.37	0.84	19.6	12.9
22	B1	21-38	42.77	26.50	2.73	0.81	19.1	12.9
23	B21	38-60	42.78	32.06	2.26	0.78	17.6	10.8
24		60-80	41.71	27.83	2.54	0.70	16.8	10.8
25		80-100	41.29	30.62	2.28	0.73	18.3	12.9
26	B22	100-150	42.78	29.76	2.44	0.81	17.2	12.9
27	B23	150-200	45.45	29.70	2.60	0.90	17.3	10.8
28		200-250	43.31	28.63	2.58	0.97	17.3	10.9
29		250-300	48.31	25.51	3.21	1.32	16.3	10.3
30		300-350	53.48	26.36	3.44	2.20	16.3	10.3
				Profile 2 - Montan				
44	A1	0-17	53.48	30.62	2.97	0.88	22.7	12.9
45	B1	17-37	54.01	26.44	3.46	0.81	23.5	23.4
46		37-64	50.91	27.83	3.10	0.82	21.4	18.4
47	B21	64-84	50.90	24.77	3.47	0.81	19.4	15.7
48		84-104	53.48	26.44	3.44	0.86	22.9	16.2
49		104-124	53.05	28.11	3.21	0.77	19.2	12.9
50		124-153	48.13	25.89	3.15	0.73	21.2	17.9
51	B22	153-173	48.14	27.83	2.95	0.86	18.7	13.5
52		173-200	48.13	24.77	3.29	0.97	18.9	12.4
53		200-227	48.13	25.89	3.15	1.06	21.2	12.9
54	C1	227-310	43.31	24.77	2.97	1.60	21.4	11.9
55	C2	310-350	48.73	23.94	3.46	1.77	19.1	13.5

Table 10 (Continued)

Sample	Horizon	Depth	SiO_2	Al_2O_3	SiO_2/Al_2O_3	K_2O	CEC Mg$(OAc)_2$	CEC NH_4OAc
		cm	%	%	Molar ratio	%	meq/100 g clay	
				Profile 3 - Naval				
8	A1	0-13	54.54	25.05	3.69	4.54	19.7	21.8
9	B21	13-33	53.48	22.27	4.07	3.21	29.3	22.8
10		33-52	53.49	22.27	4.07	2.87	26.5	23.4
11	B22	52-72	54.54	22.28	4.06	2.70	29.6	21.3
12		72-105	53.48	23.71	3.83	2.45	30.1	23.4
13	B23	105-142	45.56	25.61	3.02	2.62	32.3	23.2
14	B24	142-200	50.27	19.48	4.38	2.71	35.9	26.0
15		200-250	51.33	21.15	4.12	2.79	36.5	26.0
				Profile 4 - Polvor				
31	A1	0-17	50.91	22.96	3.77	1.69	33.2	24.3
32	B1	17-47	54.01	23.81	3.85	1.83	34.4	24.3
33	B21	47-80	50.90	23.82	3.63	1.94	30.8	24.3
34	B22	80-120	53.05	22.67	3.97	1.60	28.8	23.2
35		120-157	53.05	22.68	3.97	1.69	27.8	23.2
36	C1	157-210	54.01	22.96	3.99	1.84	37.7	30.7
				Profile 5 - Tacana				
1	A1	0-10	50.27	26.49	3.21	1.86	28.6	21.3
2	B21	10-30	53.48	25.61	3.54	1.69	26.0	20.8
3		30-50	50.28	25.65	3.33	1.77	27.0	19.8
4		50-70	50.27	26.49	3.22	1.77	25.5	19.7
5		70-83	53.48	26.27	4.07	1.35	21.9	15.6
6	B22	83-140	50.28	27.83	3.06	1.69	25.7	17.7
7	B23cn	140-200	50.27	26.48	3.22	1.77	22.4	16.6

Table 10 (Continued)

Sample	Horizon	Depth	SiO_2	Al_2O_3	SiO_2/Al_2O_3	K_2O	CEC	
							$Mg(OAc)_2$	NH_4OAc
		cm	%	%	Molar ratio	%	meq/100 g clay	
				Profile 6 - Leguiz				
37	A1	0-20	56.15	23.96	3.97	1.96	33.7	31.8
38	B21	20-80	50.91	22.67	3.82	1.35	36.5	27.6
39	B22	80-133	50.91	22.68	3.80	1.60	38.0	30.7
40	IIB23	133-173	50.90	23.96	3.60	1.04	42.3	37.4
41	IIC1	173-215	48.13	20.88	3.92	1.43	38.2	33.3
42	IIC2	215-243	53.48	20.89	4.34	1.60	49.8	42.1
43	IIIC3	243-265	50.91	20.89	4.14	1.43	37.7	29.2
				Profile 7 - Guavia				
16	A11	0-25	50.27	25.05	3.40	1.77	21.9	13.0
17	A12	25-47	50.27	25.61	3.33	1.86	22.9	14.0
18	B21	47-75	49.20	25.50	3.15	1.94	19.1	13.0
19	B22cn	75-97	49.21	25.05	3.33	2.45	20.1	13.0
20	IIC	124-140	41.71	22.27	3.18	3.72	24.5	14.0
				Profile 8 - Floren				
56	A1	0-16	43.31	22.27	3.29	2.19	22.9	14.6
57	B21	16-85	43.85	28.23	3.63	2.28	10.7	12.9
58	B22	85-173	43.85	28.90	2.58	2.03	10.7	13.5
59	B3	173-208	43.88	28.23	2.63	2.71	9.9	11.9
60	C1	208-228	45.45	28.90	2.66	3.81	8.2	8.2
61	C2	228-247	45.05	23.52	3.26	1.95	13.5	13.0
62	C3	247-350	42.24	28.40	3.53	2.11	8.0	7.6

Table 10 (Continued)

Sample	Horizon	Depth	SiO_2	Al_2O_3	SiO_2/Al_2O_3	K_2O	CEC $Mg(OAc)_2$	 NH_4OAc
		cm	%	%	Molar ratio	%	meq/100 g clay	
				Profile 9 - Asis				
63	A1	0-12	48.13	23.39	3.50	1.78	29.1	28.1
64	B2	12-86	48.13	21.26	3.83	1.78	27.4	27.0
65	IIC1	86-138	48.15	22.67	3.60	2.62	30.1	30.2
66	IIC2	138-214	48.16	20.41	4.00	2.62	31.1	30.8
67	IIC3	214-296	48.13	21.26	3.83	2.63	30.3	28.8
68	IIIC4	296-350	48.14	20.97	3.90	2.11	24.0	25.3

Table 11. Amorphous silica and alumina extracted from deferrated clay by selective dissolution analysis[a]

Sample	Horizon	Depth	SiO_2	Al_2O_3 Total	Al_2O_3 In gibbsite	Al_2O_3 Net	$\frac{SiO_2}{Al_2O_3}$
		cm	%	%	%	%	Molar ratio
			Profile 1 - Miraf				
21	A1	0-21	3.53	8.97	4.55	4.42	1.36
22	B1	21-38	3.10	9.40	5.85	3.55	1.48
23	B21	38-60	3.54	9.21	5.20	4.01	1.49
24		60-80	3.53	9.40	5.85	3.55	1.68
25		80-100	2.57	9.21	6.50	2.71	1.61
26	B22	100-150	2.57	9.21	7.15	2.06	2.73
27	B23	150-200	2.25	9.47	6.50	2.97	1.29
28		200-250	2.35	10.62	5.20	5.42	0.73
29		250-300	2.25	7.08	3.25	3.83	1.00
30		300-350	2.04	4.60	1.30	3.30	1.05
			Profile 2 - Montan				
44	A1	0-17	3.85	2.67	0.0	2.67	2.88
45	B1	17-37	3.32	2.31	0.0	2.31	2.44
46		37-64	3.21	2.21	0.0	2.21	2.46
47	B21	64-84	3.64	2.50	0.0	2.50	2.47
48		84-104	3.21	2.55	0.0	2.55	2.14
49		104-124	4.17	2.31	0.0	2.31	3.05
50		124-153	4.46	2.78	0.0	2.78	2.71
51	B22	153-173	3.42	2.83	0.0	2.83	2.05
52		173-200	3.10	2.36	0.0	2.36	2.22
53		200-227	2.67	2.31	0.0	2.31	1.97
54	C1	227-310	2.72	2.29	0.0	2.29	2.05
55	C2	310-350	2.57	1.23	0.0	1.23	3.55
			Profile 3 - Naval				
8	A1	0-13	4.28	2.01	0.0	2.01	3.61
9	B21	13-33	3.74	2.13	0.0	2.13	2.99
10		33-52	4.28	2.13	0.0	2.13	3.39
11	B22	52-72	3.31	2.14	0.0	2.14	2.63
12		72-105	3.31	2.01	0.0	2.01	2.80
13	B23	105-142	3.64	2.39	0.0	2.39	2.58
14	B24	142-200	4.28	2.83	0.0	2.83	2.57
15		200-250	4.17	2.13	0.0	2.13	3.33
			Profile 4 - Polvor				
31	A1	0-17	3.10	2.36	0.0	2.36	2.22
32	B1	17-47	3.11	2.39	0.0	2.39	2.21
33	B21	47-80	3.06	2.36	0.0	2.36	2.21
34	B22	80-120	3.06	1.87	0.0	1.87	2.76
35		120-157	2.25	1.84	0.0	1.84	2.06
36	C1	157-210	3.21	2.05	0.0	2.05	2.66

Table 11 (Continued)

Sample	Horizon	Depth	SiO_2	Al_2O_3			$\frac{SiO_2}{Al_2O_3}$
				Total	In gibbsite	Net	
		cm	%	%	%	%	Molar ratio
			Profile 5 - Tacana				
1	A1	0-10	3.74	5.60	1.30	4.30	1.48
2	B21	10-30	3.52	5.20	1.90	3.30	1.82
3		30-50	3.64	5.67	1.90	3.77	1.65
4		50-70	4.60	5.67	1.90	3.77	2.32
5		70-83	4.73	5.91	1.90	4.01	2.02
6	B22	83-140	3.53	5.67	2.60	3.07	1.95
7	B23cn	140-200	4.38	5.68	1.30	4.37	1.70
			Profile 6 - Leguiz				
37	A1	0-20	2.46	1.80	0.0	1.80	2.32
38	B21	20-80	2.78	2.55	0.0	2.55	1.84
39	B22	80-133	3.74	2.79	0.0	2.79	2.27
40	IIB23	133-173	3.21	2.31	0.0	2.31	2.36
41	IIC1	173-215	4.30	3.30	0.0	3.30	2.21
42	IIC2	215-243	4.60	2.83	0.0	2.83	2.77
43	IIIC3	243-265	3.64	2.31	0.0	2.31	2.66
			Profile 7 - Guavia				
16	A11	0-25	3.64	3.01	1.30	1.71	3.61
17	A12	25-47	3.32	3.07	0.65	2.42	2.32
18	B21	47-75	3.10	3.54	0.65	2.89	1.81
19	B22	75-97	3.10	2.98	1.30	1.63	3.22
20	IIC	124-140	2.46	1.18	0.0	1.18	3.53
			Profile 8 - Floren				
56	A1	0-16	4.81	4.73	1.30	3.42	2.41
57	B21	16-85	4.49	5.20	1.95	3.25	2.34
58	B22	85-173	4.85	4.12	1.95	2.17	3.78
59	B3	173-208	4.06	4.96	1.30	3.66	1.88
60	C1	208-228	4.06	4.30	1.30	3.00	2.29
61	C2	228-247	4.38	4.72	0.65	4.07	1.83
62	C3	247-350	5.15	6.14	0.65	5.49	2.41
			Profile 9 - Asis				
63	A1	0-12	4.17	3.46	0.0	3.46	2.05
64	B2	12-86	3.66	3.26	0.0	3.26	2.75
65	IIC1	86-138	3.10	2.36	0.0	2.36	2.22
66	IIC2	138-214	2.03	1.25	0.0	1.25	2.73
67	IIC3	214-296	2.14	1.70	0.0	1.70	2.12
68	IIIC4	296-350	2.14	1.75	0.0	1.75	2.07

[a] Selective dissolution analysis by Hashimoto and Jackson (1960)

Montmorillonite is present in all soils, except in profiles 1, 5, and 7. However, in some cases it was difficult to distinguish between montmorillonite and vermiculite. The origin of the montmorillonite in these soils constitutes an interesting problem which deserves further study. Some possibilities are explored. In soils 2, 8 and 9, the relatively small amount of montmorillonite may have been formed from micas, according to the weathering sequence: mica → vermiculite → montmorillonite. Another possibility of montmorillonite formation in these soils is by a process of dealuminization of the 2:1-2:2 minerals in very acid environment, where a protonation results in the solubilization of interlayer materials giving rise to minerals which are free to expand (Malcolm _et al_., 1969; Gjems, 1970).

In the soils with impeded drainage (profiles 3 and 4), "neoformation" (Pedro _et al_., 1969) or recombination of Si and Al in presence of bases may have produced some of the montmorillonite found in sizeable concentrations in the lower portions of the profiles 3 and 4.

In profile 6 montmorillonite is high and becomes dominant in the lower part of the profile. The presence of volcanic glass, volcanic rock fragments and the layered nature of the soil suggests that montmorillonite was formed from volcanic ash deposited either directly as showers or brought about from the Andes into the Amazonic Llanos by the Putumayo River. There is increasing evidence that volcanic ash falls have occurred in the eastern portion of Colombia, and even very thin blankets of ash or volcanic dust have had an influence on the chemical characteristics of the soils; for example by increasing the CEC (Goosen).[3]

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[3] Goosen, Doeko, Professor of Soils, International Training Center (I.T.C.), Delft, Holland; personal communication

After this general digression it seems convenient to describe the clay mineralogy of the individual profiles and some of the implications. Discussion of profile 1 will be relatively extensive because many of the findings and points treated apply for all soils of the area.

Soil 1 Miraf

In the A1 horizon of profile 1, the principal peak intensities were recorded at 14.1, 7.1, 4.82, 4.37, 3.57 Å, with a very small hump at 10.2 Å. The relatively broad 14.1 Å peak was identified as vermiculite and 2:1-2:2 intergrade because the glycerol-solvated sample did not shift the peak; K-saturation did not alter the 14 Å peak, heating the K-saturated sample resulted in a breakdown of the 14 Å with a shift of intensities mainly to broaden 10 Å and 12 Å.

The 7.1 Å and 3.57 Å peaks were very sharp,asymmetrical peaks, indicating a very well crystallized kaolinite. The 4.82 Å and 4.37 Å peaks were identified as gibbsite, which was later confirmed by DTA results.

In the B horizon of profile 1 a similar behavior to the different treatments, and the same peaks as in the A horizon, was identified, except that in samples 25 to 30 a 10 Å peak was present. This peak, identified as mica, increased in intensity with depth.

The intensity and sharpness of the gibbsite reflections increased with depth until sample 28 (200 cm) and then gradually decreased. The same trend is shown in the quantitative analysis by DTA (Table 9). The kaolinite peak intensities decrease from surface to the top of the B22 horizon, then tend to decrease.

Table 9 and Figure 4 summarize the mineralogical composition of the clay fraction and the free iron oxide content in the clay and in the whole soil. Table 10 contains the results of total elemental analysis of clay (silica, alumina, potassium) as well as the CEC of the clay as determined with $Mg(OAc)_2$ and NH_4OAc.

Since K-feldspars were not detected in the clay fraction of any of the soils, the total K was attributed to the mica. The amount of mica was estimated using the factor 1% K_2O equal 10% mica, proposed by Jackson (1956) and Mehra and Jackson (1959). However, it must be admitted that not all the calculated mica is true mica. Part of the K is in mica particles (which give 10 Å peak) and part is formed by the complete transition series from mica → vermiculite, which may contain traces of K. It is reasonable to assume that the use of the 10% K_2O leads to an overestimation of the mica present; however, this ratio is extensively used for comparative purposes. Jackson (1964) has indicated that for clays containing vermiculites, montmorillonites, about 5 to 10% overestimation of micas may result when the 10% K_2O equal 100% mica factor is used.

In samples 21-24 of profile 1, the X-ray diffractograms showed no evidence of mica; however, about 8% of mica based on K_2O is present. Tan (1971) has found that the mica in soil clay was detected by X-ray diffraction when the amount was slightly above 8.2%. Also [illegible] and Dixon (1963) have concluded that 15% or more of mica, based on K content, may not be shown as a discrete 10 Å X-ray peak and that larger amounts often show only small peaks and broad humps produced by interstratified systems.

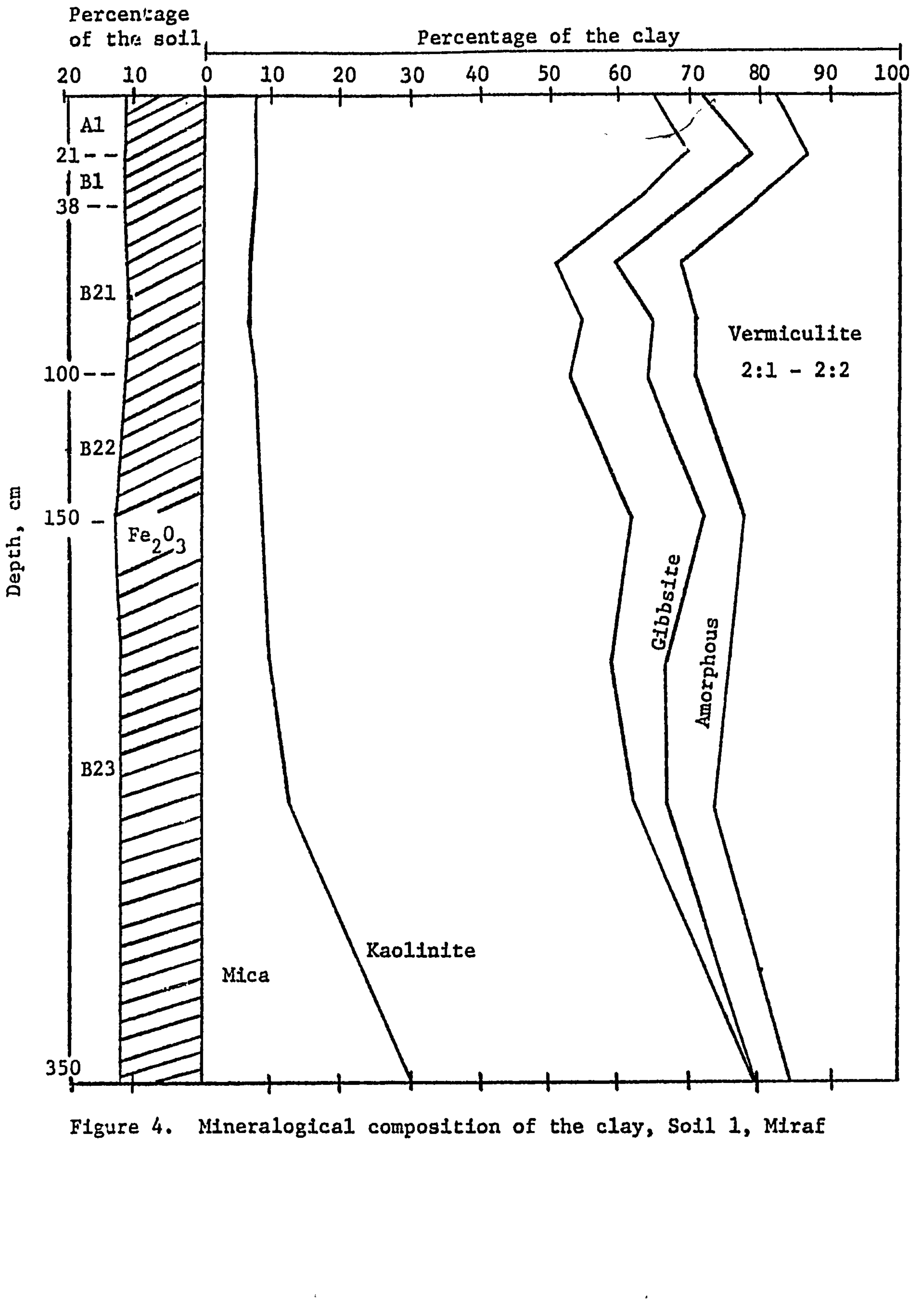


Figure 4. Mineralogical composition of the clay, Soil 1, Miraf

In profile 1 the mica content increased as kaolinite content decreased with depth. The gibbsite content increases from the A to B22 horizon and then decreases to 2% at the bottom. The content of amorphous material decreases slightly with depth. The free iron oxide content of the clay fraction decreases in the B1 and B21 horizons and increases slightly in the B22 and B23 horizons.

According to the estimation made from the X-ray diffraction pattern, the vermiculite content decreased with depth, being 10-25% in the A1 and B22 and decreasing to less than 10% in the B23 horizon. The 2:1-2:2 intergradient minerals were present in amounts less than 10% through the profile.

Accumulation of polymeric hydroxy-aluminum cations as interlayers in the 2:1 minerals of soil is a characteristic of pedochemical weathering, with the formation of 2:1-2:2 intergrades, which are regarded as a genetic stage in the 2:2 → 1:1 weathering sequence through which kaolinite develops (Jackson, 1963). The occurrence of interlayered 2:1 minerals has been reported in many acid tropical soils (Estrada, 1971; Guerrero, 1971; Lepsch, 1973). The relatively low amounts of 2:1-2:2 minterals in the Amazonian soils must be due either to a relatively low concentration of 2:1 minerals and/or to the lack of frequent wetting and drying (Rich, 1968).

In general, the mineralogical picture of the profile 1 follows the Jackson weathering sequence and the Jackson weathering depth function (Jackson and Sherman, 1953). The horizons near the surface are more weathered than the deeper horizons. In fact, kaolinite, a resistant material, indicative of advanced weathering, decreases with depth. Mica, with moderate weathering resistance, increases progressively from surface downward and simultaneously the vermiculite content decreases with depth. The relatively low gibbsite content in the A1 may be due to the relatively low pH that prevents gibbsite nucleation and favors the deposition of aluminum in the interlayer positions of the vermiculite (antigibbsite effect--Jackson, 1964) and/or to the presence of organic matter that complexes the Al (Glenn and Nash, 1963).

The total SiO_2 (Table 10) of soil 1 tends to increase and Al_2O_3 tends to decrease as a function of depth.

The cation exchange capacity of the clay tends to decrease with depth (Table 10) correlating with the amount of vermiculite present which tends to decrease with depth (Table 8).

The contents of amorphous materials (Table 9) are relatively low. Moniz and Jackson (1967) have reported 16 to 40% for soils developed from basalts; Townsend and Reed (1971) found about 20% in latosol of Panama developed from basaltic pebbles; Perkins et al. (1971) and Tan et al. (1970) found more than 30% amorphous materials in Ap horizon, more than 48% in B22 and more than 84% in the C horizon of a Reddish Brown Lateritic soil. The relatively low values reported here are due to the nature of the parent material.

The amorphous materials in this and in the other soils studied are products from the weathering of clay minerals. The molar ratio of amorphous silicates (Table 11) is low with respect to that of kaolinite, suggesting that they are being converted into gibbsite and SiO_2 which is leached out of the profile.

The profile 1 has the highest content of free Fe_2O_3 of all the soils studied (11%). In other soils the free Fe_2O_3 ranges from 9% in the C horizon of profile 2 to 0.2% in the A1 horizon of profile 3. The relatively low content of iron oxide reflects the nature of the sedimentary parent material which was derived mostly from acid rocks low in ferromagnesium minerals. The Oxisols of Llanos Orientales have comparable amounts of free Fe_2O_3 (Guerrero, 1971) and some Ultisols of the Peruvian Amazonia have amounts varying between 2 and 8% free iron oxide. Brazilian Oxisols usually have higher amounts ranging between 15 and 30% (Moniz and Jackson, 1967; Moura, 1968; Pratt et al., 1969).

In soil 1 the amount of free Fe_2O_3 associated with the clay is around 13%, which is about equal to the "saturation point," of the clays by free iron. Saturation point has been determined to be from 10 to 12% Fe_2O_3 for some Congo clays (D'Hoore, 1954); 10 to 14% for Ultisols (Soileau and McCracken, 1967) and for other tropical soils (Eswaran and Sys, 1970). According to the saturation point concept, introduced by D'Hoore (1954), the clays act as centers for the precipitation of the iron compounds during soil development. When the free Fe_2O_3 is greater than 10 to 14%, the clay will be saturated with iron and the excess will settle on other fractions of soil material. When the saturation point of kaolinitic clay is reached, it will provide a suitable surface for the initiation of an iron pan (Oades, 1963). When the free Fe_2O_3 is below the saturation point, there is no Fe available for cementing any of the particles.

The relatively low content of free iron oxide may be one of the causes for the differences in structure between the Brazilian Oxisols, strong very fine granular, very stable, so that granules act as sand grains, and the prismatic, blocky and weak to moderate granular structures observed in the Upper Amazon soils.

In the Soil Taxonomy (Soil Survey Staff, 1970), the amounts of free iron oxide and gibbsite in the soil with relation to clay are diagnostic for the oxidic family. In the control section of profile 1, the ratio equals

$$\frac{11\%\ Fe_2O_3 + 6.5\%\ \text{gibbsite}}{72\%\ \text{clay}} = 0.24$$

and the required value for oxidic family is 0.2. However, the quartz in the silt and sand (0.002-2 mm) is higher than 90%, violating the requirement for oxidic family, of less than 90% quartz, and consequently soil 1 cannot be oxidic. In this situation it seems to be sound to put soil 1 in the kaolinitic family (50% of clay is kaolinite) or possibly in a kaolinitic-oxidic family.

Soil 2 Montan

X-ray diffractograms of soil 2 show very sharp symmetrical 7.18 Å peaks, indicating a very well crystallized and ordered kaolinite. The peak intensity increases from the A1 to the B1 horizon, then decreases in the top of the B22 horizon and increases again to a maximum in the C horizon. A small, sharp peak at 3.34 Å is present in all horizons; it is attributed to the presence of quartz and/or third-order mica.

In the A1 and B1 horizon, no 10 Å peak was detected, but one is present in the B21 horizon and increases in intensity with depth. In samples 51, 52, 53 and 54 there is a very broad peak extending from

10.2 to 14.4 Å, suggesting that a complete transition series between mica → vermiculite is present. The glycerol-solvated specimens show shifting of the peak to 15.8-16 Å, suggesting that some expansible clays are present. Potassium saturation did not enhance the 10 Å peak and after 350°C heating the peaks do not collapse completely to 10 Å. Upon 550°C heating 10 Å and 12 Å peaks are detected. The behavior of samples to the different treatments indicates the presence of montmorillonite-vermiculite and 2:1-2:2-type minerals in amounts of less than 10% each.

No indication of gibbsite is found in the X-ray patterns or in the DTA curves of soil 2. This is the main difference with soil 1.

The mineralogical distribution as a function of depth (Table 9, Figure 5) shows a uniform content of mica from the A1 to the B21 horizon (about 8%) and an increase in the B22 and C horizons. The content of vermiculite, 2:1-2:2 and montmorillonite tends to decrease with depth. The kaolinite content ranges between 54 and 77%, but there is no consistent pattern distribution with depth. Quartz is present in small amounts and uniformly distributed; in the C2 horizon it increases from 2 to 5%.

The amorphous material (SiO_2 and Al_2O_3) accounts for about 7% of the clay fraction with a slight decrease in the B horizon. The SiO_2/Al_2O_3 molar ratio in the amorphous materials (Table 11) is equal to or higher than 2.0. Probably some kaolinite was dissolved by the Hashimoto and Jackson (1960) selective dissolution procedure.

The free iron oxide contents of the soil and clay tend to increase in the B horizon and then decrease in the C2 horizon. This distribution

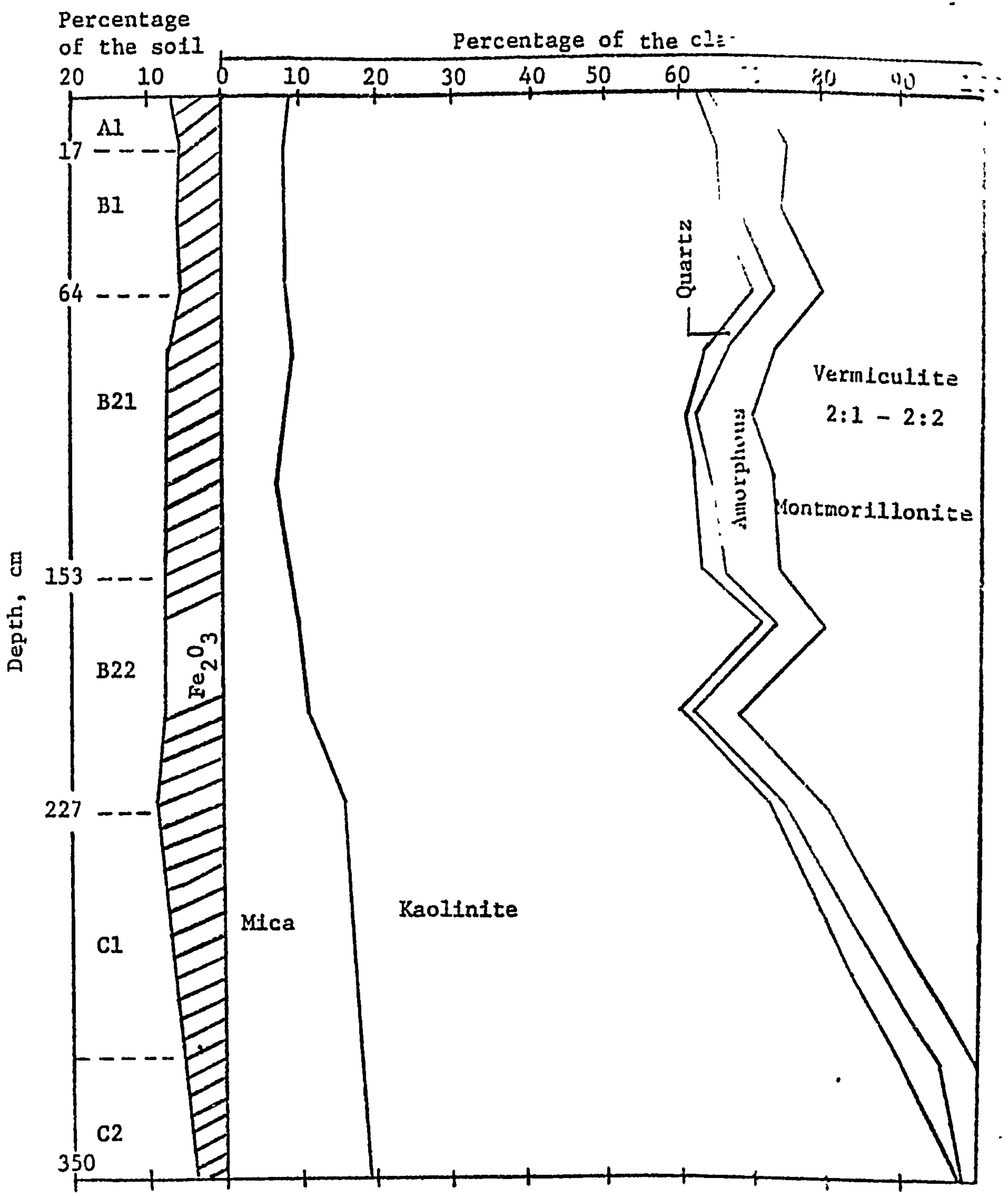


Figure 5. Mineralogical composition of the clay, Soil 1, Montan

suggests some iron movement from the upper part (weak podzolization process).

The Fe_2O_3/clay ratio is less than 0.2; so soil 2 does not classify in the oxidic family but rather in the kaolinitic family.

The total elemental analyses of the clay (Table 10) shows a decrease of SiO_2 and Al_2O_3 content with depth. The molar ratio SiO_2/Al_2O_3 for the clay is relatively high, in all cases equal or greater than 3.0. In part this is due to the presence of quartz and also the presence of 2:1 clay minerals.

The CEC of the deferrated clay is higher than 19 meq/100 g. These relatively high values are explained by the presence of 2:1 minerals (mica, vermiculite, montmorillonite, 2:1-2:2) which are contributing to the CEC.

Soils 1 and 2 have a similar mineralogy, except for the presence of gibbsite in profile 1. Both contain 8 to 10% mica and about 30% vermiculite-montmorillonite and 2:1-2:2 minerals. Initially these soils were considered as Oxisols, but in the light of the mineralogical information presented here, they do not meet the requirements, from the mineralogical standpoint, of the oxic horizon, which must consist of "a mixture of hydrated oxides of iron or aluminum or both, with variable amounts of 1:1 lattice clays and no more than traces of primary aluminosilicates such as feldspars and micas." Al-interlayered 2:1 clay minerals are permitted in the oxic horizon on the grounds that they are very resistant to weathering, perhaps more than kaolinite (Soil Survey Staff, 1970). If it is accepted that soils 1 and 2 do not have an oxic horizon and do not have an argillic horizon (no clay translocation), they may be classified as Inceptisols. Probably in the future it may be desirable to establish a new order to include soils more weathered than Inceptisols but less weathered than the true Oxisols.

Soil 3 Naval

The X-ray diffraction patterns of the moderately well drained soil 3 reveals the presence of 14 Å minerals, mica, kaolinite, quartz, and traces of pyrophyllite.

A small quartz peak (4.26 Å) is present in the A1, B21 and B24 horizons. The kaolinite peak shows a straight line boundary on the higher angle side but a tailing line on lower angle side, giving an asymmetrical pattern that suggests a poorly crystallized or disordered kaolinite. The kaolinite peak intensity decreases in the lower part of the B21 horizon and then increases in the B22 horizon. The mica peak (10.2 Å) is very intense in the A1 horizon, decreases in B21 horizon and then increases in the B24 horizon.

A broad to diffuse 14.2 Å peak is present in the Mg-saturated samples in all horizons of the Mg-saturated specimen. This suggests that the 2:1 minerals are rather poorly crystallized. The glycerol-solvated samples show some shifting of the peak toward 16 and 18 Å, due to the presence of some 2:1 expanding minerals. In sample 15, at the bottom of the profile, a more definite expansion to 18 Å was obtained due to a higher amount of montmorillonite. In K-saturated specimens the 14 Å line moves to 10 Å, but a small 11-12 Å peak is present and persists after heating, except in the A1 horizon. The interpretation is that montmorillonite, vermiculite and 2:1-2:2 clay minerals are present in the profile; the montmorillonite tends to increase with depth from probably less than 10% to 10-25% in the B24 horizon. The lack of 2:1-2:2 mineral in the A1 horizon may be due to the effect of organic matter (1.8% C) that complexes the aluminum and to the very low pH (4.3) that tends to de-aluminize or solubilize the interlayered hydroxy-Al, according to Malcolm _et al_. (1969).

The quantitative distribution of the minerals in the clay of soil 2 is presented in Table 9 and Figure 6. The mica content is very high in the A1 horizon (confirmed by the high intensity of the 10 Å peak) and decreases in the B22 horizon and then gradually increases toward the bottom of the profile. The distribution of the mica with higher amounts in the surface horizons apparently contradicts the weathering-depth function principle. Similar distribution has been reported by Glenn and Nash (1963) in Mississippi Coastal Plain soils, with 18% mica in surface soil and 4% in the subsoil, and by Bryant and Dixon (1963) in Alabama Piedmont soil with a decrease in mica from 43% in the A1 horizon to 19% in the B3 horizon. The explanations for the high content of micas in the A horizon may be some stratification of parent material with new additions of rich mica materials. A more sophisticated explanation may include (a) the formation of pedogenic micas, under the influence of K phytocycling, which may occur even in sesquioxidic soils, according to Jackson (1968), or (b) the tropospheric dust as a source of mica (Jackson, 1968).

The amount of kaolinite increases from the A1 to the B22 horizon and then decreases. Quartz (4.26 Å) is present in small amounts in A1, B21 and B24 horizons. The amorphous materials are uniformly distributed through the profile with a molar SiO_2/Al_2O_3 ratio between 2.6 and 3.6.

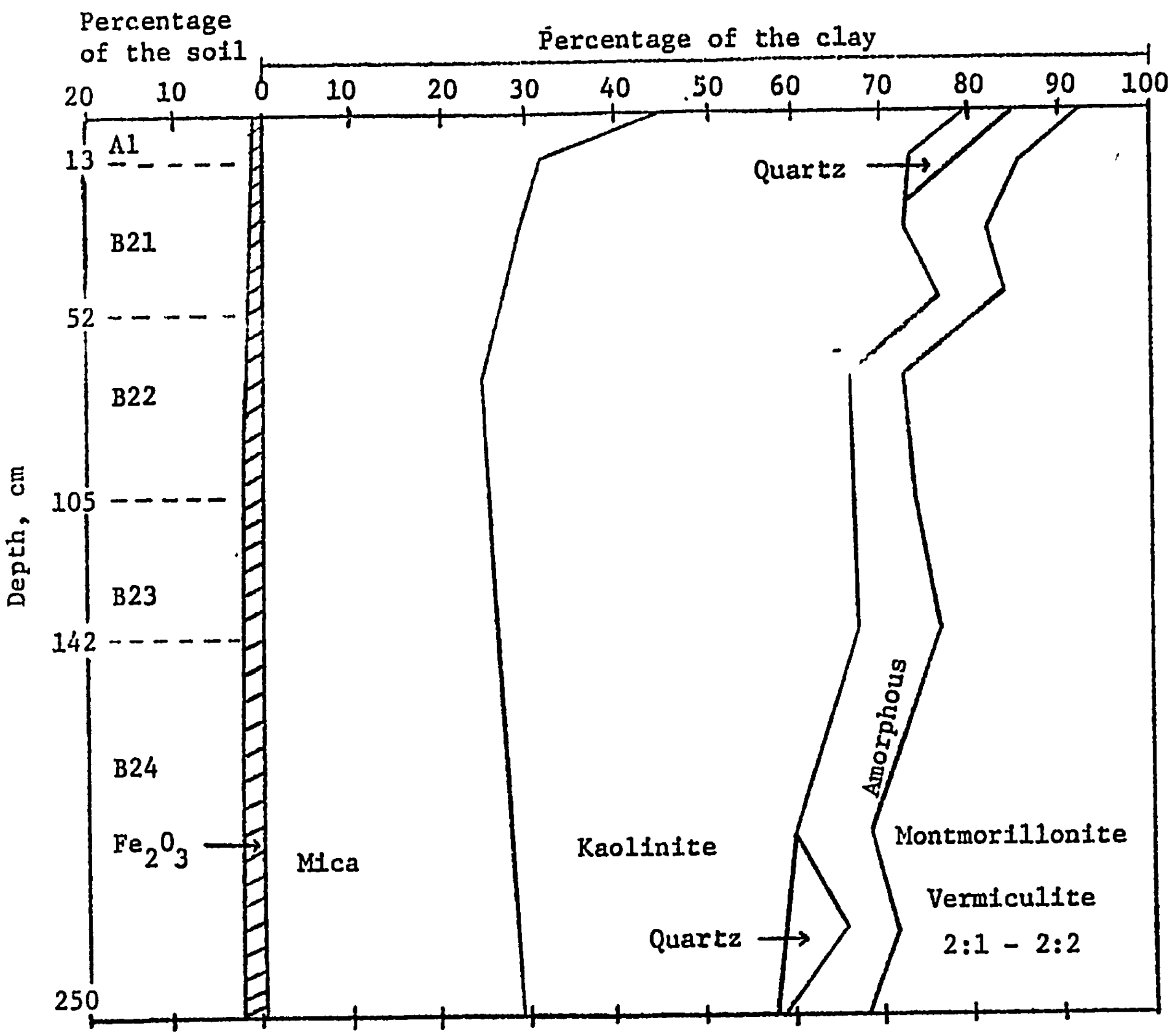


Figure 6. Mineralogical composition of the clay, Soil 3, Naval

The free Fe_2O_3 content is low and increases from 0.2% in the A1 horizon to 1.5% in the B24 horizon. The distribution pattern suggests that a translocation of iron has taken place, concomitant with clay movement.

The total analysis of the clay (Table 10) shows a high SiO_2 content, and a SiO_2/Al_2O_3 ratio above 3, due to presence of montmorillonites, other 2:1 minerals and quartz.

The cation exchange capacity is relatively high and increases consistently with depth in concordance with the increased content of montmorillonite and vermiculite. The difference between Mg-CEC and NH_4-CEC may be an indication of NH_4^+ fixation by vermiculites.

Soil 3 is included in the mixed mineralogy family because apparently none of the clay minerals is higher than 50% in the control section.

Soil 4 Polvor

X-ray diffractograms of soil 4 reveal the presence of a well crystallized kaolinite as the dominant mineral. Micas and minor amounts of quartz are also present.

The intensity and sharpness of the 4.26 Å quartz increases with depth until the C1 horizon. The intensity of the 7.24 Å kaolinite peak decreases slightly with depth from the A1 to the B22 horizon and then increases again in the C horizon.

The 10 Å mica peak is not clear, but rather diffuse and continuous toward the 14 Å peak, which indicates the presence of a transitional phase between mica and vermiculite-montmorillonite. After glycerol solvation an expansion is observed toward 16-18 Å. This shift is most marked in the C horizon. The montmorillonite tends to increase with depth while the vermiculite tends to decrease. The intergradient 2:1-2:2 minerals are present in small amounts (probably less than 10%).

The quantitative distribution of the minerals (Table 9, Figure 7) as a function of depth shows an equal amount of mica (about 17%), an increase in kaolinite in the B1 horizon (48%) and then a decrease in the C horizon (39%). The quartz content increases from the surface until the B22 and then decreases. The content of amorphous materials is relatively low and decreases slightly with depth. The molar ratio of the amorphous material is above 2.1.

The free iron oxide content of the soil is highest in the B horizon and lowest in A1 and C2 horizons. Probably some podzolization has taken place and may be responsible for the iron redistribution, along with clay translocation. The composition of the clay (Table 10) is similar to that of profile 3 and the SiO_2/Al_2O_3 ratio approaches values of 4.0. The CEC values are relatively high, due to the presence of 2:1 minerals mixed with the kaolinite, and are of the same order of magnitude reported for soil 3. Because the kaolinite content is less than 50% of the minerals in the clay fraction, the soil 4 must be included in a mixed mineralogy family.

Profiles 3 and 4 are moderately well drained and this condition may have favored the formation of montmorillonite, which is more abundant in the lower horizons. After formation, montmorillonites tend to be self-protected in the lower horizons by decreasing the permeability and reducing excess leaching (Buol et al., 1972).

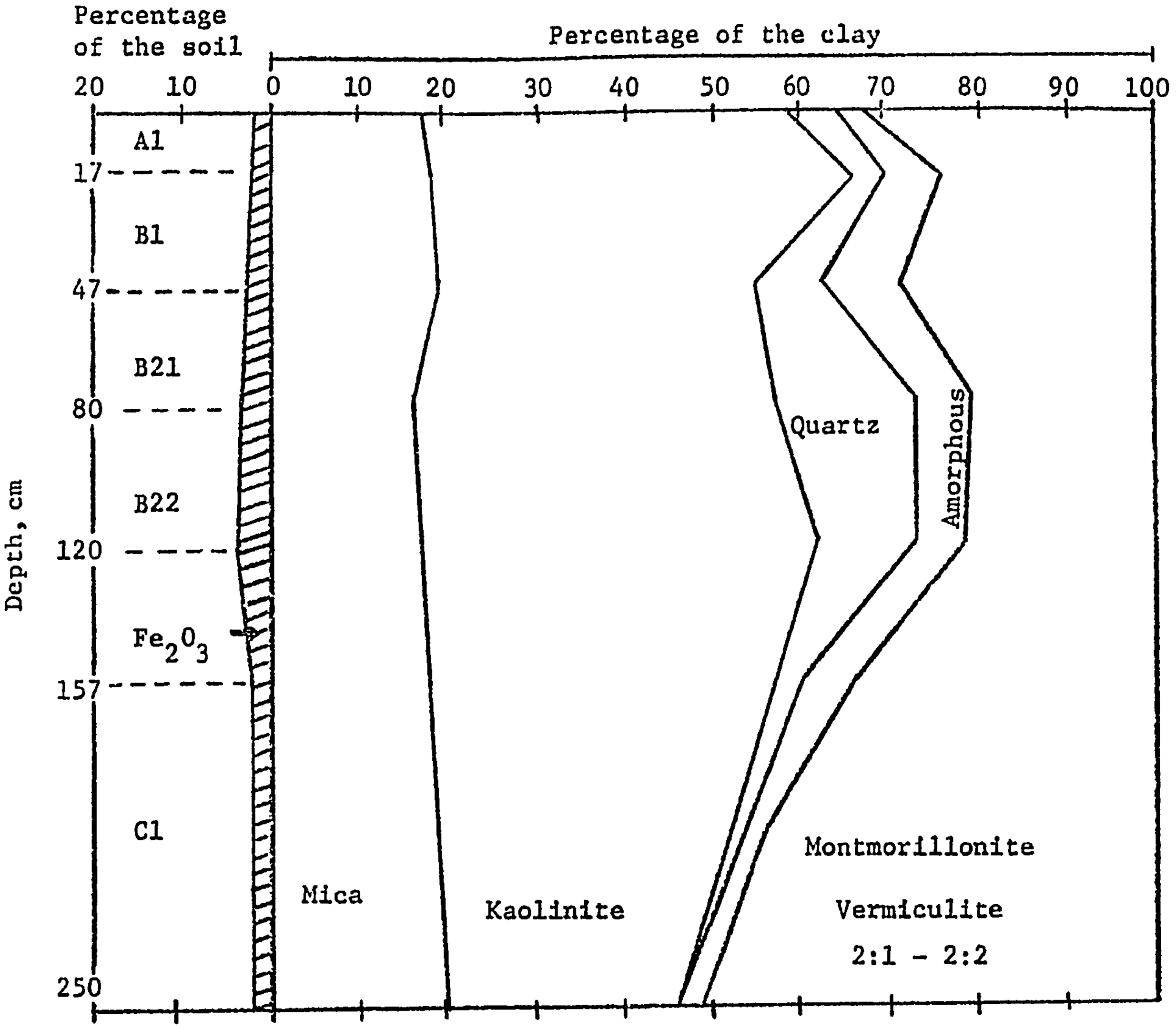


Figure 7. Mineralogical composition of the clay, Soil 4, Polvor

Soil 5 Tacana

In the X-ray traces of soil 5, 14.4 Å, 10.2 Å, 9.3 Å, 7.2 Å, 4.86 Å, 4.26 Å, 3.57 Å, 3.34 Å and 3.10 Å peaks are observed. The 14 Å peak does not shift with glycerol treatment indicating an absence of montmorillonite. The K-saturated clay upon heating indicates the presence of 2:1-2:2 intergradient minerals, being more abundant in the B horizon (25-50%) and decreasing with depth (10-25%). Vermiculite is also present in all horizons and contents tend to decrease with depth.

The 7.2 Å peak is very broad extending from approximately 6.5 to 9 Å in all horizons; this may suggest that kaolinite is starting to decompose and form amorphous material or a poorly crystallized and disordered type of kaolinite.

The small peaks at 9.3 and 3.1 Å indicate the presence of traces of pyrophyllite, a mineral that has been reported in the Llanos Orientales soils by F.A.O. (1966), Leon (1964) and Guerrero (1971). The 10.2 Å peak, corresponding to micas, is ill-defined in all horizons, except in the B23cn horizon; however, more than 14% mica is estimated by the K_2O method. This is again in accordance with the finding of several researchers (Rich and Obenshain, 1955; Rich, 1960; Dixon and Jackson, 1962; Bryant and Dixon, 1963) who have indicated that in many cases 15% or more mica, based on K_2O, show only small and broad X-ray diffraction peaks.

The 4.86 Å peak is interpreted as gibbsite, and confirmed by the DTA results. The intensity of the peak tends to decrease with depth.

The 4.26 Å and 3.34 Å peaks of the quartz have low intensity and in some cases only the 3.34 Å appears.

Figure 8 and Table 9 show the quantitative estimations of the minerals in the clay fraction of soil 5 and their distribution with depth. The free Fe_2O_3 content in the soil varies between 2.1 and 5.1%. It is low in the A1 horizon and increases consistently in the B horizons and then decreases in the B23cn horizon. The vertical distribution of the iron suggests some enrichment in the B22 horizon which may be correlated with some increase in clay content.

Content of amorphous materials constitutes between 8 and 11% of the clay and is more or less uniformly distributed throughout the profile. The SiO_2/Al_2O_3 molar ratios (Table 11) are low and comparable with the values of profile 1 that also contains gibbsite.

The content of quartz varies between 4 and 10% and no specific trend in its vertical distribution is noticed. The gibbsite content is low (2-4%), being lowest at the A1 horizon.

Kaolinite is the predominant mineral constituting 50% of the clay fraction in the A1 horizon and decreasing to about 40% in the B21 horizon and increasing in B22 and B23 horizons. The mica content calculated from K_2O content varies between 14 and 19%. Here, again, as in the case of profile 3, which is in the same area (Leticia), the maximum value for mica is found in the A1 horizon.

The CEC of the clay varies from 22 to 28 meq/100 g. The higher values are in A1 and B21 horizons. The NH_4-CEC is lower than the Mg-CEC due probably to NH_4^+ fixation by vermiculite. The SiO_2/Al_2O_3 ratio of the clay is about 3.3, except in sample 5, where it is higher due to a significant presence of quartz in the clay.

The mineralogical family of soil is mixed since the kaolinite content is less than 50% in the control section.

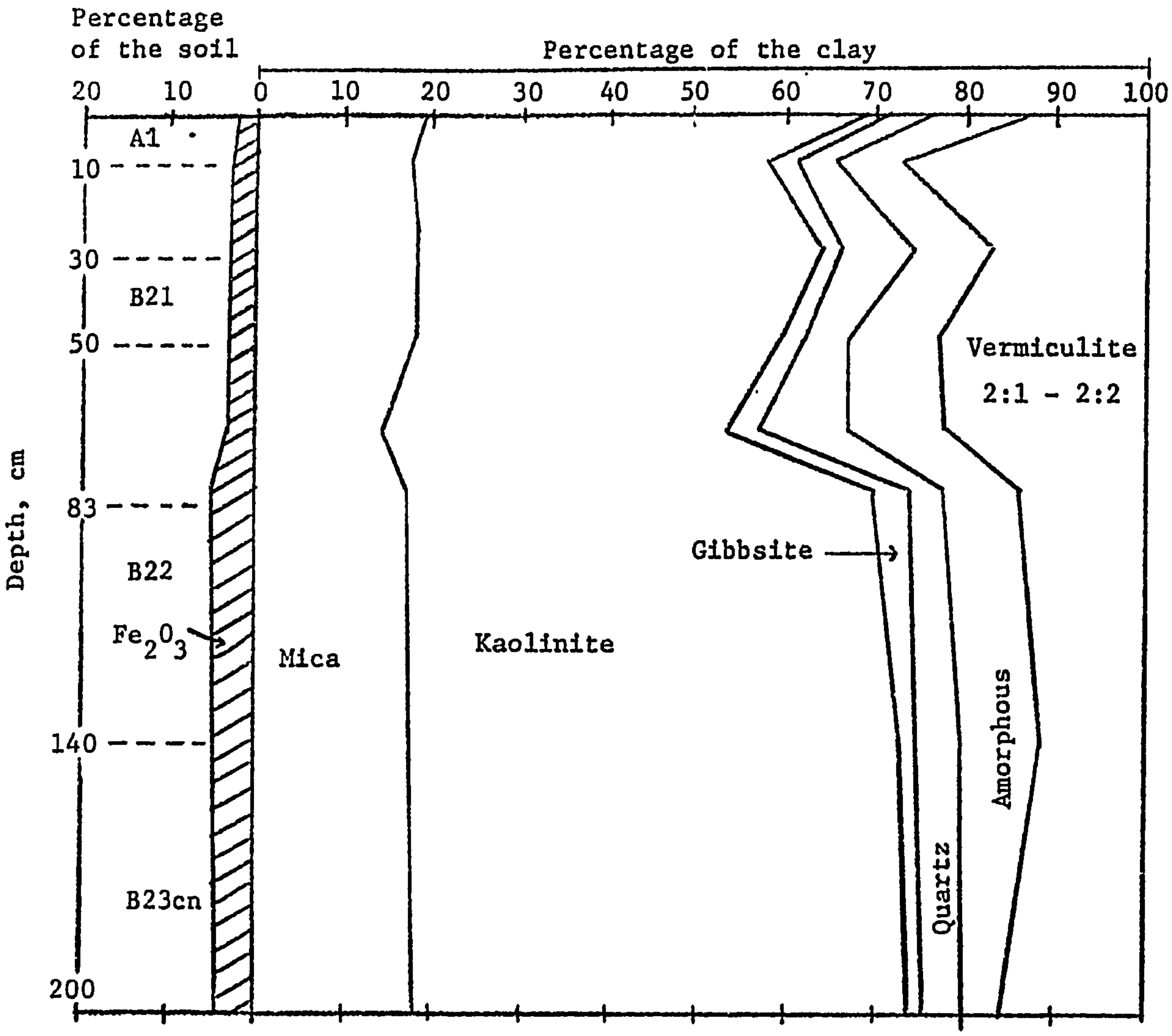


Figure 8. Mineralogical composition of the clay, Soil 5, Tacana

Soil 6 Leguiz

In the clay fraction of soil 6, kaolinite, montmorillonite, mica, vermiculite and 2:1-2:2 intergradient are present in all horizons; some quartz is found in the A1 and B22 horizons and traces of pyrophyllite are present in the A1 horizon.

The kaolinite peaks are sharp and symmetrical, but the 10 Å peak is ill-defined, being in some cases a shoulder of the upper angle side of the 14.4 Å peak which extends from 10 to 16 Å. After glycerol solvation there is a partial expansion of the 14.4 Å peak to 16 and 18 Å. The shifting of the peak from 14.6 Å to 18 Å is very noticeable in sample 42 (IIC2 horizon), suggesting that a substantial amount of montmorillonite is present (probably about 50% of the clay). This is the largest amount of expanding clay found in the soils analyzed. The behavior of the K-saturated sample at room temperature and after heating (350, 550°C) shows that vermiculite and 2:1-2:2 intergradient minerals are also present in the clay but in relatively lower amounts than kaolinite and montmorillonite.

Quartz is found only in the surface soil (9%) and in the B22 horizon (6%). A small peak at 9.4 Å is identified as traces of pyrophyllite.

The mica estimated from percent K_2O (Table 9, Figure 9) is highest in the A1 horizon (19%) and then decreases to 14 and 16% in the B and C horizons. The kaolinite content, determined by DTA, varies with depth, increasing from 39% in the A horizon to 48% in the B22 horizon, decreasing to 28% in the IIC2 horizon and then increasing again. The decreases in kaolinite are correlated with increases in the amounts of 2:1 minerals. The vertical variation of the kaolinite content is

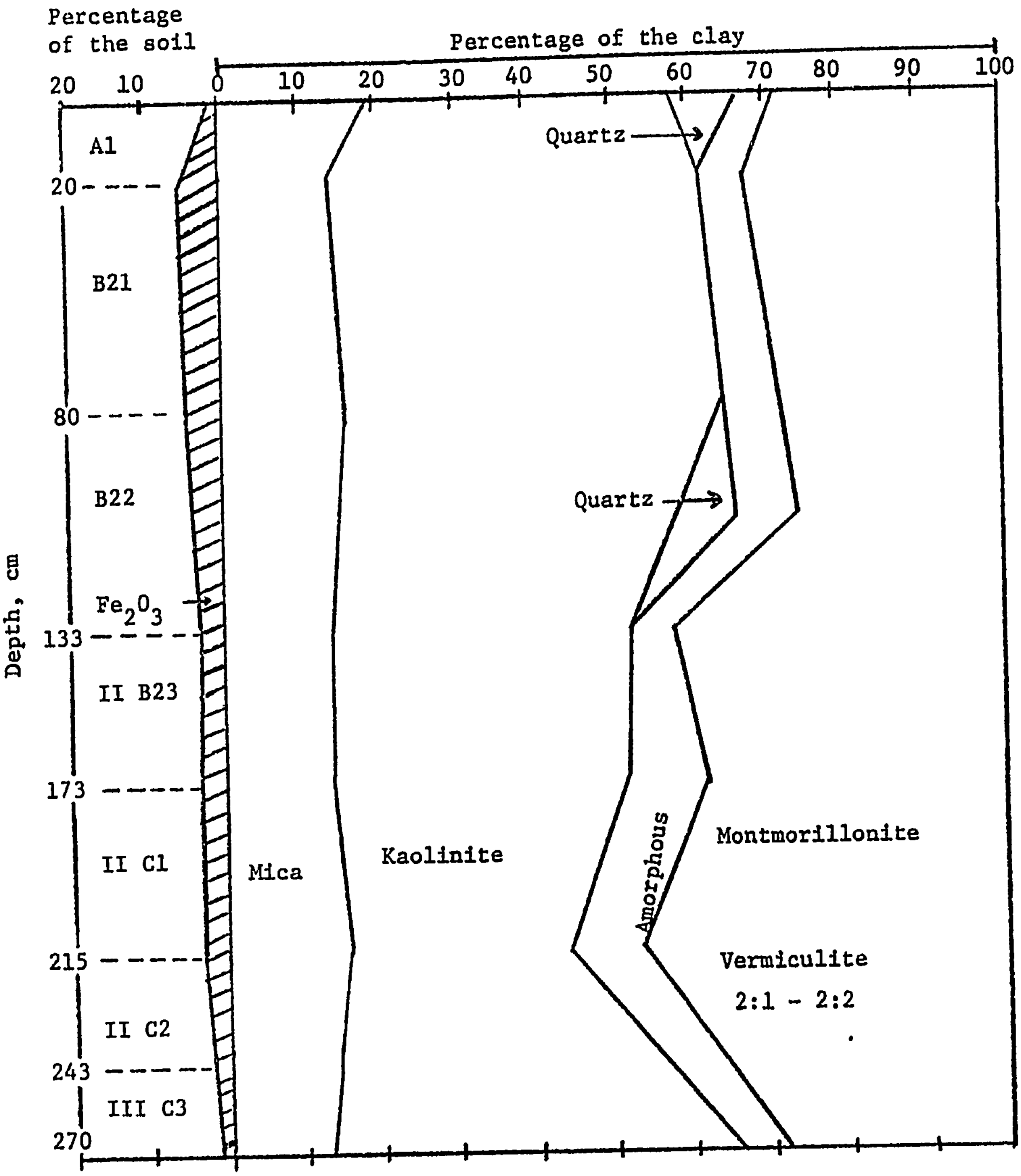


Figure 9. Mineralogical composition of the clay, Soil 6, Leguiz

probably due to the layered nature of the profile (lithologic discontinuities). The association of montmorillonite with volcanic glass and volcanic rock fragments suggests that it may have been produced from volcanic ash materials. This suggestion needs further study.

The content of amorphous materials is low (5%) in the A1 horizon and tends to increase with depth. The SiO_2/Al_2O_3 ratio (Table 11) is about 2 in the A and B horizons and increases to 2.7 in the C2 horizon where montmorillonite content is highest.

The total analyses of the clay (Table 10) show a slight increase in SiO_2 content with depth; the Al_2O_3 is more or less uniform in all horizons and the SiO_2/Al_2O_3 ratio is high and tends to increase with depth.

The Mg-CEC of the clay is high, between 34 and 50 meq/100 g, due to the presence of montmorillonite and vermiculite. The CEC, as determined with NH_4OAc, is lower than the CEC determined with $Mg(OAc)_2$. The decrease is attributed to NH_4^+ fixation.

In the control section of soil 6 no mineral is in a proportion greater than 50%, so it must be included in the mixed mineralogy family.

Soil 7 Guavia

Soil 7 is developed in sediments coming from the Puerto Arturo sandstone and deposited over a concretionary iron pan underlain by a clay. The X-ray diffractograms of the clay from the A11, A12, B21 and B22 horizons show 14.4 Å, 10.2 Å, 7.2 Å and 4.8 Å peaks.

The 14.4 Å peak is relatively sharp and intense in the A11 horizon and decreases both in intensity and sharpness in the B22 horizon. There is no expansion upon glycerol solvation. With K-saturation and heating

(350°C), the specimens yield 10.2 and 12 to 13 Å peaks, indicating the presence of both vermiculite and 2:1-2:2 minerals. From the peak intensity it is estimated that each one of these minerals accounts for 10 to 25% in the A and B21 horizons and less than 10% in the B22 horizon. Except in the B22 horizon, the diagnostic peak of the mica (10.1 Å) is poorly defined in spite of the fact that mica, determined by the K_2O content is present in amounts higher than 18%.

The gibbsite peak (4.84-4.86 Å) is broad and small, indicating that there are only traces present.

The X-ray patterns of the clay from the IIC horizon show a very diffuse peak in the 14 Å region, and an intense, sharp 10.2 Å peak tailing somewhat toward the low angle. The 7.2 Å peak is very intense, very sharp and symmetrical indicating well crystallized kaolinite and similar to the kaolinite peaks of the soil 4. There is no evidence of gibbsite.

The distribution of the minerals with depth is shown in Figure 10 and Table 9. The free iron oxide content is low and increases from 1.6 to 3.3 from the A11 to the B22 horizon and to 5.7% in the IIC horizon. Amorphous materials are uniformly distributed in the solum and decrease in the IIC horizon. Probably the clay under the ironstone is being protected from weathering and consequently the amount of amorphous material is low. The absence of gibbsite and the high amount of mica also tend to confirm the protective effect of the iron cap. The SiO_2/Al_2O_3 ratio of the amorphous minerals varies between 1.8 and 3.5 (Table 11). The percentages of kaolinite and the micas increase with depth and vermiculite and chloritized vermiculite contents decrease with depth.

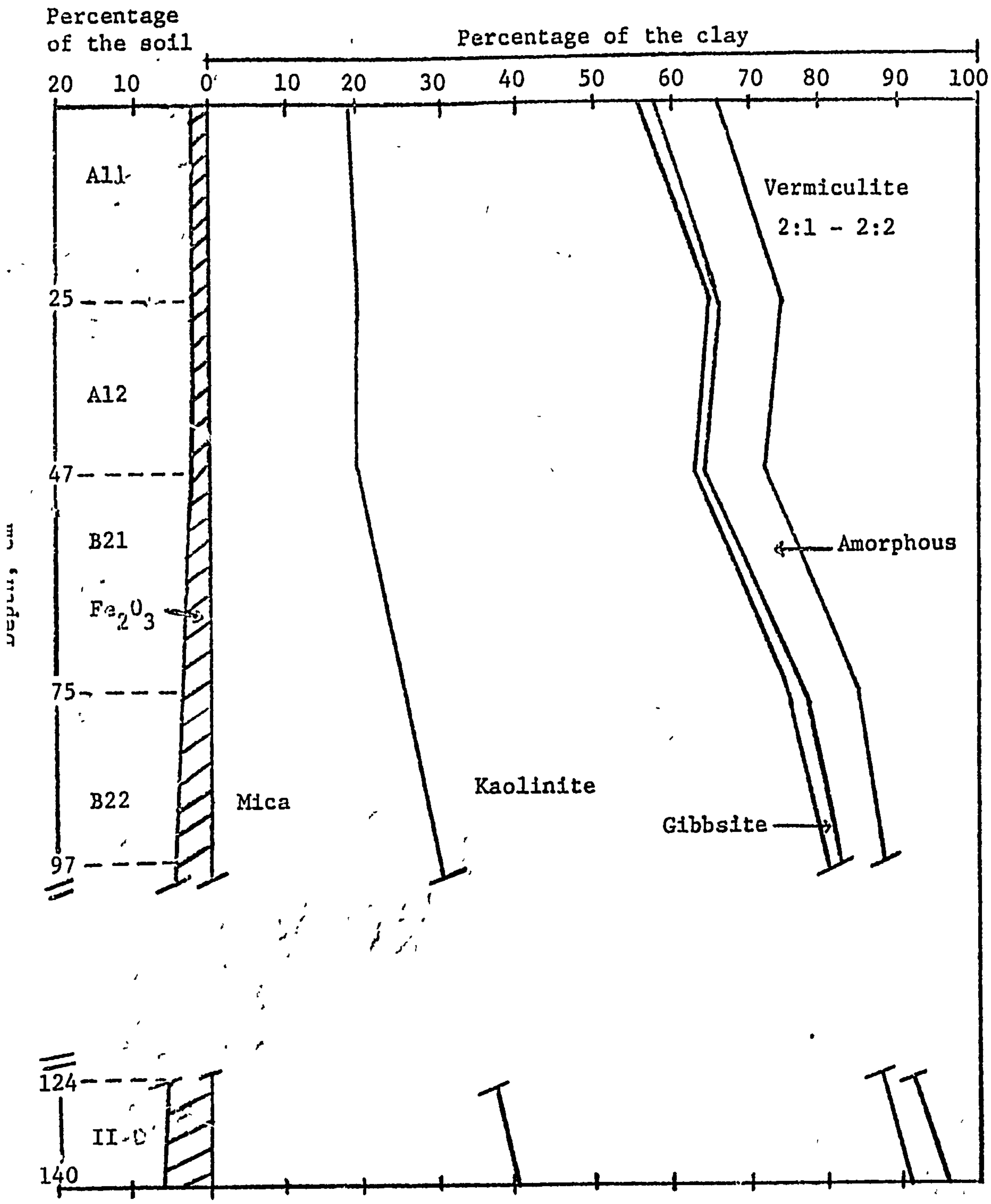


Figure 10. Mineralogical composition of the clay, Soil 7, Guavia

The CEC of the clay varies between 19 and 24 meq/100 g. The relatively high value is explained by the mixed mineralogy present in the clay fraction.

The clay content in the control section of soil 7 is less than 35%, and the mineralogy in the 0.02-2 mm is dominated by quartz and chert (more than 90%). Therefore the soil must be included in the fine loamy textural family and siliceous mineralogy family.

Soil 8 Floren

The dominant mineral in the clay fraction of soil 8 revealed by the X-ray diffractograms is a poorly crystallized kaolinite. The 7.2-7.3 Å peaks are very broad (the sides of the peak extending from 6 to 10 Å) and somewhat asymmetrical. Mica peaks (10.2 Å) are present in all horizons and the intensity increases with depth. The 14 Å peak is poorly defined, very diffuse, with some small intermediate peaks in the 10-14 Å range.

In the glycerol-solvated specimens the 14 Å peak expands somewhat to 16-18 Å, indicating the presence of a small amount of expansible 2:1 mineral. Upon K-saturation and heat treatments the collapse indicates the presence of small amounts of vermiculite and chloritized vermiculite (2:1-2:2). Gibbsite (4.86 Å) is present in all horizons, and its presence was confirmed by the DTA.

The quantitative distribution of minerals with depth is presented in Figure 11 and Table 9. The free Fe_2O_3 content varies between 1.7 and 6%. There is no clear distribution pattern through the profile. The amorphous materials account for about 9% of the clay and are uniformly distributed throughout the profile and their SiO_2/Al_2O_3 ratios vary

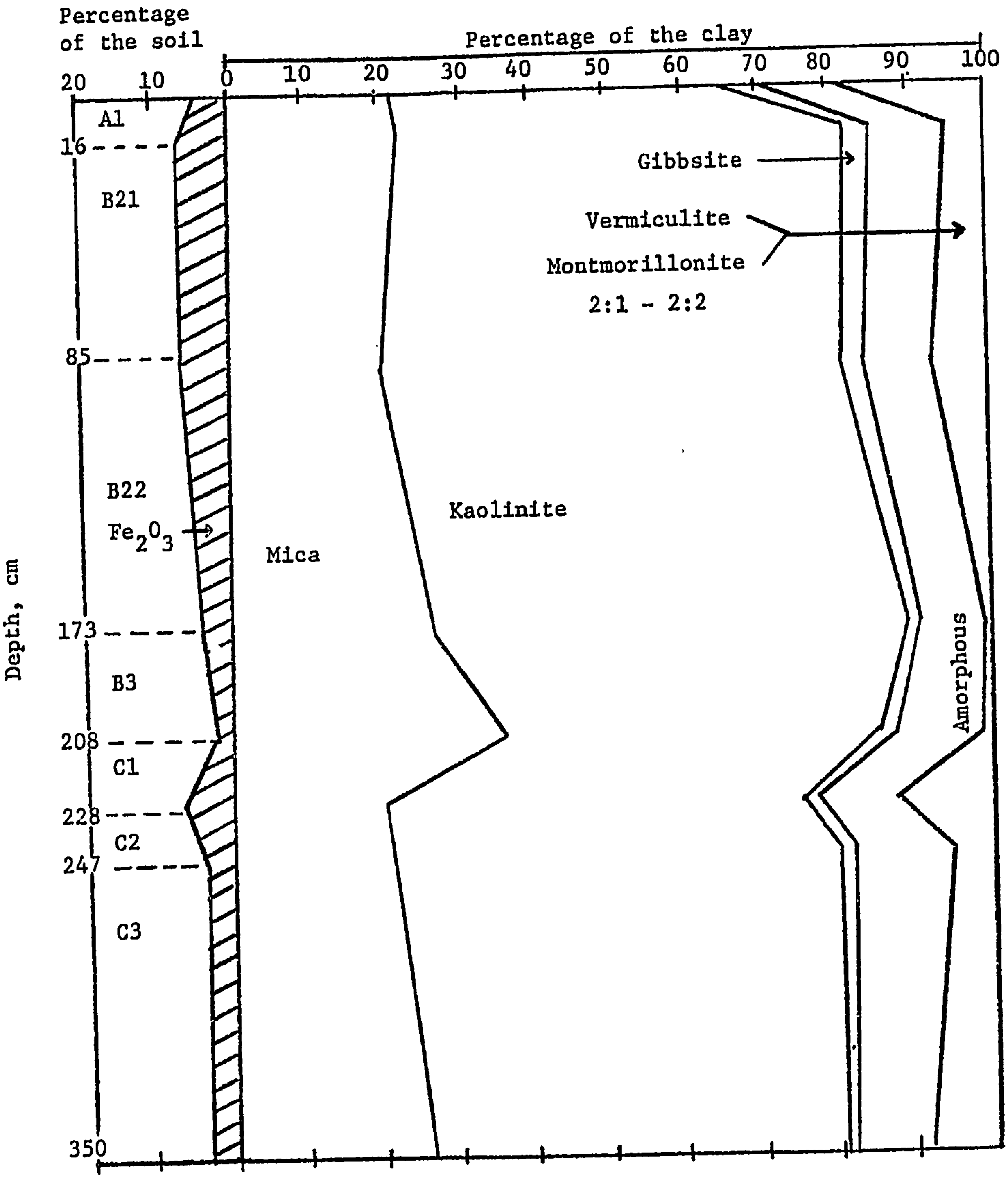


Figure 11. Mineralogical composition of the clay, Soil 8, Floren

between 1.9 and 3.7. The amorphous silica content tends to decrease from the A1 horizon to the C1 horizon. Gibbsite accounts for only 1 to 3% of the clay, increasing slightly from the A1 horizon to the B22 horizon and then decreasing in the C horizons. Kaolinite is very abundant and shows a bimodal distribution, increasing from the A1 horizon to the B3 horizon (from 45 to 62%) and then increases again from the C1 horizon to the C3 horizon (from 50 to 59%). The mica estimated from K_2O content varies between 20 and 38%; no clear distribution pattern is observed.

The percentage of total silica in the clay of soil 8 (42-45%) is similar to that of soil 1. Both soils have lower SiO_2 and higher Al_2O_3 contents than the rest of the soils. The SiO_2/Al_2O_3 ratio varies between 2.6 and 3.5.

The CEC of the clay is high in the A1 horizon due to the presence of 2:1 minerals (see Figure 11). The low values in the lower horizons are explained by the significant predominance of kaolinite and mica and the small amounts of vermiculite-montmorillonite. Comparing the Mg-CEC and NH_4-CEC, one may conclude that there is no NH_4^+ fixation because of the small amounts of vermiculites.

The ratio (Fe_2O_3 + gibbsite)/percent clay is less than 0.2; consequently soil 8 is not in the oxidic family. Kaolinite constitutes more than 50% of the clay in the control section.

<u>Soil 9 Asis</u>

The mineralogy of the clay consists of well crystallized kaolinite, poorly crystallized vermiculite-montmorillonite, mica, quartz and traces of phyrophyllite (9.4 Å). In the A1 and B2 horizons the small peaks appear at 4.84 and 4.89 Å, corresponding to gibbsite. However, the DTA, which is very sensitive for the detection of this mineral (MacKenzie, 1964), gave no indication of gibbsite.

In the 10 to 14 Å region there is a continuous series of very poorly defined peaks. The behavior of the samples with standard treatments indicates that variable amounts of micas, vermiculites-montmorillonites and 2:1-2:2 minerals are present.

Figure 12 and Table 9 show the distribution of the minerals in the clay of the soil 9. The free Fe_2O_3 increases from the A1 horizon to IIIC horizon and decreases in the IIIC4 horizon. The amorphous silicates are highest in the topsoil and decrease in the subsoil. The SiO_2/Al_2O_3 molar ratio of the amorphous materials varies between 2.0 and 2.7 (Table 11). The quartz increases from the surface to downward. The amount of mica varies between 18% in A and 82 and 26% in C horizons.

The SiO_2/Al_2O_3 ratio (Table 10) of the clay varies from 3.5 to 4.0, relatively high values, due to the quartz and the 2:1 minerals.

The CEC of the clay is relatively high because of the presence of 2:1 minerals. The NH_4-CEC is almost equal to Mg-CEC; apparently no fixation of NH_4^+ is taking place in this soil and suggests that the amount of vermiculite may be small or the charge of the vermiculite may be low or both.

Soil 9 is classified in the mixed mineralogy family because no one mineral in the clay fraction accounts for 50% or more of that fraction.

The presence of micas, vermiculite, montmorillonite, 2:1-2:2 intergradient materials, kaolinite and gibbsite in the soils, and the general distribution trend in the profiles (micas tend to increase and

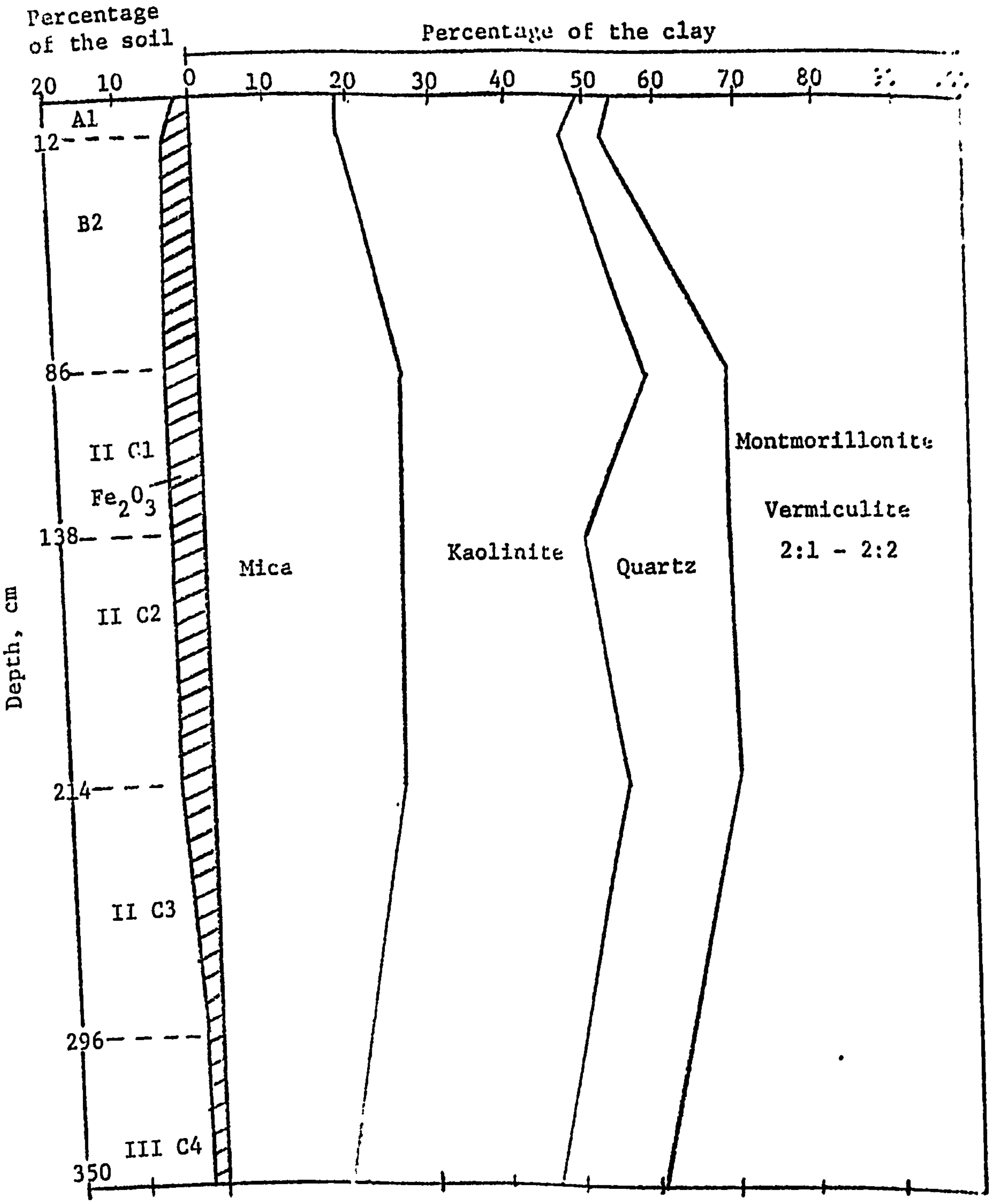
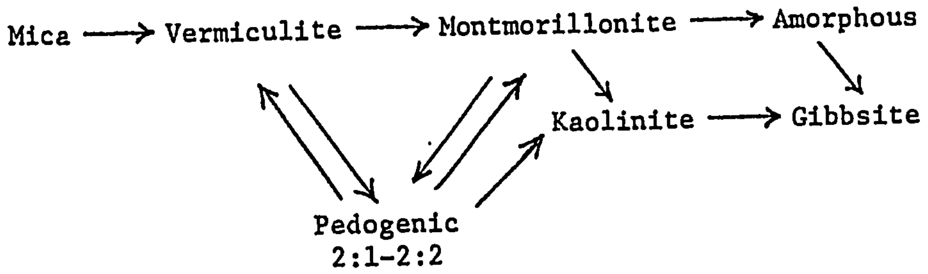


Figure 12. Mineralogical composition of the clay, Soil 9, Asia

2:1 tend to decrease with depth), suggest that alteration of micas is taking place in general agreement with the following weathering sequence:



This sequence proposed by Jackson (1964) for soils of temperate zones also occurs in some soils in Brazil (Moniz and Jackson, 1967).

It is accepted that in tropical environments (Loughnan, 1969), the continued weathering processes cause the desilication and decomposition of the 2:1 minerals. As the weathering process advances, the 1:1 minerals are also desilicated and destroyed, leaving in place only the most resistant compounds such as gibbsite, hematite, geothite and zircon.

Weathering Means

In order to have an idea about the degree of weathering of the Amazonian soils, the Jackson "weathering mean" (m) was calculated (Jackson, 1956).

$$m = \frac{(ps)}{(p)}$$

In this equation p is the percentage mineral in the soil clay and s is the "weathering stage" of the mineral. The weathering stage has been defined by Jackson (1968) in terms of 13 specific mineral groups which become successively dominant as chemical weathering progresses and to each group a weathering index (s) is assigned. In the calculations the following weathering indexes were used (Jackson, 1968).

Quartz = 6
Dioctahedral micas = 7
Vermiculite = 8
Montmorillonite = 9
2:1-2:2 minerals = 9
Amorphous materials = 10
Kaolinite = 10
Gibbsite = 11

The calculated "weathered mean" for the B2 horizon of the Amazonian soils studied and other related information are presented in Table 12. The weathering mean values indicate that these soils are between the vermiculitic-montmorillonitic stages (index 8 and 9), approaching the kaolinitic stage (10). Soils 1, 2, 7 and 8 are more weathered than soils 3, 4, 6 and 9.

There is a certain degree of correlation between the weathering mean and the CEC of the clay, but a less consistent relationship exists with the SiO_2/Al_2O_3 ratio of the clay.

Martini (1970) has proposed a clay weathering index (Iw):

$$Iw = \frac{\text{CEC of the clay}}{\text{\% clay in the horizon}}$$

The index decreases with a decrease in CEC and with an increase in clay content, as a result of weathering. The index has been tested with soils of Panama and Central America and Martini has indicated that it is a sensitive measurement of weathering. The index was calculated (Table 12) and it was found that soils 3, 4, 6 and 9 are less weathered and soils 1, 2, 7 and 8 are more weathered. There is good agreement between the weathering mean of Jackson and the weathering index of Martini.

Table 12. Mean stage of chemical weathering in the B horizon of the Amazonian soils--K_2O, SiO_2/Al_2O_3 molar ratio, CEC of the clay and Martini clay weathering index

Profile	Horizon	Depth	Weathering mean	Clay K_2O	Clay SiO_2/Al_2O_3	Clay CEC	Martini clay weathering index
		cm	m	%	Molar ratio	meq/100 g clay	(Iw)
1 - Miraf	B22	100-150	9.82	0.81	2.44	17.21	0.24
2 - Montan	B22	153-173	9.54	0.86	2.95	18.66	0.24
3 - Naval	B22	52-72	9.02	2.70	4.06	29.58	0.79
4 - Polvor	B21	47-80	8.74	1.94	3.63	30.85	0.66
5 - Tacana	B21	50-70	9.07	1.77	3.22	25.50	0.56
6 - Leguiz	B22	80-133	9.01	1.60	3.80	37.99	0.87
7 - Guavia	B22	75-97	9.13	2.45	3.33	20.14	0.51
8 - Floren	B22	85-173	9.38	2.03	2.58	10.71	0.22
9 - Asis	B2	12-86	8.77	1.78	3.83	27.39	0.60

Chemical Properties

Soil Reaction

The results from three methods of pH determination are listed in Table 13. Except for the A1 horizon of soils 2 and 3, which are extremely acid, all of the soils are very strongly acid (pH 4.5-5.0). Within profiles the pH values tend to increase with depth. The same pattern was found by Guerrero (1971) and by Toquica and Bernal (1964) in some soils of the Llanos Orientales. Estrada (1971), on the other hand, has found some Amazonian soils in Peru with a noticeable decrease in pH with depth (from 4.8 in the A1 horizon to 3.9 in the B horizon).

In all cases the pH values in KCl and in $CaCl_2$ were lower than pH values in water. The lower pH values in 1 N KCl than in water indicate that the soil colloids have a net negative charge, which is expected since the clays are dominated by layered silicates and not by oxides and hydrous oxides. The ΔpH values (pH in KCl-pH in water) varies between -0.65 and -1.40. Also, in all profiles the ΔpH values increased with depth.

Exchangeable Bases, Exchangeable Acidity

All soils included in this study were found to have low to very low amounts of exchangeable bases (Table 13). Calcium and Mg are the predominant exchangeable basic cations, with K present in much lower amounts.

The distribution pattern of the exchangeable bases with depth for soils 1, 2, 3, 4, 7 and 8 shows a relative richness of basic cations in the upper horizons, a decrease in the middle of the profile and an increase in the lower horizons. This distribution shows the combined effect of the biocycling and leaching processes. Root systems of forest

Table 13. pH, exchangeable bases, exchangeable acidity and percent base saturation (PBS)

Sample	Horizon	Depth from surface	pH			Exch. bases				Sum of bases	Exch. acidity[a]		ECEC[b]	PBS[c]
			H_2O 1:1	$CaCl_2$ 1:2	KCl 1:1	Ca	Mg	K	Na		Al	H		
		cm				---meq/100 g soil---								%
						Profile 1 - Miraf								
21	A1	0-21	4.67	4.15	3.90	0.85	0.26	0.22	0.12	1.45	4.2	0.3	5.95	24
22	B1	21-38	4.55	4.10	3.80	0.41	0.21	0.06	0.13	0.81	4.3	0.6	5.71	14
23	B21	38-60	4.50	4.15	3.85	0.38	0.11	0.13	0.09	0.71	4.2	0.4	5.31	13
24		60-80	4.70	4.25	3.95	0.29	0.08	0.02	0.06	0.45	3.1	0.4	3.95	11
25		80-100	4.75	4.30	4.00	0.20	0.04	0.04	0.08	0.45	2.5	0.6	3.55	13
26	B22	100-150	4.70	4.30	4.00	0.21	0.07	0.03	0.05	0.36	2.0	0.1	2.46	14
27	B23	150-200	4.85	4.25	4.05	0.21	0.09	0.02	0.10	0.42	1.9	0.1	2.42	17
28		200-250	4.85	4.30	4.05	0.20	0.08	0.04	0.04	0.36	2.0	0.0	2.36	15
29		250-300	4.80	4.25	3.95	0.24	0.16	0.02	0.06	0.48	2.8	0.0	3.28	15
30		300-350	4.80	4.25	3.90	0.28	0.18	0.04	0.07	0.57	3.5	0.0	4.07	14
						Profile 2 - Montan								
44	A1	0-17	4.30	3.80	3.45	0.60	0.44	0.22	0.07	1.33	7.0	1.2	9.53	14
45	B1	17-37	4.40	3.80	3.40	0.12	0.28	0.10	0.20	0.70	8.7	1.0	10.40	7
46		37-64	4.50	3.95	3.50	0.12	0.10	0.02	0.04	0.28	8.3	0.6	9.18	3
47	B21	64-84	4.60	4.05	3.55	0.11	0.22	0.02	0.05	0.40	6.9	0.8	8.10	5
48		84-104	4.65	4.12	3.60	0.11	0.17	0.02	0.14	0.44	7.4	0.8	8.64	5
49		104-124	4.85	4.16	3.70	0.11	0.17	0.02	0.05	0.35	7.1	0.4	7.85	4
50		124-153	4.85	4.20	3.65	0.11	0.21	0.01	0.06	0.39	6.2	0.8	7.39	5
51	B22	153-173	4.95	4.25	3.70	0.06	0.22	0.01	0.05	0.34	6.0	0.8	7.14	5
52		173-200	5.00	4.25	3.75	0.10	0.05	0.04	0.06	0.25	6.4	0.8	7.45	3
53		200-227	4.95	4.20	3.70	0.11	0.16	0.03	0.04	0.34	6.3	1.0	7.64	4
54	C1	227-310	5.00	4.25	3.70	0.10	0.26	0.08	0.08	0.52	7.1	0.6	8.22	6
55	C2	310-350	4.96	4.12	3.65	0.10	0.26	0.11	0.06	0.53	8.5	0.0	9.03	6

Table 13 (Continued)

Sample	Horizon	Depth from surface	pH H$_2$O 1:1	pH CaCl$_2$ 1:1	pH KCl 1:1	Exch. bases Ca	Exch. bases Mg	Exch. bases K	Exch. bases Na	Sum of bases	Exch. acidity[a] Al	Exch. acidity[a] H	ECEC[b]	PBS[c]
		cm				---meq/100 g soil---								%
						Profile 3 - Naval								
8	A1	0-13	4.35	3.80	3.60	0.23	0.22	0.08	0.13	0.66	5.1	0.7	6.46	10
9	B21	13-33	4.60	4.10	3.80	0.18	0.17	0.05	0.06	0.46	4.1	0.4	4.96	9
10		33-52	4.60	4.10	3.82	0.13	0.10	0.05	0.05	0.33	4.1	0.7	5.13	6
11	B22	52-72	4.55	4.00	3.75	0.14	0.08	0.02	0.07	0.31	6.3	1.0	7.61	4
12		72-105	4.80	4.12	3.78	0.11	0.11	0.13	0.06	0.41	10.1	1.2	11.71	4
13	B23	105-142	4.80	4.12	3.70	0.20	0.13	0.13	0.07	0.53	11.9	0.9	13.33	4
14	B24	142-200	4.90	4.12	3.70	0.18	0.16	0.18	0.06	0.58	14.6	1.7	16.88	3
15		200-250	5.00	4.16	3.75	0.12	0.16	0.17	0.12	0.57	12.9	1.6	15.07	3
						Profile 4 - Polvor								
31	A1	0-17	4.60	4.10	3.78	0.83	0.16	0.07	0.09	1.15	5.0	0.6	6.75	17
32	B1	17-47	4.60	4.10	3.75	0.21	0.21	0.02	0.07	0.51	5.2	0.6	6.31	8
33	B21	47-80	4.60	4.05	3.65	0.31	0.05	0.04	0.07	0.47	7.3	0.8	8.57	5
34	B22	80-120	4.65	4.00	3.65	0.21	0.05	0.04	0.06	0.36	9.1	1.0	10.46	3
35		120-157	4.65	4.00	3.65	0.10	0.16	0.04	0.06	0.36	10.1	1.0	11.46	3
36	C1	157-210	4.70	3.95	3.50	0.21	0.26	0.12	0.03	0.62	12.9	1.2	14.72	4
						Profile 5 - Tacana								
1	A1	0-10	4.58	4.10	3.80	0.17	0.29	0.13	0.11	0.70	5.2	0.2	6.10	11
2	B21	10-30	4.80	4.25	3.95	0.15	0.17	0.01	0.06	0.39	5.1	0.3	5.79	7
3		30-50	4.70	4.25	3.90	0.17	0.13	0.04	0.08	0.42	4.3	0.6	5.32	8
4		50-70	4.45	4.15	3.85	0.14	0.14	0.05	0.06	0.39	5.1	0.4	5.89	7
5		70-83	4.55	4.20	3.85	0.20	0.13	0.01	0.06	0.40	5.2	0.4	6.00	7
6	B22	83-140	4.90	4.20	3.85	0.13	0.20	0.06	0.05	0.44	6.4	0.5	7.34	6
7	B23cn	140-200	4.95	4.20	3.85	0.16	0.08	0.04	0.05	0.33	6.4	0.8	7.53	4

Table 13 (Continued)

Sample	Horizon	Depth from surface	pH			Exch. bases				Sum of bases	Exch. acidity[a]		ECEC[b]	PBS[c]
			H_2O 1:1	$CaCl_2$ 1:1	KCl 1:1	Ca	Mg	K	Na		Al	H		
		cm				--------------------meq/100 g soil-----------------								%
						Profile 6 - Leguiz								
37	A1	0-20	4.90	4.20	3.80	1.69	1.07	0.31	0.03	3.10	4.3	0.1	7.50	41
38	B21	20-80	4.80	4.15	3.70	0.96	0.88	0.14	0.04	2.02	7.3	0.6	9.92	20
39	B22	80-133	4.80	4.10	3.70	0.21	0.75	0.11	0.09	1.16	9.3	0.9	11.36	10
40	IIB23	133-173	4.90	4.00	3.65	0.11	0.68	0.14	0.08	1.01	11.6	1.1	13.71	7
41	IIC1	173-215	4.95	4.05	3.70	0.16	0.42	0.07	0.06	0.71	7.9	0.6	9.21	8
42	IIC2	215-243	4.95	4.05	3.65	0.11	0.70	0.14	0.05	1.00	10.8	1.0	12.80	8
43	IIIC3	243-265	4.95	4.05	3.70	0.10	0.57	0.02	0.06	0.75	5.8	0.7	7.25	10
						Profile 7 - Guavia								
16	A11	0-25	4.55	4.15	3.90	0.17	0.11	0.03	0.05	0.36	2.8	0.5	3.66	10
17	A12	25-47	4.60	4.25	3.95	0.19	0.12	0.01	0.05	0.37	2.8	0.3	3.47	11
18	B21	47-75	4.70	4.25	4.00	0.19	0.02	0.01	0.04	0.26	2.9	0.1	3.26	8
19	B22cn	75-97	4.60	4.15	3.90	0.23	0.03	0.02	0.06	0.34	3.3	0.3	3.94	9
20	IIC	124-240	5.00	4.10	3.75	0.17	0.20	0.14	0.08	0.59	8.0	1.0	9.59	6
						Profile 8 - Floren								
56	A1	0-16	4.78	4.25	3.80	0.95	0.80	0.23	0.08	2.06	3.2	0.4	5.66	36
57	B21	16-85	4.70	4.10	3.75	0.22	0.43	0.03	0.06	0.74	6.7	0.9	7.74	10
58	B22	85-173	4.90	4.20	3.80	0.10	0.47	0.08	0.04	0.69	6.3	0.2	7.19	8
59	B3	173-208	4.90	4.15	3.75	0.10	0.41	0.13	0.04	0.68	6.1	0.9	7.68	9
60	C1	208-228	4.92	4.10	3.75	0.20	0.56	0.11	0.04	0.91	5.3	1.5	7.71	12
61	C2	228-247	4.96	4.15	3.75	0.16	0.63	0.17	0.04	1.00	8.1	0.5	9.60	10
62	C3	247-350	4.96	4.15	3.80	0.16	0.53	0.21	0.05	0.95	6.1	0.5	7.55	12

Table 13 (Continued)

Sample	Horizon	Depth from surface	pH			Exch. bases				Sum of bases	Exch. acidity[a]		ECEC[b]	PBS[c]
			H_2O 1:1	$CaCl_2$ 1:1	KCl 1:1	Ca	Mg	K	Na		Al	H		
		cm				------------------meq/100 g soil-----------------								%
						Profile 9 - Asis								
63	A1	0-12	4.80	4.30	3.70	2.10	1.40	0.40	0.10	4.00	4.2	0.9	9.10	44
64	B2	12-86	4.80	4.20	3.55	0.60	1.10	0.12	0.04	1.86	14.7	1.5	18.06	10
65	IIC1	86-138	4.72	4.13	3.50	0.60	0.60	0.20	0.04	1.44	21.4	2.1	24.94	6
66	IIC2	138-214	4.90	4.10	3.50	0.40	0.81	0.20	0.04	1.45	19.1	1.4	21.95	7
67	IIC3	214-296	4.90	4.10	3.50	0.41	0.60	0.20	0.03	1.24	17.9	1.9	21.04	6
68	IIIC4	296-350	4.90	4.12	3.60	0.60	0.40	0.10	0.04	1.14	7.4	2.1	10.64	11

[a] Exchangeable acidity, extracted by unbuffered 1 N KCl

[b] ECEC = effective cation exchange capacity (exchangeable bases plus exchangeable acidity)

[c] PBS = percent base saturation by ECEC base

vegetation take up nutrients from the B horizons and bring them to the soil surface via litter. The result of this transfer of nutrients is the enrichment of the A1 horizon and a relative depletion of the B horizon. On the other hand, the percolating water tends to leach the bases from the upper part of the solum. The relative accumulation of bases in the lower part of the profiles suggest (a) that the soil materials are less weathered there and/or (b) there is a relative accumulation of the leaching bases due to a decrease in water mobility or permeability. In profile 6 the distribution of total bases is somewhat disrupted due to lithologic discontinuities. Profile 9, on the other hand, shows a continuous decrease in basic cation content from the A1 horizon to the IIIC4 horizon. This distribution indicates considerable leaching or slight differences in composition of the different strata.

The total amounts of exchangeable bases in the Amazon soil studied are comparable with those of some soils in the southeastern United States. The following data are inserted for comparison:

Soil	Exchangeable bases (meq/100 g) Horizon A1	B2	C	Source
Davidson - Ultisol	3.54	0.41	0.66	Perkins *et al.* (1971)
Cecil - Ultisol N.C.	1.05	0.68	--	McCracken *et al.* (1971)
Hayesville - Ultisol N.C.	0.70	1.20	0.80	McCracken *et al.* (1971)

"Exchangeable acidity" here is defined as that portion of soil acidity extracted by 1 N unbuffered KCl solution and determined by titration. The exchangeable acidity consists predominantly of exchangeable Al with small amounts of "exchangeable hydrogen." However, some workers (Dewan and Rich, 1970; Zelazny *et al.*, 1972) have indicated that the H^+ detected in the 1 N KCl extracts may not be exchangeable H^+ but produced by hydrolysis of a portion of the exchangeable Al or from some non-exchangeable acidic groups present in the soil during the salt extraction.

The amount of exchangeable Al varies from profile to profile and from horizon to horizon within the profile.

In profile 1 the exchangeable Al decreases from 4.2 meq/100 g in the A horizon to 2.0 meq/100 g in the B22. In profile 2 it varies from 6.0 to 8.7 meq/100 g and there is no clear distribution pattern with depth. Soils 5 and 7 have around 5 and 3 meq/100 g, respectively. In soil 8 exchangeable Al increases from the A horizon to the C2 horizon. In these 5 profiles, which are considered more weathered, the exchangeable Al tends to decrease or is distributed more or less uniformly throughout the profile, except in soil 8. In contrast, in soils 3, 4, 6 and 9, considered less weathered, the increase of exchangeable Al with depth is substantial. In soil 3 the increment with depth is almost three times (5 to 15 meq/100 g); in soil 4 it is about 2.5 times (5 to 13 meq/100 g) and in soil 9 the increase is about five times. The same situation has been observed by Estrada (1971) in the less weathered soils of Pucallpa-Tarapato (Peru). The less weathered soils, or the less weathered horizons within the soil, have more weatherable clay minerals that are being decomposed by the weathering forces and the released Al constitutes a source of exchangeable acidity (Heddleson _et al._, 1960). Some low values of exchangeable Al in topsoil and subsurface may be explained by the complexing effect of the organic matter.

Coleman _et al._ (1959) developed the concepts and methods for determining the "permanent charge" and the "pH-dependent charge." The "permanent CEC," now named "effective cation exchange capacity" (ECEC), leads to a more realistic appraisal of exchange characteristics related with crop production (Pratt, 1961; Kamprath, 1967, 1970) and is operationally defined as the sum of exchangeable bases plus the exchangeable Al extracted by 1 N unbuffered KCl. In the case of Amazonian soils with a low base status, the ECEC consists almost entirely of exchangeable Al, with the exception of some topsoils that have a slightly high content of bases. Consequently, the Al saturation is high and varies from 56% in the A horizon of soil 9 to 90% in the A horizon of soil 3, and from 80 to 97% in the subsoil of profiles 6 and 2, respectively.

Nye et al. (1961), Evans and Kamprath (1970) and Kamprath (1967, 1970, 1972) have found that when surface soils have an exchangeable Al saturation of 60%, the concentration of Al in the soil solution is high enough to affect the growth of most crops. Based on these findings it is reasonable to predict that for the Amazonian soils studied, introduced annual crops will be affected by Al toxicity.

In order to prevent the Al toxicity, Kamprath and Foy (1971) have proposed two possibilities--(a) application of lime in order to reduce the levels of exchangeable Al and (b) developed crop varieties that are tolerant or resistant to high levels of Al, for regions where it is difficult or not economical to alter the soil conditions. This fertility-genetic approach has a tremendous potentiality and may be the solution for bringing cultivation to many of the acid tropical lands of South America.

Kamprath (1970) and Reeve and Sumner (1970) have used the exchangeable Al as criteria for lime requirement, instead of buffer methods which indicate the amount of lime needed to bring the soil near neutrality (pH 6.5). The method is based upon the amount of lime needed to reduce the exchangeable Al to non-toxic levels. The lime requirement is calculated multiplying the milliequivalent of exchangeable Al by 1.5. Soils with pH higher than 5.5 have small amounts of exchangeable Al and do not require liming.

Mehlich[4] developed a lime requirement test for soils of North Carolina. The "soil acidity" is determined using a buffer solution (pH 6.6) and the lime requirement is based on the soil acidity and the soil pH in water.

In order to know if "soil acidity" by Mehlich and the KCl-exchange acidity are related, the correlation and regression coefficients were determined for all 68 horizons considered as a population and independently for some profiles. The dependent variable Y is the KCl-exchange acidity and X is the Mehlich "soil acidity," reported in meq/100 cm^3 of soil. The obtained coefficients were as follows:

Description	Mean values		r	Regression equation
	Y	X		
All samples (68)	7.83	7.68	0.96**	$Y = -2.92 + 1.40X$
Profile 4 (10)	3.34	4.83	0.96**	$Y = -0.49 + 0.79X$
Profile 7 (12)	7.99	7.92	0.86**	$Y = -0.57 + 1.08X$
Profile 9 (7)	16.10	13.88	0.97**	$Y = -2.40 + 1.33X$

It seems that the test for acidity may be used for rapid estimation of the exchangeable acidity.

The lime requirement calculated according to Mehlich and Kamprath (1970) for the first two horizons of each profile are presented in Table 14.

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[4] Mehlich, A., Professor, Soil Testing Division, N. C. Department of Agriculture, Raleigh

Table 14. Lime requirement according to Mehlich and Kamprath (1970) procedures

Soil	Lime requirement	
	Mehlich	Kamprath
	--------$CaCO_3$ ton/ha------	
1 - Miraf		
A1	7.8	6.8
B1	8.3	7.4
2 - Montan		
A1	14.1	12.3
B1	13.4	14.5
3 - Naval		
A1	11.5	8.7
B21	9.0	6.8
4 - Polvor		
A1	8.4	8.4
B1	8.2	8.7
5 - Tacana		
A1	9.1	8.1
B21	6.0	8.1
6 - Leguiz		
A1	4.4	6.6
B21	7.5	11.8
7 - Guavia		
A11	6.9	4.9
A12	6.0	4.6
8 - Floren		
A1	6.2	5.4
B21	7.3	10.5
9 - Asis		
A1	6.4	7.6
B2	13.5	24.3
Mean	8.6	9.1

In some soils (2, 4) the lime requirements by the two methods coincide; however, in other cases like in the subsoil of profile 9 the values are very far apart. In this case probably the exchangeable Al exceeded the capacity of the buffer solution in the "soil acidity" determination.

If the transfer of the experiences from the Ultisols of North Carolina to the Amazonian soils is valid, an assumption that seems to be sound in view of the similarities among these soils (Sanchez and Buol, 1971), the conclusion may be made that the soils of the Colombian Amazon basin may require lime in amounts ranging between 5 and 12 $CaCO_3$ ton/ha. There are some limestone sources in the Eastern Cordillera that can be exploited, but the transportation is so expensive that any liming program is probably impracticable in the actual circumstances at this time.

Extractable Acidity, CEC, pH-Dependent CEC

There is much confusion in the terminology related to soil acidity and cation exchange properties of the soil. Therefore, it seems convenient first to describe or define the terms and then to discuss the properties.

The "extractable acidity" as defined by the Soil Survey Staff (Soil Survey Investigation Report 1, 1967) is that portion of acidity extracted by leaching a soil sample with $BaCl_2$-TEA pH 8.2 and titrating the excess base with HCl. The extractable acidity is obtained as the difference between the acid consumed by a blank (of the extracting solution) and by the soil leacheate.

Cation exchange capacity by "sum of cations" is equal to extractable acidity by $BaCl_2$-TEA pH 8.2 plus exchangeable bases extracted by 1 N NH_4OAc (Soil Survey Staff, 1960, 1967). "Cation retention" is equal to the CEC determined by unbuffered 1 N NH_4Cl, washed free of excess salt (Soil Survey Staff, 1970). pH-dependent acidity according to Pratt (1961) is the difference between extractable and exchangeable acidity, and pH-dependent CEC is equal to CEC by sum of cations less the ECEC:

$$\text{pH-dependent CEC} = (\text{CEC by sum of cations}) - (\text{ECEC}).$$

Table 15 presents the values obtained for extractable acidity, CEC by sum of cations, CEC by 1 N NH_4Cl pH 7.0, cation retention, ECEC, pH-dependent CEC and the ratio of pH-dependent CEC/ECEC.

The extractable acidity varies between profiles. In soils 1, 2, 5 and 8, considered more weathered, the extractable acidity tends to decrease with depth. This distribution pattern suggests some relationship with organic matter.

In the moderately well drained soils 3 and 4, with argillic horizon, the extractable acidity tends to increase with depth, reflecting the increase of clay in the B horizon.

In profile 7 extractable acidity decreases in the B22 horizon and then increases in IIC horizon, reflecting the lithological discontinuity. In soil 9 there is not clear distribution pattern in the profile. The extractable acidity increases from the A1 horizon to the IIC horizon and then decreases.

The extractable acidity ranges between 6 and 27 meq/100 g. The highest reported values correspond to the subsoil and substratum of profile 9. The more frequent values are between 12 and 16 meq/100 g.

According to the Soil Survey Staff (1970), the "cation retention" in acid soils, lacking amorphous aluminosilicates, "is similar to some of the permanent exchange capacity" and its numerical value in oxic

Table 15. Extractable acidity by $BaCl_2$-TEA pH 8.2, cation exchange capacities by sum of cations, 1 N pH 7 NH_4OAc, unbuffered 1 N NH_4Cl (cation retention) effective CEC (ECEC), pH-dependent CEC

Sample	Horizon	Depth from surface	Extractable acidity	CEC sum of cations	CEC NH_4OAc pH 7.0	Cation retention[a]	ECEC[b]	pH dependent CEC	pH dependent CEC / ECEC
		cm	meq/100 g						Ratio
					Profile 1 - Miraf				
21	A1	0-21	19.4	20.9	13.8	6.1	6.0	14.9	2.5
22	B1	21-38	17.9	17.9	10.6	5.3	5.7	12.2	2.1
23	B21	38-60	14.9	15.6	9.5	5.9	5.3	10.3	1.9
24		60-80	12.6	13.1	7.7	4.8	4.0	9.1	2.3
25		80-100	12.2	12.7	7.3	4.4	3.6	9.1	2.8
26	B22	100-150	11.2	11.6	6.1	3.7	2.5	9.1	3.6
27	B23	150-200	10.2	10.6	6.3	4.2	2.4	8.2	3.4
28		200-250	9.5	9.9	6.3	6.9	2.4	7.5	3.2
29		250-300	10.6	11.1	7.2	7.4	3.3	7.8	2.4
30		300-350	11.2	11.8	8.2	7.8	4.1	7.7	1.9
					Profile 2 - Montan				
44	A1	0-17	22.3	23.6	16.1	10.6	9.5	14.1	1.5
45	B1	17-37	20.3	21.0	14.2	11.1	10.4	10.6	1.0
46		37-64	17.8	18.1	12.3	10.4	9.2	8.9	1.0
47	B21	64-84	17.4	17.8	12.0	10.6	8.1	9.7	1.2
48		84-104	15.8	16.2	11.8	9.5	8.6	7.6	0.9
49		104-124	14.9	15.3	10.7	9.7	7.9	7.4	0.9
50		124-153	14.8	15.2	11.0	9.1	7.4	7.8	1.1
51	B22	153-173	14.5	14.8	10.8	9.9	7.1	7.7	1.1
52		173-200	13.9	14.2	10.9	9.2	7.5	6.7	0.9
53		200-227	13.9	14.2	11.5	9.6	7.6	6.6	0.9
54	C1	227-310	13.8	14.3	11.1	9.3	8.2	6.1	0.7
55	C2	310-350	12.0	12.5	10.5	9.3	9.0	3.5	0.4

Table 15 (Continued)

Sample	Horizon	Depth from surface	Extractable acidity	CEC sum of cations	CEC NH_4OAc pH 7.0	Cation[a] retention	ECEC[b]	pH dependent CEC	pH dependent CEC / ECEC
		cm	meq/100 g						Ratio
					Profile 3 - Naval				
8	A1	0-13	12.0	12.7	9.2	7.6	6.5	6.2	1.0
9	B21	13-33	8.0	8.5	6.1	5.5	5.0	3.5	0.7
10		33-52	7.2	7.5	6.2	5.7	5.1	2.4	0.5
11	B22	52-72	10.4	10.7	9.1	8.2	7.6	3.1	0.4
12		72-105	15.3	15.7	13.8	12.5	11.7	4.0	0.3
13	B23	105-142	16.7	17.2	16.0	14.7	13.3	3.9	0.3
14	B24	142-200	19.8	20.4	19.5	18.3	16.9	3.5	0.2
15		200-250	20.0	20.6	17.0	15.9	15.1	5.5	0.4
					Profile 4 - Polvor				
31	A1	0-17	13.5	14.7	11.2	9.1	6.8	7.9	1.2
32	B1	17-47	12.1	12.6	9.8	10.9	6.3	6.3	1.0
33	B21	47-80	13.5	14.0	11.3	10.0	8.6	5.4	0.6
34	B22	80-120	16.0	16.4	13.4	6.2	10.5	5.9	0.6
35		120-157	16.6	17.0	14.1	15.1	11.5	5.5	0.5
36	C1	157-210	17.1	17.7	16.3	14.4	14.7	3.0	0.2
					Profile 5 - Tacana				
1	A1	0-10	16.7	17.4	11.9	7.1	6.1	11.3	1.9
2	B21	10-30	13.5	13.9	9.8	6.9	5.8	8.1	1.4
3		30-50	15.2	15.6	9.4	6.3	5.3	10.3	1.9
4		50-70	12.2	12.6	9.7	6.7	5.9	6.7	1.1
5		70-83	12.2	12.6	9.9	7.5	6.0	6.6	1.1
6	B22	83-140	12.6	13.0	11.5	10.0	7.3	5.7	0.8
7	B23cn	140-200	11.5	11.8	11.4	9.3	7.5	4.3	0.6

Table 15 (Continued)

Sample	Horizon	Depth from surface	Extractable acidity	CEC sum of cations	CEC NH_4OAc pH 7.0	Cation[a] retention	ECEC[b]	pH dependent CEC	pH dependent CEC / ECEC
		cm	meq/100 g						Ratio
				Profile 6 - Leguiz					
37	A1	0-20	9.0	12.1	9.1	11.8	5.5	6.6	1.2
38	B21	20-80	14.7	16.7	13.4	14.5	9.9	6.8	0.7
39	B22	80-133	15.2	16.4	13.8	10.1	11.4	5.0	0.4
40	IIB23	133-173	16.9	17.9	15.8	15.8	13.7	4.2	0.3
41	IIC1	173-215	11.9	12.6	11.1	7.8	9.2	3.4	0.4
42	IIC2	215-243	16.1	17.1	17.2	9.1	12.8	4.3	0.3
43	IIIC3	243-265	9.4	10.2	8.1	9.8	7.3	2.9	0.4
				Profile 7 - Guavia					
16	A11	0-25	10.3	10.7	7.3	3.8	3.7	7.0	1.9
17	A12	25-47	10.4	10.8	6.1	3.8	3.5	7.3	2.1
18	B21	47-75	10.3	10.6	5.9	3.3	3.3	7.3	2.2
19	B22cn	75-97	6.3	6.6	6.3	4.1	3.9	2.7	0.7
20	IIC	124-240	12.2	12.8	12.1	9.8	9.6	3.2	0.3
				Profile 8 - Floren					
56	A1	0-16	14.3	16.4	11.8	7.4	5.7	10.7	1.9
57	B21	16-85	12.3	13.0	11.9	9.5	7.7	5.3	0.7
58	B22	85-173	12.2	12.9	10.9	11.5	7.2	5.7	0.8
59	B3	173-208	10.4	11.1	9.0	9.1	7.7	3.4	0.4
60	C1	208-228	7.7	8.6	7.3	7.7	7.7	0.9	0.1
61	C2	228-247	13.1	14.1	11.7	12.2	9.6	4.5	0.5
62	C3	247-350	9.9	10.9	8.9	8.8	7.6	3.3	0.4

Table 15 (Continued)

Sample	Horizon	Depth from surface	Extractable acidity	CEC sum of cations	CEC NH_4OAc pH 7.0	Cation[a] retention	ECEC[b]	pH dependent CEC	pH dependent CEC / ECEC
		cm	meq/100 g						Ratio
			Profile 9 - Asis						
63	A1	0-12	15.9	19.9	15.7	9.6	9.1	10.8	1.2
64	B2	12-86	20.7	22.6	20.7	18.1	18.1	4.5	0.2
65	IIC1	86-138	27.0	28.4	26.4	24.7	24.9	3.5	0.1
66	IIC2	138-214	22.5	24.0	23.0	22.6	22.0	2.0	0.1
67	IIC3	214-296	21.6	22.8	22.7	22.0	21.0	1.8	0.1
68	IIIC4	296-350	11.3	12.4	11.3	11.8	10.6	1.8	0.2

[a] Cation retention is CEC by unbuffered 1 N NH_4Cl

[b] ECEC = effective cation exchange capacity

horizons approximates the ECEC, and either one can be used as a diagnostic parameter for oxic horizons. In soils 1 and 2 the cation retention is higher than the ECEC. In soils 3, 7 and 9 the cation retention and the ECEC are very close. In general, there is a good agreement between the two determinations and for classification purposes only the ECEC may be used and so the cation retention determination avoided. However, it should be noticed that very different values can be obtained in soil soils. For example, a Catalina oxic horizon from Puerto Rico gives 9.5 meq/100 g clay by cation retention and only 5.0 by ECEC, and the Cialitos soil gives 22 and 12 meq/100 g clay, respectively (Soil Survey Staff, 1970).

The pH-dependent CEC ranges from 1 to 15 meq/100 g soil. With the exception of soils 3 and 6, the maximum values for the pH-dependent CEC correspond to the top soil. The more weathered soils like 1, 2, 5 and 7 tend to have higher pH-dependent CEC values and the less weathered soils (3, 9, 6) tend to show lower values.

Taking the average values for the profile, a ranking order from higher to lower values results as follows:

Mean pH-dependent CEC	Soil
9.59	1 - Miraf
8.06	2 - Montan
7.57	5 - Tacana
5.50	7 - Guavia
5.22	4 - Polvor
4.83	8 - Floren
4.73	6 - Leguiz
4.06	9 - Asis
4.01	3 - Naval

The distribution of the pH-dependent CEC as a function of depth shows a clear tendency to decrease with depth. In general, the decrease is gradual from top to the bottom; for example, in profiles 1, 2, 4, 5 and 6. However, in profiles 7, 8 and 9 there are some rather abrupt changes from one horizon to another.

The decrease of pH-dependent CEC with depth suggests that some sources of pH-dependent CEC originate in the organic matter, which decreases gradually with depth. The increase of the magnitude of pH-dependent CEC with increasing degree of weathering suggests that Al and Fe interlayered in 2:1-2:2 minerals and Al and Fe coatings are also sources of the pH-dependent CEC.

It seems that in the Amazon soils organic matter and Al and Fe interlayers and coatings are the sources of the pH-dependent CEC and this is in accordance with the accepted views. Coleman and Thomas (1967) indicate that pH-dependent CEC has two components--(a) the weakly dissociated acid groups of organic matter and (b) the Al and Fe polycations deposited in the interlayers of 2:1 minerals and/or the sesquioxide coatings enveloping the clay mineral surfaces. De Villiers and Jackson (1967a, 1967b) have explained the mechanisms by which the pH-dependent CEC originates in chloritized vermiculites and sesquioxidic allophanes. The pH functional variation in CEC for soil clays is attributed to deprotonation of positive hydroxy-Al of the pedogenic aluminous chlorite; the cited authors conclude that permanent CEC and pH-dependent CEC are identical in origin. Both arise from isomorphous substitution, but pH-dependent charge is blocked by positively charged hydroxy Al ions.

On the other hand, the increase of CEC with increase in pH is explained by the release of protons from weakly dissociated organic groups, mainly carboxyl groups of the organic matter.

Sawhney et al. (1970) and Sawhney and Norris (1971) have developed a procedure to differentiate the contributions of organic matter and sesquioxide coating or interlayers to the pH-dependent charge. They found for some soils of Australia the contribution attributed to Fe and Al interlayers and coatings (irreversible component of pH-dependent charge) is of small magnitude. According to the cited authors the "reversible component" of the pH-dependent charge may be assigned to the organic matter as well as to kaolinite, halloysite and allophane. They found that when these minerals are present, they may contribute significantly to the reversible component of the pH-dependent CEC.

The increase in CEC as the pH rises from the pH of the soil up to pH 8.2 or so is a characteristic of many Ultisols from southeastern United States (Coleman et al., 1959; McCracken et al., 1971; Fiskell, 1970) and of many tropical soils (Middleton, 1965; LeRoux and de Villiers, 1966; Pratt and Alvahydo, 1966; Reeve and Sumner, 1971; Sawhney and Norris, 1971).

The increase in CEC from the pH of the soil to pH 8.2 in the Amazon soils is similar to that reported in Ultisols and varies from profile to profile and from horizon to horizon. The increase varies from about 1.2X to 4.5X being higher in the upper part of the profiles and diminishing with depth.

Pratt and Alvahydo (1966) found characteristic ratios of the pH-dependent CEC to ECEC for different types of Brazilian soils. Average values were 4.0 for Red Latosols, 2.7 for Red-Yellow Latosols and 1.6 for Red-Yellow Podzolic soils. In the Amazon soils (Table 15) the ratios are lower than those reported for the Brazilian soils and there is not a clear indication that permits the discrimination into specific groups. Taking only the ratios of the A horizon, as Pratt and Alvahydo (1966) did, a little higher values are noted for the soils considered more weathered.

The ranking order was as follows:

Soil	pH-dependent CEC/ECEC
1 - Miraf	2.5
8 - Floren	1.9
7 - Guavia	1.9
5 - Tacana	1.9
2 - Montan	1.5
9 - Asis	1.2
6 - Leguiz	1.2
4 - Polvor	1.2
3 - Naval	1.0

Carbon and Nitrogen

Walkley-Black wet combustion method was used to determine the readily oxidizable organic C (Allison, 1965). The results by this procedure may be affected by the presence of readily oxidizable substances other than C. Buol (1972) has indicated the possibility that a high content of Mn in tropical soils may constitute a significant source of error. In order to check this possible source of error and to determine the percent recovery of the wet combustion method, carbon was also determined by the dry combustion method which is considered more reliable and the standard method for determining soil organic carbon. The results are presented in Table 16. In seven samples the carbon by Walkley-Black method gave slightly higher carbon values than dry combustion. In all other samples the reverse was true.

The average effectiveness of the wet combustion method was calculated (excluding the samples in which the wet combustion C was higher than dry combustion C) and found to be 71%, with a considerable

Table 16. Organic carbon, total nitrogen, carbon:nitrogen ratio, nitrogen mineralized by aerobic and anaerobic incubations

Sample	Depth from surface	Carbon		Total N	C/N	Mineralized N		Rate of aerobic mineralization[a]
		Dry combustion	Wet oxidation			Aerobic	Anaerobic	
	cm	-------------%-------------		%	Ratio	------ppm-----		%
			Profile 1 - Miraf					
21	0-21	2.55	1.97	0.26	7.6	32	75	1.23
22	21-38	1.65	1.22	0.17	7.2	22	36	1.29
23	38-60	0.50	0.82	0.12	6.8	2	13	0.17
24	60-80	0.85	0.59	0.10	5.9	2	8	0.20
25	80-100	0.58	0.51	0.08	6.4	2	5	0.25
26	100-150	0.34	0.34	0.07	4.9	--	--	----
27	150-200	0.24	0.23	0.07	3.3	--	--	----
28	200-250	0.20	0.19	0.07	2.7	--	--	----
29	250-300	0.25	0.20	0.08	2.5	--	--	----
30	300-350	0.13	0.15	0.07	2.1	--	--	----
			Profile 2 - Montan					
44	0-17	3.31	2.54	0.26	9.8	39	122	1.50
45	17-37	1.70	1.16	0.17	6.8	29	40	1.71
46	37-64	0.99	0.69	0.12	5.6	2	10	0.17
47	64-84	0.95	0.58	0.11	5.3	2	10	0.18
48	84-104	0.69	0.52	0.10	5.2	2	5	0.20
49	104-124	0.53	0.39	0.11	3.5	--	--	----
50	124-153	0.54	0.29	0.09	3.2	--	--	----
51	153-173	0.42	0.32	0.08	4.0	--	--	----
52	173-200	0.34	0.27	0.08	3.3	--	--	----
53	200-227	0.13	0.20	0.07	2.9	--	--	----
54	227-310	----	0.14	0.06	2.3	--	--	----

Table 16 (Continued)

Sample	Depth from surface	Carbon		Total N	C/N	Mineralized N		Rate of aerobic mineralization^a
		Dry combustion	Wet oxidation			Aerobic	Anaerobic	
	cm	--------------%----------------		%	Ratio	------ppm------		%
				Profile 3 - Naval				
8	0-13	1.77	1.41	0.17	8.3	27	63	1.59
9	13-33	0.59	0.38	0.07	5.4	11	15	1.57
10	33-52	0.29	0.20	0.05	4.0	4	2	0.80
11	52-72	0.08	0.13	0.04	3.3	4	3	1.00
12	72-105	0.12	0.12	0.05	2.4	4	2	0.80
13	105-142	0.13	0.10	0.04	2.5	--	--	----
14	142-200	----	0.07	0.04	1.8	--	--	----
15	200-250	----	0.07	0.04	1.8	--	--	----
				Profile 4 - Polvor				
31	0-17	1.80	1.34	0.17	7.9	35	44	2.06
32	17-47	0.62	0.57	0.09	6.3	--	12	----
33	47-80	0.54	0.35	0.09	3.9	--	6	----
34	80-120	0.29	0.21	0.07	3.0	--	4	----
35	120-157	0.41	0.17	0.06	2.8	--	--	----
36	157-210	0.04	0.05	0.02	2.5	--	--	----
				Profile 5 - Tacana				
1	0-10	2.72	1.85	0.24	7.7	50	119	2.08
2	10-30	1.37	0.91	0.13	7.0	31	33	2.06
3	30-50	1.03	0.67	0.11	6.1	21	15	1.91
4	50-70	0.93	0.57	0.07	8.1	21	9	3.00
5	70-83	0.69	0.42	0.08	5.3	15	7	1.88
6	83-140	0.29	0.17	0.04	4.3	4	4	1.00
7	140-200	0.12	0.08	0.03	2.7	--	--	----

Table 16 (Continued)

Sample	Depth from surface	Carbon		Total N	C/N	Mineralized N		Rate of aerobic mineralization*
		Dry combustion	Wet oxidation			Aerobic	Anaerobic	
	cm	---------------%---------------		%	Ratio	------ppm------		%
				Profile 6 - Leguiz				
37	0-20	1.83	1.39	0.17	8.2	--	--	----
38	20-80	0.77	0.38	0.04	9.5	2	6	0.50
39	80-133	0.32	0.21	0.10	2.0	--	--	----
40	133-173	0.16	0.09	0.06	1.5	--	--	----
41	173-215	0.09	0.05	0.02	2.5	--	--	----
42	215-243	0.12	0.06	0.02	3.0	--	--	----
43	243-265	----	0.07	0.02	3.5	--	--	----
				Profile 7 - Guavia				
16	0-25	1.16	1.03	0.10	10.0	12	23	1.20
17	25-47	0.94	0.76	0.07	10.8	7	12	1.00
18	47-75	0.67	0.55	0.06	9.2	2	7	0.67
19	75-97	0.37	0.30	0.06	5.0	2	2	0.67
20	124-240	----	0.23	0.05	4.6	--	--	----
				Profile 8 - Floren				
56	0-16	1.89	2.02	0.22	9.2	26	128	1.18
57	16-85	0.49	0.51	0.08	12.4	4	11	0.50
58	85-173	0.19	0.22	0.05	4.4	4	2	0.80
59	173-208	----	0.15	0.03	5.0	--	--	----
60	208-228	----	0.08	0.02	4.0	--	--	----
61	228-247	----	0.09	0.02	4.5	--	--	----
62	247-350	----	0.07	0.02	3.5	--	--	----

Table 16 (Continued)

Sample	Depth from surface	Carbon		Total N	C/N	Mineralized N		Rate of aerobic mineralization[a]
		Dry combustion	Wet oxidation			Aerobic	Anaerobic	
	cm	------------%-------------		%	Ratio	-----ppm-----		%
				Profile 9 - Asis				
63	0-12	3.02	2.32	0.30	7.7	86	62	2.87
64	12-86	0.33	0.35	0.09	3.9	4	7	0.44
65	86-138	----	0.16	0.07	2.3	2	2	0.29
66	138-214	----	0.15	0.04	3.8	--	--	----
67	214-296	----	0.14	0.05	2.8	--	--	----
68	296-350	----	0.05	Tr	---	--	--	----

[a] Rate of aerobic mineralization is equal to the N mineralized by aerobic incubation expressed as percent of the total nitrogen

variability for profiles and for individual samples. The range for individual samples is from 41 to 96% and averages for profiles are between 59% (profile 6) and 83% (profiles 1 and 2). The great variation in the amount of organic carbon recovered by the Walkley Black method suggests that the use of this method to determine accurately and consistently the soil organic carbon cannot be considered a satisfactory substitute for the dry combustion method, if precise data are required.

It is noticed that in the three upper horizons of the well drained soil 8, the wet combustion C is higher than the dry combustion C. The pH's are 4.78, 4.70 and 4.90, respectively. The acidity conditions here are probably favorable for certain accumulation of Mn^{++} which consumes $K_2Cr_2O_7$ and the carbon appears higher than the real amount. The extracted Mn^{++} is high in the first horizon (290 ppm) but relatively low in the second and third horizons (26 and 48 ppm, respectively).

The values of organic carbon in the A1 horizons range from 3.31% (soil 2) to 1.16% (soil 7). All profiles showed a clear vertical distribution pattern of the organic carbon. The maximum values are in A horizons and decrease with depth. The decrease from the A horizons to the B horizons is rather abrupt (except in profiles 1, 2 and 7) and from B to C horizons is gradual.

There is a general relationship between carbon and clay content. Soils with higher clay contents tend to have higher contents of organic carbon.

The total nitrogen content in the A horizon varies from 0.26% (soils 1 and 2) to 0.10% (soil 7). These are relatively high values compared with that of the Ultisols of the southeastern United States. Some of the reasons advanced for explaining the relative nitrogen richness of the tropical forest soils are the abundance of leguminous trees (Jenny et al., 1948), non-legume symbionts that fix nitrogen, free-living, N-fixing microorganisms in the phyllosphere, nitrogen-fixing blue-green algae, release of indigenous fixed ammonium and subsequent absorption by plant roots may make significant contributions to the biological nitrogen (Jaiyebo and Moore, 1963; Moore and Ayke, 1965).

It is commonly accepted that nitrogen and phosphorus are probably the most limiting factors of crop production in the tropical soils. In order to obtain an idea about the capacity of the Amazon soils to supply available nitrogen mineralization, tests were made by aerobic and anaerobic incubation. The amount of nitrogen mineralized by aerobic incubation (Table 16) decreased from the topsoil to the subsoil; in some profiles the decrement is gradual (profile 5) but in others is abrupt (soils 1, 2, 8 and 9).

The amounts of N-NO_3 mineralized in the topsoils varies from 12 to 86 ppm. Five of the soils (1, 2, 4, 5 and 9) have a relatively high capacity for nitrification; all produced more than 30 ppm. This may indicate that some of the Amazon soils may be able to supply substantial amounts of the nitrogen required by plants. Welch (1960) found, for the well drained Ultisols of North Carolina, that there is no significant increase in corn yield, due to nitrogen fertilization, when the mineralized N-NO_3 is above about 25 ppm. He also found that the amount of NO_3 produced during 14 days incubation by many of the well drained soils varied from 10 to 25 ppm.

With one exception (soil 9), the anaerobic incubation produced significantly more nitrogen than aerobic incubation. The differences may be due to the influence of the very acid conditions of the soils on the organisms that accomplish the ammonification and the nitrification processes. The ammonifying microorganisms are not very sensitive to acidity and they can transform the organic nitrogen into ammonium in very acid or slightly acid environments. However, the autotrophic ammonium-oxidizing organisms are pH-sensitive and the ammonium oxidation is inhibited by low soil pH values. As a rule, nitrification is promoted by a reaction approaching neutrality.

The amounts of N-NH_4 produced by anaerobic incubation varied between 23 and 128 ppm of N-NH_4. This relatively large production of available nitrogen in waterlogged conditions may be significant in rice production.

The carbon/nitrogen ratio in the A1 horizon varies between 8 and 11 and decreases in the B and C horizons to very low values of 3 and even 2. The narrowing of the C/N with depth has been observed by Ramirez (1958) and Blasco (1968) in Amazon soils and by Toquica and Bernal (1964) in many profiles of the Llanos Orientales.

Studies on the vertical distribution of carbon and nitrogen in many soil profiles show that the C/N ratio tends to decrease as the depth increases. The most popular explanations for the narrowing of the C/N with depth in soil profiles are (a) there are considerable amounts of nitrogen in the subsoils in the form of fixed ammonium and (b) there is a selective preservation of nitrogen-rich compounds in the subsoil; however, the cause of this is not known.

Work by Rodriguez (1954) for the first time provided evidence that some tropical soils contain substantial amounts of clay-fixed ammonium and it is now well established that many soils have fixed ammonium and that indigenous fixed ammonium may comprise from 2 to 90% of the total nitrogen (Stevenson and Dhariwal, 1959; Young and Catani, 1962; Dureau and Dutil, 1966; Martin _et al._, 1970; Muir _et al._, 1970). Rodriguez (1954) found values of 281-1920 ppm of fixed N-NH_4 in Caribbean soils. Moore and Ayake (1965) in Nigeria found between 32 and 220 ppm of fixed N-NH_4, the surface horizons having lower amounts than deeper horizons. Mikama and Kanehiro (1968) found a range of from 0-585 ppm in Eutrustoxs of Hawaii and Stevenson (1972) reported a Red-Yellow Podzolic with 113 and 108 ppm N as fixed NH_4^+ in the A and B horizons, respectively.

It is assumed that the ammonium is fixed during the formation of the minerals, the ammonium occupying the potassium sites. It has been found that the native fixed ammonium is correlated with the total content of potassium in soils without feldspars, indicating that the fixed ammonium is carried out by micas and vermiculites (Rich, 1960; Mikamo and Kanehiro, 1968; Martin _et al._, 1970).

There is not information about the amounts and distribution of the native fixed ammonium in the Amazon soils. Looking for the possible causes of the extremely narrow C/N ratios in the subsoil of the profiles studied here, the determination of indigenous fixed ammonium was done. The results are presented in Table 17.

All soils had native fixed ammonium in amounts ranging from 57 to 374 ppm N-NH_4 and constituted between 2 and 92% of the total nitrogen. In profiles 1, 2, 3, 4, 5, 7, 8 and 9 the native fixed ammonium tended to be higher in the deeper horizons than in the surface and subsurface horizon and constituted a substantial part of the total nitrogen in the lower horizons. When the native fixed ammonium was expressed as a

Table 17. Total nitrogen, indigenous fixed ammonium, organic nitrogen and organic carbon:organic nitrogen ratio

Sample	Depth from surface	Total N	Fixed $N\text{-}NH_4$		Fixed $N\text{-}NH_4$ as % total N	Organic nitrogen	$C/O.N^a$
	cm	ppm	ppm	meq/100g	%	ppm	Ratio
			Profile 1 - Miraf				
21	0-21	2600	72	0.50	3	2528	7.8
22	21-38	1700	68	0.49	5	1632	7.5
23	38-60	1200	60	0.43	5	1140	7.2
24	60-80	1000	57	0.41	6	943	6.3
25	80-100	800	63	0.45	8	737	7.0
26	100-150	700	71	0.51	10	629	5.4
27	150-200	700	72	0.52	10	628	3.7
28	200-250	700	96	0.70	14	604	3.2
29	250-300	800	183	1.31	23	617	3.2
30	300-350	700	236	1.69	34	464	3.2
			Profile 2 - Montan				
44	0-17	2600	136	0.98	5	2464	10.3
45	17-37	1700	96	0.69	6	1604	7.3
46	37-64	1200	92	0.66	8	1108	6.3
47	64-84	1100	101	0.72	7	999	5.8
48	84-104	1000	112	0.80	11	888	5.9
49	104-124	1100	94	0.67	12	1006	3.9
50	124-153	900	104	0.75	12	796	3.6
51	153-173	800	126	0.90	16	674	4.7
52	173-200	800	166	1.19	21	634	4.3
53	200-227	700	163	1.17	23	537	3.8
54	227-310	600	187	1.34	32	413	3.4
55	310-350	300	240	1.72	80	60	13.3
			Profile 3 - Naval				
8	0-13	1700	104	0.75	6	1596	8.9
9	13-33	700	117	0.84	17	583	6.5
10	33-52	500	132	0.95	26	368	5.4
11	52-72	400	133	0.95	33	267	4.9
12	72-105	500	171	1.23	34	329	3.7
13	105-142	400	242	1.74	61	158	6.3
14	142-200	400	270	1.94	68	130	5.4
15	200-250	400	252	1.81	63	148	4.7
			Profile 4 - Polvor				
31	0-17	1700	88	0.63	5	1612	8.4
32	17-47	900	140	1.00	16	760	7.5
33	47-80	900	129	0.92	14	771	4.5
34	80-120	700	119	0.85	17	581	3.6
35	120-157	600	184	1.32	31	416	4.1
36	157-210	200	218	1.56	+100	---	---

Sample 17 (Continued)

Sample	Depth from surface	Total N	Fixed N-NH$_4$		Fixed N-NH$_4$ as % total N	Organic nitrogen	C/O.N[a]
	cm	ppm	ppm	meq/100g	%	ppm	Ratio
			Profile 5 - Tacana				
1	0-10	2400	72	0.52	3	2328	8.0
2	10-30	1300	93	0.67	7	1207	7.6
3	30-50	1100	123	0.88	11	977	6.9
4	50-70	700	79	0.57	12	621	9.2
5	70-83	800	77	0.55	11	723	5.8
6	83-140	400	157	1.13	39	243	7.0
7	140-200	300	163	1.18	54	137	5.8
			Profile 6 - Leguiz				
37	0-20	1700	162	1.16	9	1538	9.1
38	20-80	400	155	1.11	39	245	15.5
39	80-133	1000	117	0.84	12	883	2.4
40	133-173	600	162	1.16	27	438	2.1
41	173-215	200	132	0.95	66	68	7.3
42	215-243	200	148	1.06	74	52	11.5
43	243-265	200	129	0.92	65	71	9.9
			Profile 7 - Guavia				
16	0-25	1000	98	0.70	10	902	11.4
17	25-47	700	117	0.84	17	583	13.1
18	47-75	600	121	0.87	20	479	11.7
19	75-97	600	184	1.32	31	416	7.3
			Profile 8 - Floren				
56	0-16	2200	164	1.18	7	2036	10.1
57	16-85	800	221	1.58	28	579	8.9
58	85-173	500	210	1.51	42	290	7.6
59	173-208	300	270	1.94	90	30	26.0
60	208-228	200	---	----	--	---	---
61	228-247	200	184	1.32	92	16	43.0
62	247-350	200	---	----	--	---	---
			Profile 9 - Asis				
63	0-12	3000	119	0.85	4	2881	8.3
64	12-86	900	298	2.14	33	602	5.8
65	86-138	700	236	1.69	34	464	3.5
66	138-214	400	---	----	--	---	---
67	214-296	500	321	2.30	64	179	7.8

[a] C/O.N = carbon/organic nitrogen ratio

percent of the total nitrogen, it was found that the values increased consistently with depth between 2 and 10% in surface soil and between 31 and 92% in the lower horizons, indicating that the organic nitrogen (total nitrogen less fixed $N-NH_4$) decreased substantially with depth.

The C/organic N ratio values (Table 17) increase somewhat with relation to C/N (Table 16) but still remain low in the deeper horizons. The decrease of the C/organic N with increasing depth is a phenomenon that soil scientists still have not explained (Stevenson, 1972).

The agronomic significance of the native fixed ammonium is not known but it may signify a sizeable contribution in the humid tropical soils covered by forest, where weathering may be rapid and occur at considerable depths. Kellog (1963) has pointed out that the release of fixed ammonium account in part for the rapid buildup of nitrogen in surface soils under tropical rain forest.

Total Organic and Available Phosphorus

It is usually believed that the increase of the weathering produces a decline in the levels of total phosphorus and an increase in the proportion of organic and occluded forms of phosphorus (Olson and Engelstead, 1972). According to the cited authors, surface horizons of mature Latosols usually have less than 200 ppm of total phosphorus.

In order to have information about the levels of total and organic phosphorus, analyses were done in the upper horizons of all profiles. The results are presented in Table 18. The total phosphorus content of A1 horizons varies between 600 ppm (soil 1) and 190 ppm (soil 5). Similar values have been obtained by other workers for Amazonian soils of Brazil and Colombia. Vieira and Bornemisza (1968) found amounts

Table 18. Total organic and available phosphorus

Sample	Depth from surface	P			P extracted by		
		Total	Organic	Organic P	Bray II	N.C.	Modified Olsen
	cm	ppm	ppm	%	ppm	ppm	ppm
Profile 1 - Miraf							
21	0-21	500	250	50	2.4	1.5	17.0
22	21-38	450	224	50	0.9	0.5	12.0
23	38-60	475	224	47	0.9	0.5	8.0
24	60-80	450	220	49	0.4	---	----
25	80-100	435	219	50	0.4	---	----
Profile 2 - Montan							
44	0-17	600	286	48	3.5	2.5	18.5
45	17-37	550	322	58	1.5	1.0	13.0
46	37-64	490	314	64	0.9	0.5	5.5
47	64-84	491	293	60	0.9	---	----
48	84-104	521	334	64	0.9	---	----
Profile 3 - Naval							
8	0-13	180	90	50	3.0	5.0	16.0
9	13-33	104	50	48	0.9	0.5	3.0
10	33-52	104	46	44	0.4	0.5	3.0
11	52-72	100	46	46	0.4	---	----
12	72-105	98	47	48	0.0	---	----
Profile 4 - Polvor							
31	0-17	340	246	72	2.0	2.0	12.0
32	17-47	340	245	72	0.9	0.5	5.5
33	47-80	400	246	62	0.9	0.0	3.0
34	80-120	410	298	73	2.0	0.0	----
Profile 5 - Tacana							
1	0-10	190	107	56	2.4	1.5	11.0
2	10-30	140	68	49	0.4	0.5	7.0
3	30-50	130	65	50	0.0	0.0	4.5
4	50-70	140	59	42	0.0	---	----
5	70-83	110	52	47	3.0	---	----
6	83-140	108	50	46	0.4	---	----
Profile 6 - Leguiz							
37	0-20	360	---	--	3.0	1.5	12.0
38	20-80	340	181	53	1.5	0.0	4.5
39	80-133	340	187	55	0.4	0.0	1.0

Table 18 (Continued)

Sample	Depth from surface	P			P extracted by		
		Total	Organic	Organic P	Bray II	N.C.	Modified Olsen
	cm	ppm	ppm	%	ppm	ppm	ppm
		Profile 7 - Guavia					
16	0-25	200	130	65	0.9	1.0	10.0
17	25-47	190	134	71	0.9	0.5	5.5
18	47-75	230	153	67	0.4	0.0	3.0
19	75-97	280	180	64	0.0	---	----
		Profile 8 - Floren					
56	0-16	250	146	58	3.5	1.5	14.5
57	16-85	200	104	52	0.9	0.0	2.0
58	85-173	164	71	43	0.0	0.0	2.0
		Profile 9 - Asis					
63	0-12	310	206	66	2.4	1.5	16.0
64	12-86	290	178	61	1.5	0.0	4.5
65	86-138	340	187	55	1.5	0.0	3.0

ranging between 176 and 594 ppm for Amazonian Latosols; Fassbender and Diaz (1970) reported 470 to 750 ppm for soils of Maranhao and Blasco (1968) found values ranging between 200 and 406 for soils of the Leticia region.

Except in profiles 4 and 7, the total phosphorus tended to decrease with increasing depth, suggesting the influence of the organic matter in the vertical distribution.

Taking the mean value of total phosphorus in each profile, it is noticed that soils of the same geologic region tend to have values of similar order of magnitude. For example, soils 1 and 2 on the Orito formation have 460 and 530 ppm, soils 4 and 6 from Leguizamo in the Putumayo basin have 374 and 346 ppm, soils 3 and 5 from Leticia have 135 and 117 ppm, and soils 8 and 9 from Andean foothills have mean values of 205 and 346. The noted geographic distribution pattern indicates that the parent material determines to a great extent the amounts of total phosphorus.

The organic phosphorus constitutes a substantial portion of the total. The percentage of organic phosphorus varies from sample to sample and from profile to profile. The range for samples is from 42% up to 72%; the mean values for profiles varies from 47% (profile 3) to 69% (profile 4). The results reported here are similar to those obtained by Blasco (1970) who found that organic phosphorus is the predominant fraction, constituting as much as 78% of total phosphorus in soils under forest in the Leticia area. Fassbender and Diaz (1970) also reported that organic phosphorus is about 72% of the total phosphorus both for soils and subsoils. On the other hand, Vieira and Bornemisza (1968) found that the organic fraction contributed between 20 and 50% of the total phosphorus in several Amazonian Latosols.

The available phosphorus was assessed using three extractant solutions--Bray II, North Carolina and Modified Olsen. The amounts extracted are in Table 18.

The Bray II phosphorus contents in the A horizons are very low. They range from 0.9 to 3.5 ppm and usually decrease with depth. Similar values were obtained by Estrada (1971) for Peruvian soils. The critical level of the Bray II phosphorus for cereal crops in Colombia has been estimated in 20 ppm P (Calle and Uexkull, 1970). This reference level suggests that the Amazon soils are extremely low in available phosphorus.

The phosphorus extracted from the A horizons by the North Carolina solution is also very low. In six soils it is lower than the Bray II sphorus; in one soil it is equal and in two soils it is higher. The nt extracted decreased with depth, being zero in some horizons.

The modified Olsen solution is becoming popular in South America several field and laboratory experiments are being conducted for relation with responses to applied fertilizers. For comparison poses the phosphorus was extracted with the modified Olsen solution. results are shown in Table 18. The amounts extracted are from four 13 times the amount extracted by Bray II. Due to the presence of EDTA, e of the forms of organic phosphorus are probably complexed and exacted. There is not a good correlation in values between Bray II and odified Olsen. A calculation of the rank correlation coefficient ndicates no significant correlation ($r_s = 0.65$).

A tentative critical value for the modified Olsen has been estimated o be about 16 to 20 ppm (Hunter[5]). All of the soils included in the present study are below the critical level. However, by this method the phosphorus deficiency does not appear to be as critical as indicated by the Bray II and North Carolina procedures.

The results presented here all lead to the conclusion that these soils are very low in available forms of phosphorus. Therefore, before agricultural development can take place in the area, phosphate fertilizers must be added. The results of preliminary greenhouse tests (Appendix C) indicated that phosphorus is the most limiting factor for the dry matter production.

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[5] Hunter, A., Professor of Soil Science, North Carolina State University at Raleigh; personal communication

Micronutrient Analysis

The amounts of manganese, copper and zinc extracted by the North Carolina and modified Olsen are presented in Table 19.

The Olsen solution extracts greater amounts of micronutrients than does the North Carolina solution. For manganese the differences are very substantial. With a few exceptions, the content of extractable micronutrients decreases with depth, suggesting a relationship with organic matter content. The critical limits for manganese and zinc extracted by the Olsen solution has been established as 15 and 3 ppm, respectively.[6] If this criteria is applied to the data presented in Table 18, the manganese status may be interpreted as follows: soil 7, deficient; soils 3, 5, 1 and 4, well supplied and soils 2, 8, 6 and 9, excessive amounts present and toxic effects may occur.

Regarding the zinc status, all soils, except numbers 1 and 3, are above the critical limit and probably there will not be a response to zinc application.

The copper values by Olsen vary within a narrow range from 1.3 to 4.7 ppm. Soils 3, 5, 6 and 7 have less than 3 ppm and soils 1, 2, 4, 8 and 9 have 3 or more ppm. All the soils are probably well supplied with copper; however, the critical value has not been established.

In an exploratory greenhouse study no significant responses to the application of micronutrients were found (Appendix C).

Some relationship is noted between the clay content and the amount of micronutrients extracted.

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[6] Hunter, A., Professor of Soil Science, North Carolina State University at Raleigh; personal communication

Table 19. Manganese, copper and zinc extracted by North Carolina and modified Olsen solutions

Depth from surface	Mn		Cu		Zn	
	N. C.	Olsen	N. C.	Olsen	N. C.	Olsen
cm	ppm	ppm	ppm	ppm	ppm	ppm
Profile 1 - Miraf						
0-21	5.6	34	1.0	3.0	5.8	8.5
21-38	3.6	26	1.0	3.0	5.6	10.0
38-60	2.8	26	0.8	2.7	2.9	5.8
Profile 2 - Montan						
0-17	16.4	110	1.4	3.7	3.3	5.8
17-37	6.4	26	1.6	2.7	1.1	10.0
37-64	6.4	8	1.6	4.3	0.7	2.2
Profile 3 - Naval						
0-13	1.2	18	1.0	1.7	1.6	3.2
13-33	0.6	8	0.8	1.3	0.8	2.2
33-52	0.6	8	0.7	1.7	0.8	2.2
Profile 4 - Polvor						
0-17	5.6	48	1.4	3.0	4.3	8.0
17-47	2.0	26	1.0	2.7	1.1	4.0
47-80	2.0	18	0.9	2.7	1.1	3.5
Profile 5 - Tacana						
0-10	5.6	26	1.5	2.3	1.6	2.8
10-30	2.8	8	1.2	1.7	0.8	2.2
30-50	5.6	8	1.4	2.0	0.9	2.2
Profile 6 - Leguiz						
0-20	+75	472	0.9	1.7	6.2	8.0
20-80	18	168	1.0	2.7	1.2	3.5
80-133	12	118	0.9	2.7	1.0	3.5
Profile 7 - Guavia						
0-25	1.2	8.0	1.0	1.3	0.9	1.5
25-47	0.6	8.0	0.7	1.3	0.7	1.5
47-75	1.2	8.0	0.6	1.0	0.9	1.5
Profile 8 - Floren						
0-16	47.0	290	2.4	4.7	3.5	5.8
16-85	3.6	26	1.3	3.4	0.8	2.5
85-173	4.8	48	1.0	3.0	1.0	3.2
Profile 9 - Asis						
0-12	68.0	578	1.7	3.4	2.7	4.3
12-86	10.4	110	1.1	2.3	1.4	4.3
86-138	9.6	110	1.2	2.3	1.3	4.0

CLASSIFICATION OF SOILS

The classification of the soils according to the U. S. Soil Taxonomy (Soil Survey Staff, 1970) is presented here.

Moisture Soil Regime

The amount and distribution of the rainfall (Table 2) and the water balance calculations indicate that the area, except San Jose de Guaviare, has rainfall equal or greater than potential evapotranspiration. In San Jose de Guaviare there are two months (January and February) with less rainfall than potential evapotranspiration. However, the soil does not become dry for 60 days because of the water stored in the profile. Thus all soils studied have an udic soil moisture regime.

Temperature Soil Regime

From the climate data (Table 1) it may be deducted that the soil temperature at 50 cm depth is higher than 22°C and the difference between the highest and the lowest mean monthly temperatures is less than 5°C. Consequently, the soils are placed in the isohyperthermic temperature class.

Soils 1 and 2

Soils 1 and 2 have an ochric epipedon. The subsurface horizons have characteristics of a cambic horizon intergrading to the oxic horizon. The B horizon of soil 1 meets the following requirements of the oxic horizon, dispersible clay less than 5%, apparent cation exchange capacity of clay less than 16 meq/100 g clay, and cation retention capacity of less than 10 meq/100 g clay, but does not meet the requirement of no more than traces of micas and vermiculites.

The cambic horizon must contain more than 6% muscovite. The mineralogical analysis revealed that muscovite is not present in the sand fraction. However, the X-ray diffractograms of the silt fraction indicated the presence of mica and the clay contained between 8 to 22% of mica, determined from the K_2O%. These amounts expressed on the whole soil bases gave values higher than 6% of mica and therefore the B horizon of soil 1 is classified as a cambic horizon, excluding the possibility of the oxic horizon.

The B horizon of soil 2 also has some characteristics of the oxic horizon, such low content of water-dispersible clay and apparent cation exchange capacity of less than 16 meq/100 g clay. But it has mica in the silt and between 9 and 11% in the clay, giving more than 6% mica on the whole soil basis. In this case, like in soil 1, the B horizon must be classified as a cambic horizon.

Soils 1 and 2 have cambic horizons; therefore, they must be included in the Inceptisol order. Since they have isohyperthermic temperature regimes, they are classified as Tropepts at the suborder level.

Since the soils 1 and 2 have a base saturation (by NH_4OAc) that is less than 50% in all subhorizons between 25 and 100 cm, they are included in Dystropept great group.

Furthermore, soils 1 and 2 have an apparent cation exchange capacity of less than 24 meq/100 g clay, in all horizons in 100 cm from surface; consequently, they must be classified as Udoxic Dystropepts, at the subgroup level.

The Udoxic Dystropept is a subgroup intergrading towards the Oxisols. Soils 1 and 2 are among the more weathered soils of the group studied here. Nevertheless, they are not weathered enough to be classified as Oxisols.

According to the Soil Survey Staff (1970 "the identification of the clay minerals should rarely be necessary to identify oxic horizon" because they say the permanent charge, the cation retention or NH_4OAc-CEC are too high for oxic horizon, when 2:1 lattice clays are present in significant amounts. However, in the present case, soils 1 and 2 have sizeable amounts of micas and vermiculites that sets them aside from the Oxisol order, while their cation exchange capacities are below the values now established for the Oxisol order. McCracken et al. (1971) have pointed out that in Untisols the cation exchange capacity measurements are rather insensitive and do not reflect the nature of the clay mineralogy due to the masking effect of hydrous iron and aluminum oxides which block or counteract the negative charges of the layer silicates.

The finding observed here suggests that a better definition of the critical values of CEC and of the clay mineralogy of the oxic horizon is desirable. If only traces of micas and vermiculites are permitted in the oxic horizon, the values for apparent cation exchange capacity and for cation retention of the Oxisols probably should be lowered. If the actual limits of cation exchange capacity are kept, the presence of certain amounts of mica, vermiculite and probably montmorillonite should be permitted.[1]

At the family level, soils 1 and 2 are classified as follows:

Soil 1: Very fine, clayey kaolinitic isohyperthermic Udoxic Dystropept

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[1] See discussion of mineral family placement in "Mineralogy of the Clay" section (pp. 76-120)

Soil 2: Very fine clayey kaolinitic isohyperthermic Udoxic Dystropept

Soils 3 and 4

Soils 3 and 4 have ochric epipedons and argillic horizons. The presence of argillic horizons is substantiated by the increase of clay by more than 1.2X in a vertical distance of 30 cm and presence of cutans observed in the field and in thin sections; the clay skins, however, are not thick enough to reach 1% of the cross section, but it is considered that the cutans are not well preserved due to the high biological activity.

The base saturation (by sum of cations), at 1.8 m, is less than 35% and the temperature regime is isohyperthermic. Consequently, soils 3 and 4 meet the requirements of the Ultisols. Furthermore, the soils have redder hues and higher chromas than Aquults, have less than 0.9% organic carbon in the upper 15 cm of argillic horizon and have udic moisture regimes. Therefore soils 3 and 4 are included in the Udult suborder.

The argillic horizons of soils 3 and 4 have less than 10% weatherable minerals in the 20-200 μ fraction and the clay content in the argillic horizon does not decrease within 1.5 m of the soil surface; therefore, these soils are classified in the Paleudult great group.

Soils 3 and 4 have, in the upper 75 cm of the profile, mottles that have moist color values of four or more and chromas of less than two, along with mottles of higher chroma. These are color characteristics of the aquic subgroup. Both soils are classified at the subgroup level as Aquic Paleudults. At the family level the soils are classified as follows:

Soil 3: Fine clayey, mixed, isohyperthermic, Aquic Paleudult
Soil 4: Fine clayey, mixed, isohyperthermic, Aquic Paleudult

Soils 5 and 6

Soils 5 and 6 have ochric epipedons. The subsurface horizons are classed as cambic because of the apparent cation exchange capacities of the clay which are higher than 16 meq/100 g clay. They have isohyperthermic temperature regimes, udic moisture regimes, percentages of base saturation less than 50% (by NH_4OAc) between 25 and 100 cm depth. According to these characteristics, soils 5 and 6 are classified as Dystropepts.

Soil 5 has an apparent cation exchange capacity less than 24 meq/100 g of clay in all horizons between the surface and 1.0 m depth; therefore, it is classified as an Udoxic Dystropept.

Soil 6 fits all definitions for the typic subgroup of the Dystropepts; therefore, it is included in the Typic Dystropept subgroup.

At the family level both soils are included in the fine clayey, mixed mineralogy, since in the clay fraction there is no clay mineral in proportion higher than 50%.

The classification of soils 5 and 6 is as follows:

Soil 5: Fine clayey, mixed, isohyperthermic Udoxic Dystropept
Soil 6: Fine clayey, mixed, isohyperthermic Typic Dystropept

The organic carbon distribution in soil 6 does not decrease regularly at depth (173-265 cm) but differences are very low and may be due to random analytical error. Therefore, this soil is considered typic and not fluventic.

Soil 7

Soil 7 has an umbric epipedon and a cambic horizon because the apparent cation exchange capacity of the clay is higher than 16 meq/100 g clay. The percent base saturation is less than 50% in all profiles. Therefore, it is classified as a Udoxic Dystropept, like soil 5.

In the control section soil 7 has less than 35% clay and more than 15% of fine sand. The mineralogy in the 0.02-2 mm fractions is dominated by quartz and chert (more than 90%). At the family level soil 7 is classified as fine loamy siliceous, isohyperthermic, Udoxic Dystropept.

Soils 8 and 9

Soils 8 and 9 have ochric epipedons and cambic horizons. They also have all other characteristics defined for the Dystropepts.

Soil 8 has an apparent cation exchange capacity of less than 24 meq/100 g clay; therefore, it is included in the Udoxic Dystropept subgroup.

Soil 9 has an apparent cation exchange capacity higher than 24 meq/100 g clay and is classified as a Typic Dystropept.

At the family level soil 8 is classified as fine clayey, kaolinitic, isohyperthermic, Udoxic Dystropept and soil 9 as fine clayey, mixed, isohyperthermic Typic Dystropept.

In conclusion, the soils of the Colombian Amazon basin are classified as follows:

Soil	Family	Subgroup
1 - Miraf	Very fine clayey, kaolinitic, isohyperthermic	Udoxic Dystropept
2 - Montan	Very fine clayey, kaolinitic, isohyperthermic	Udoxic Dystropept
3 - Naval	Fine clayey, mixed, isohyperthermic	Aquic Paleudult

Soil	Family	Subgroup
- Polvor	Fine clayey, mixed, isohyperthermic	Aquic Paleudult
- Tacana	Fine clayey, mixed, isohyperthermic	Udoxic Dystropept
- Leguiz	Fine clayey, mixed, isohyperthermic	Typic Dystropept
- Guavia	Fine loamy, silicic, isohyperthermic	Udoxic Dystropept
- Floren	Fine clayey, kaolinitic, isohyperthermic	Udoxic Dystropept
- Asis	Fine clayey, mixed, isohyperthermic	Typic Dystropept

SUMMARY AND CONCLUSIONS

Amazonia constitutes about one-third of Colombia and consists of undulating, but not flat plains, dissected by a dendritic system of small tributaries, standing at about 100-400 meters above sea level. It is covered by Cenozoic sediments; outcrops of the Guayana Shield basement rocks are found in some areas. The annual rainfall is about 3000 mm in the Amazonic Llanos and about 4000 mm near the Eastern Cordillera slopes. There is no dry season and the mean annual temperature varies between 26 and 29°C. Amazonia is covered by evergreen tropical forest characterized by a great diversity of tree species.

Mineralogical, chemical and physical studies were conducted on nine soil profiles described and samples in the Colombian Amazonia with the following conclusions:

1. The mineral composition of the sand fraction is dominated by quartz with negligible amounts of weatherable minerals; namely, micas and feldspars. In profiles 6, 8 and 9, those near the Eastern Cordillera, the presence of volcanic glass and volcanic rock fragments was observed indicating that pyroclastic materials have been spread into the areas closer to the Andes.

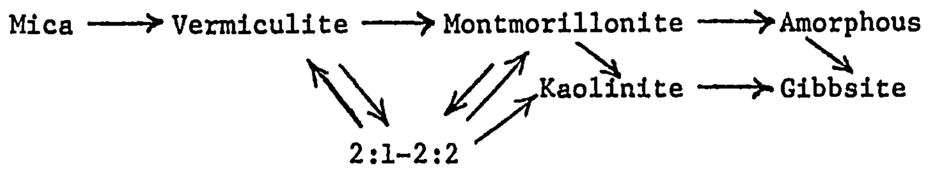
In the silt fraction, in addition to the dominance of quartz, the presence of mica, mainly in the fine and medium silt, and kaolinite was observed. In profiles 3, 6 and 9 some 2:1-type minerals were found, mainly in the fine silt.

2. The X-ray diffraction, differential thermal analysis, selective dissolution and total analysis of the clay fraction show that, with few exceptions, kaolinite was the predominant clay mineral in all

profiles. Mica was present in all soils. It constituted 8% of the clay in soils 1 and 2 and up to 37, 38 and 45% in some profiles (2, 3 and 7). These values were determined from the K_2O%. However, X-ray diffractograms did not show any distinct peak when mica was present in amounts less than 8-12%. Vermiculite and lesser amounts of 2:1-2:2-type minerals were present in all soils. A rather poorly crystallized montmorillonite was found in the B and C horizons of soil 6, in amounts between 10 and 50% of the clay fraction. Montmorillonite was also found in soils 2, 3, 4, 8 and 9. The clay of soil 1 contained gibbsite, estimated as 7-10% by DTA. Soils 5, 7 and 8 also contained small amounts of gibbsite. Quartz was present in small amounts in the clay fractions of soils 2, 3, 4, 5, 6 and 9. The SiO_2/Al_2O_3 molar ratio of the clays ranged from 2.2 to 4.4.

Probably the bulk of the kaolinite and mica is inherited from the sediments that constitutes the parent material. The primary sources of mica are the rocks of the Garzon Massif and of the Eastern Cordillera.

The presence and distribution of micas, vermiculites, other 2:1-type minerals and gibbsite in the profiles indicate that the alteration of micas and other clay minerals is taking place in the general weathering sequence:



3. The cation exchange capacity of the deferrated clays varied among profiles and reflected the nature of the clay mineralogy. Values of 8 to 50 meq/100 g were found, being low in horizons high in

kaolinite and high in horizons where greater amounts of 2:1 lattice clay minerals were present.

4. The contents of free iron oxide varied among soil profiles. The highest amounts were found in the very fine clayey soils, 13% in soil 1, 7% in soil 2. Other profiles had modest to low amounts of free iron oxide (5 to 0.2%). The lowest content was found in the moderately well drained soil 3, classified as Aquic Paleudult. Amorphous silicates were present in all soils, ranging from 4 to 13%, with no great variation within profiles. SiO_2/Al_2O_3 ratios of amorphous materials varied between 0.7 and 3.6 with relatively large variation within profiles.

5. The mean stage of chemical weathering suggests that the soils studied are between the vermiculitic and the kaolinitic stages and consequently are not as highly weathered as usually assumed. This is also substantiated by the relatively high values of the cation exchange capacity in the clay fraction.

6. The soils are extremely to very strongly acid. They have effective cation exchange capacity values from 5 meq/100 g to as high as 20 meq/100 g. A high aluminum saturation (usually above 60%) was also determined. Extractable acidity content (extracted by $BaCl_2$-TEA pH 8.2) was high and tended to decrease with depth in the more weathered soils and to increase in the less weathered soils. The pH-dependent cation exchange capacity varied between and within profiles. The maximum and minimum values reported were 15 and 1 meq/100 g. The pH-dependent charge was between 0.1 and 3.6 times the effective cation exchange capacity. Sources of pH-dependent charge were related to organic matter and hydroxy aluminum and iron oxide interlayers and coatings.

7. Organic carbon content decreased regularly with depth. Total nitrogen content was relatively high and the C/N ratio decreased with depth to very low values. Indigenous fixed ammonium was present in all profiles and its content tended to increase with depth. This explains in part the narrow C/N ratios in the subsoils. The amount of native fixed ammonium varied between 57 and 320 ppm and is similar to that reported for other tropical soils.

8. Total phosphorus content varied between 100 and 600 ppm. Between 40 and 70% of the total was bounded to the organic fraction. A relationship of P content to parent material source was also noticed. Available P contents were very low.

9. Analysis of micronutrients suggested that Zn and Cu are not so low and in some cases are above the critical levels. In soils 6, 8 and 9 there was a high amount of extractable Mn that may be toxic to some crops.

10. According to the U. S. Soil Taxonomy, none of the subsurface horizons of the nine profiles meet the requirements of the oxic horizon, which means that by the actual accepted standards there are no Oxisols in the sites studied. Seven profiles fall into the Inceptisol order with some of them intergrading towards the Oxisol order. Two soils (represented by profiles 3 and 4) have argillic horizons and low base saturation and are therefore classified as Ultisols. After a study of all the soil characteristics and the definitions and requirements of the Soil Taxonomy, the soils were classified at the subgroup level and assigned a weathering index as follows:

oil	Soil taxonomy Subgroup	Jackson weathering mean (m)	CEC of clay meq/100 g clay
Miraf	Udoxic Dystropept	9.82	17.21
Montan	Udoxic Dystropept	9.54	18.66
Floren	Udoxic Dystropept	9.38	10.71
Guavia	Udoxic Dystropept	9.13	20.14
Tacana	Udoxic Dystropept	9.07	25.50
Leguiz	Typic Dystropept	9.01	37.99
Asis	Typic Dystropept	8.77	27.39
Naval	Aquic Paleudult	9.00	29.58
Polvor	Aquic Paleudult	8.74	30.85

11. The soils initially thought to be Oxisols are now classified Inceptisols due to the mineralogy of the clay fraction, which is not aracteristic of the Oxisols. It is important to note that the clay ites found in the Amazon soils used in this study have some important rtility and management implications: (a) Inceptisols of the Amazonia ve higher amounts of exchangeable aluminum than Oxisols and therefore quire more lime; (b) the mica present in the clay must release potas- um which may constitute a considerable source of this nutrient and onsequently no high responses to potassium fertilization may be expected, hich is not the case of Oxisols; (c) the presence of appreciable amounts f native ammonium fixed by the micas and vermiculites, which may be low r may not occur in Oxisols, may become available as weathering ad- ances and (d) the vermiculites present may fix applied potassium and mmonium, which is an advantageous situation because this may prevent r decrease the leaching of the applied nutrients.

12. None of the soil features observed indicate that insurmountable or even unusual soil features are present that would impede development of the agriculture. However, for commercial crop production

liming and fertilization must be a fundamental part of the soil management. It is imperative that the economical stability and infrastructure needed to make these materials available be incorporated in any plan to develop Amazonia and the economic-agronomic feasibility must be clearly established.

13. More research about the characterization, mapping and management are desirable and required in order to make a reliable evaluation of the agricultural potentiality of Amazonia, taking into consideration other economic, ecological and social factors.

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APPENDICES

Appendix A. Description of the Soil Profiles

SOIL PROFILE 1. MIRAF

LOCATION: Municipio Miraflores; left margin of Vaupes River; near Army quarters.

ALTITUDE: 200 m above sea level.

RELIEF: Undulating.

SLOPE: 7-12% (general).

POSITION OF THE PROFILE: Upper part of the hillslope, about 70 m above Vaupes River; local slope about 20%

EROSION: Slight laminar.

VEGETATION: Originally tropical rain forest; actually grasses and bushes.

PARENT MATERIAL: Oligocene-Miocene sediments.

WATER TABLE: Very deep.

DRAINAGE: Well drained.

MOISTURE CONDITIONS OF THE PROFILE: Moist all profile.

DATE SAMPLED: June 24, 1972.

A1 horizon; 0-21 cm depth

Brown to dark brown (7.5 YR 4/4);[1] clay; moderate medium subangular blocky structure that breaks to moderate fine granular; friable, sticky, plastic; many fine and common medium tubular pores; common fine and medium roots; many ants, termites and earthworms; there are abundant pedotubules of very dark gray color; smooth, gradual boundary.

B1 horizon; 21-38 cm depth

Yellowish red (5 YR 4/6); clay; weak fine prismatic that breaks into moderate fine and very fine granular; friable, slight, slightly plastic; many fine, common medium, few coarse tubular pores; some of the pores have very thin films of the same color of soil mass; common medium and fine roots; common ants, termites and earthworms; diffuse boundary.

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[1] Colors of moist soil

B21 horizon; 38-100 cm depth

Yellowish red (5 YR 4/6); clay to silty clay; weak to moderate fine prismatic structure that breaks to moderate fine granules; friable, slightly sticky, slightly plastic; many fine tubular pores; there are some pores coated with thin films of the same color of soil; few medium and coarse roots, few ants and earthworms in the upper portion of the horizon; diffuse boundary.

B22 horizon; 100-150 cm depth

Yellowish red (5 YR 7/4); clay; weak fine and medium prismatic structure that breaks into moderate fine granules; friable, slightly sticky, slightly plastic; many fine tubular pores; some pore walls and some ped faces have thin, discontinuous shining films.

B23 horizon; 150-350 cm depth

Yellowish red (5 YR 4/4); clay; moderate fine, medium prismatic structure with subrounded edges and some reniform shapes that break into strong fine and medium, angular and subangular; structure; friable, sticky, plastic; common fine tubular pores.

SOIL PROFILE 2. MONTAN

LOCATION: Municipio Florencia; Montanita-Paletara Road.
ALTITUDE: About 300 m above sea level.
RELIEF: Gently undulating.
SLOPE: 3-7%.
POSITION OF THE PROFILE: Upper portion of a hillslope.
EROSION: Slight, laminar.
VEGETATION: Originally tropical rain forest; actually grasses.
PARENT MATERIAL: Oligocene-sediments (Orito clay formation).
WATER TABLE: Very deep.
DRAINAGE: Well drained.

MOISTURE CONDITIONS OF THE PROFILE: Moist all profile.
DATE SAMPLED: July 6, 1972.

A1 horizon; 0-17 cm depth

Reddish brown (5 YR 4/5); clay; moderate medium subangular blocky structure that breaks to moderate fine granular; soft, very friable, sticky, plastic; many fine, common medium tubular pores; common dark grayish brown pedotubules; few oblate, red, hard sesquioxidix nodules; common medium and fine roots; common earthworms and ants; few chambers, diffuse boundary; pH 4.5.

B1 horizon; 17-64 cm depth

Reddish brown (5 YR 4/6); clay; moderate medium prismatic structure that breaks to moderate subangular blocky and granular; friable; sticky, plastic; many fine, very fine common medium, coarse tubular pores; there are thin, continuous shining films in wall pores; and very thin discontinuous films in the ped faces; few rounded quartz grains; common fine and medium fibrous roots; few ants and ant chambers; diffuse boundary; pH 4.5.

B21 horizon; 64-153 cm depth

Reddish brown (5 YR 4/8); clay; weak and moderate medium prismatic structure that breaks to weak medium and fine angular blocky and moderate fine granular; friable, sticky, plastic; many fine, very fine, common medium and few coarse tubular pores; there are very thin shining films in fine pore walls and in some ped faces; few subrounded quartz grains; few medium and fine roots; smooth gradual boundary; pH 5.0.

B22 horizon; 153-227 cm depth

Yellowish red (5 YR 4/8); clay; moderate, medium prismatic structure that breaks to moderate medium angular blocky and moderate fine granular; friable, sticky, plastic; many fine, common medium, few coarse tubular pores; some very thin discontinuous shining films are observed in some pores and face peds; few dark red sesquioxidic nodules; few rounded "lidite" fragments and quartz grains; wavy and clear boundary; pH 5.0.

C1 horizon; 227-310 cm depth

Variegated color pattern, red (10 R 4/6) 50%, pale yellow (2.5 Y 7/4) 30%, yellowish brown (2.5 Y 6/4); clay; a layered structure predominates and a moderate medium and fine angular blocky, firm, sticky, plastic, few fine tubular pores; common "joint plains" between the horizontal layers coated with a thick film of red and yellowish brown color; in faces of peds some thin discontinuous films; few dusky red concretions (concentric fabric); few planar fabric nodules; few quartz grains; smooth gradual boundary; pH 4.5.

C2 horizon; 310-350 cm depth

This horizon has similar characteristics of C1 above, except for colors, which are variegated and consists of white (2.5 Y 8/2) 50%, red (10 R 4/6) 30%, light olive brown (2.5 Y 5/6); the layered structure of the rock is more evident.

SOIL PROFILE 3. NAVAL

LOCATION: Municipio Leticia; Naval base (brick factory).
ALTITUDE: 120 m above sea level.
RELIEF: Gently undulating to undulating.

SLOPE: 3-5%.
POSITION OF THE PROFILE: In middle part of the hillslope.
EROSION: Not apparent.
VEGETATION: Originally tropical rain forest; actually bush and grasses.
PARENT MATERIAL: ?Pleistocene sediments.
WATER TABLE: Very deep; not present at 250 cm.
DRAINAGE: Moderately well drained.
MOISTURE CONDITIONS OF THE PROFILE: Moist, all profile.
DATE SAMPLED: June 2, 1972.

01 horizon; 2-0 cm depth

Very dark brown (10 YR 3/2); decomposed leaves mixed with some mineral material; some charcoal fragments.

A1 horizon; 0-13 cm depth

Dark grayish brown (10 YR 4.5/5); silty clay loam; moderate fine and very fine granular structure; soft; very friable, slightly sticky, slightly plastic; many fine, very fine and common medium tubular pores; common fine and medium roots; many ants and earthworms; clear and smooth boundary; pH 5.5.

B21 horizon; 13-52 cm depth

Brown (10 YR 5.5/3); with few light gray (10 YR 7/1) around some of the root channels; silty clay; weak fine subangular blocky structure, friable, sticky, plastic; many fine and very fine tubular pores; common medium tubular pores; few ant and earthworm chambers; there are thin shining films around the chambers; few medium and fine roots; smooth gradual boundary; pH 5.0.

B22 horizon; 52-105 cm depth

Yellowish red (5 YR 5/6) 60%, light yellowish brown (10 YR 4/6) 20% and light gray (2.5 Y 7/2) 20%; clay; weak medium prismatic structure that breaks to moderate medium angular blocky; friable to firm; sticky, very plastic; common fine, very fine and few coarse pores; few medium and fine roots; there are vertical oriented pressure surfaces where roots penetrate abundantly; few clay films in the tubular pores and on the ped surfaces; diffuse boundary; pH 4.5.

B23 horizon; 105-142 cm depth

Variegated pattern color, light gray (5 Y 7/2) 60%, dark red (2.5 YR 3/6) and red (2.5 YR 5/6) 40% clay; weak medium prismatic structure that breaks to moderate medium and fine angular blocky; friable, sticky, very plastic; common fine tubular pores; few fine roots; few ant chambers; common, thin, discontinuous clay skins in the ped faces and in the tubular pores; diffuse boundary; pH 4.5.

B24 horizon; 142-250 cm depth

Variegated color pattern gray (2.5 Y 7/2) 50% and red (2.5 YR 4/6); red color distributed as fibrous-like spots and as coatings; clay; very weak medium prismatic structure that breaks to moderate and weak medium and fine angular blocks; friable, sticky, very plastic; common fine tubular pores; common clay films in root channels; very few roots; no macroorganisms; pH 4.5.

SOIL PROFILE 4. POLVOR

LOCATION: Municipio Leguizamo; 500 m east from Naval base.

ALTITUDE: About 150 m above sea level.

RELIEF: Gently undulating and undulating.

SLOPE: 3-12%.

POSITION OF THE PROFILE: In the middle part of the convex hillslope, local slope 5%.

EROSION: Not apparent.

VEGETATION: Originally tropical rain forest, actually grasses and shrubs.
PARENT MATERIAL: ?Pleistocene sediments.
WATER TABLE: Very deep.
DRAINAGE: Moderately well drained.
MOISTURE CONDITIONS OF THE PROFILE: Moist, all profile.
DATE SAMPLED: July 1, 1971.

A1 horizon; 0-17 cm depth

Brown (10 YR 5/3.5) with common fine faint brown (7.5 YR 4/4) and few fine distinct olive gray (5 Y 4/2) mottles; silty clay; compound weak fine angular blocky and moderate fine granular structures; hard friable; sticky, plastic; common fine and very fine tubular pores; few red hard and soft sesquioxidic nodules (1-5 mm); common fine and very fine roots; common earthworms and ants and worms excreta; few chambers; few thin shining films in the wall pores and chambers; smooth gradual boundary; pH 5.0.

B21 horizon; 17-47 cm depth

Brown (7.5 YR 4/4) with few coarse distinct reddish brown (5 YR 4/4) mottles; silty clay; weak fine subangular blocky that breaks to moderate and weak granular structure; friable, sticky, plastic; many coarse, fine and few medium tubular pores; few prolate, dark red sesquioxidic nodules; few fine roots; few ants and earthworms; there are thin cutans; diffuse boundary; pH 4.5.

B21 horizon; 47-80 cm depth

Yellowish red (5 YR 4/6) with few fine prominent light olive gray (5 Y 6/2) and fine distinct red mottles (2.5 YR 4/6) which are more common in the lower part of the horizon; clay; moderate fine angular structure; few thin, discontinuous shining cutans in the aggregate faces and in the pores; many fine, few medium tubular pores; common dark red, hard sesquioxidic nodules (2-5 mm); few fine roots; some earthworm chambers filled with very dark gray material; gradual, wavy boundary; pH 4.0.

B22 horizon; 80-157 cm depth

Variegated color pattern, red (2.5 YR 4/6) 60% pale yellow (5 YR 7.3) and yellowish brown; clay; very weak medium and fine prismatic and strong to moderate angular blocky structure; friable; very sticky and very plastic; common fine and very fine tubular pores; abundant thin, discontinuous cutans on the faces of peds; few pedotubules; few sesquioxidic nodules; few fine roots; diffuse boundary; pH 4.0.

C1 horizon; 157-210 cm depth

Variegated color pattern light gray (5 YR 7/1) 60%; red (10 R 4/6) 30%, yellowish red (5 YR 4/6); clay; very weak prismatic structure that breaks into weak fine angular blocky and into granules and some layered structure inherited from the banded strata; friable; very sticky, very plastic; few fine and very fine tubular pores; common thin, discontinuous cutans in ped faces; common red soft and few hard red sesquioxidic nodules; diffuse boundary; pH 4.0.

C2 horizon; 210-360 cm depth

This horizon has the same general characteristics of C1, with changes in the proportions of red and gray; there is an increase of red materials.

SOIL PROFILE 5. TACANA

LOCATION: Municipio Leticia; km 12 Leticia-Tarapaca road. Fray Martin Tacana Ranch.

ALTITUDE: 120 m above sea level.

RELIEF: Gently undulating.

SLOPE: 3-5% (general).

POSITION OF THE PROFILE: In the crest of the undulation, with local slope of 1%.

EROSION: Slight, laminar.

VEGETATION: Originally tropical rain forest (cut more than 20 years ago); actually pastures (Andropogan bicornis); some trees (Cecropia sp.) and bush.

PARENT MATERIAL: ?Pleistocene sediments.

WATER TABLE: Very deep (not present at 250 cm).

DRAINAGE: Well drained.

MOISTURE CONDITION OF THE PROFILE: Dry on top, moist in the rest of profile.

A1 horizon; 0-10 cm depth

Yellowish brown (10 YR 5/4); silty clay loam; moderate fine granular structure; hard, friable, slightly sticky, slightly plastic; many fine and common very fine tubular pores; common fine and medium roots; common ants and earthworms; common burrows and chambers; gradual, smooth boundary; pH 5.0 in 0-3 cm and 4.5 in 3-9 cm depth.

B21 horizon; 10-83 cm depth

Strong brown (7.5 YR 5/6); clay; weak medium and fine subangular blocky structure that breaks to moderate fine granular; friable, sticky, very plastic; common fine tubular pores; few ant chambers; few earthworm dejecta; some of the root channels and some of the chambers have diffusion coatings of the same color of the soil mass; irregular hard sesquioxidic nodules of about 5 mm diameter; few fine and coarse roots; diffuse boundary; pH 4.5.

B22 horizon; 83-140 cm depth

Red (2.5 YR 4/6) with splotches (common, medium, prominent) of light yellowish brown; clay; moderate, medium and fine subangular blocky structure; friable, sticky, very plastic; common fine and few coarse tubular pores; some of the root channels have shining coatings; few irregular, hard sesquioxidic nodules of 0.5-3 cm, which increase in amount toward the lower part of the horizon; few fine roots; few ant chambers with black coatings; diffuse boundary; pH 4.5.

B23cn horizon; 140-200 cm depth

Red (2.5 YR 4/6) with splotches of light gray (10 YR 7/2) 30% and dark red (10 YR 3.5/6); massive; clay; friable; sticky, very plastic; common fine tubular pores; many (30%) irregular and uniform hard sesquioxidic nodules of reddish brown color and 0.5-3 cm in size; pH 4.5.

Remarks: In A1 horizon there are some charcoal fragments and abundant dark grayish brown earthworm excreta. The proportion of gray color increases with depth below 200 cm.

SOIL PROFILE 6. LEGUIZ

LOCATION: Municipio Leguizamo; Km 2 Leguizamo-La Tagua road.
ALTITUDE: About 150 m above sea level.
RELIEF: Gently undulating.
SLOPE: 3-7%.
POSITION OF THE PROFILE: Upper part of a hillslope with 3%.
EROSION: No apparent.
VEGETATION: Originally tropical rain forest; actually grasses.
PARENT MATERIAL: Post-Pleistocene sediments.
WATER TABLE: Very deep.
DRAINAGE: Well drained.
MOISTURE CONDITIONS OF THE PROFILE: Moist, all profile.
DATE SAMPLED: July 4, 1971.

A1 horizon; 0-20 cm depth

Brown (7.5 YR 4/4); clay loam; moderate fine angular blocky that breaks to moderate fine granular structure; hard friable, slightly sticky, plastic; many fine, common medium tubular pores; common fine roots; many earthworms; smooth clear boundary.

B21 horizon; 20-80 cm depth

Reddish brown with common coarse faint brown 10 YR 5/3 spots; moderate medium prismatic structure that breaks to moderate fine and medium angular blocky and to moderate fine granules; friable, very sticky, very plastic; many fine and very fine tubular pores; few fine roots; few earthworms, diffuse boundary.

B21cn horizon; 80-81/82 cm depth

Hard discontinuous layer of sesquioxidic concretions with reniform shape; yellowish red and dusky red; abrupt boundary.

B22 horizon; 81/82-133 cm depth

Yellowish red (5 YR 4/6); clay; moderate medium prismatic structure that breaks into moderate fine and medium angular and subangular blocky structure; friable, very sticky, very plastic; many fine tubular pores; some hard platy fragments (pedodes?) of clay; few fine roots; gradual, wavy boundary.

IIB23 horizon; 133-173 cm depth

Yellowish red (5 YR 4/8) with common fine and coarse distinct yellowish brown (10 YR 5/6) and very pale brown (10 YR 8/3); moderate fine and medium prismatic structure that breaks to moderate medium and fine angular blocks and granules; friable, sticky, plastic; common medium and fine tubular pores; some of which have continuous films of brown color; common hard fragments of clay, gray inside and violet in surface; smooth, clear boundary.

IIC1 horizon; 173-215 cm depth

Reddish brown (2.5 YR 4/4) with common medium distinct light yellowish brown (2.5 Y 6/4) around pore walls; sandy clay loam; massive with tendency to angular blocks; friable, slightly sticky; slightly plastic; common fine and very fine tubular pores; common small fragments of mica; smooth clear boundary.

IIC2 horizon; 215-243 cm depth

Horizon formed by hard, light clay fragments and soft material of light gray (10 YR 7/1) with friable, sticky and plastic consistency horizontally arranged. In the lower boundary there is a thin layer of red color; smooth, clear boundary.

IIIC3 horizon; 243-265 cm depth

Reddish brown (5 YR 5/4); sandy loam massive; friable, slightly sticky, plastic; presence of small mica fragments.

SOIL PROFILE 7. GUAVIA

LOCATION: Municipio San Jose de Guaviare; km 5, San Jose-El Retorno road, Campo A farm.

ALTITUDE: 200 m above sea level.

RELIEF: Gently undulating to undulating.

SLOPE: 3-12%; local slope 6%.

POSITION OF THE PROFILE: Upper third part of the hillslope.

EROSION: Not apparent.

VEGETATION: Savanna, grasses and shrubs, in the transition to the forest; probably was covered by forest many years ago.

PARENT MATERIAL: Mixed sediments; the upper part of the solum sediments derived from Puerto Arturo sandstones (Precambrian?).

WATER TABLE: Very deep; not found at 250 cm.

DRAINAGE: Well drained.

MOISTURE CONDITIONS OF THE PROFILE: Moist, all profile.

DATE SAMPLED: June 12, 1971.

A11 horizon: 0-25 cm depth

Very dark grayish brown (10 YR 3/2) with few fine, distinct dark reddish brown (5 YR 2/2) mottles; sandy clay loam; moderate to weak medium and fine granular structure, soft, very friable, slightly sticky, none plastic; many fine, very fine and common medium and coarse pores; grains of clean, subrounded, quartz (1 mm in diameter); common fine and medium roots; many ants and termites (but there is not termite mounds) in the upper part of the horizon; smooth gradual boundary.

A12 horizon: 25-47 cm depth

Dark brown (10 YR 3.5/3) sandy clay loam with few fine faint dark grayish brown (10 YR 4/2) mottles, and few vertical radicular mottles of reddish brown (5 YR 4/4) color in the lower part of the horizon; weak medium and fine subangular blocky structure that breaks to weak fine granular structure; soft, friable, slightly sticky, slightly plastic; there is not evidence of cutans or films; many fine, few medium and coarse tubular pores; few clean subrounded (1-2 mm diameter) quartz grains; few very hard, red dusky subrounded and subangular nodules (0.5-5 mm); common fine, few medium roots; smooth gradual boundary.

B21 horizon: 47-75 cm depth

Reddish brown (5 YR 4/4) with few, medium, distinct oliva gray (5 Y 5/2) splotches; clay loam; very weak, fine prismatic structure that breaks into weak medium subangular blocky and to moderate fine granules; friable, slightly sticky, plastic, few fine tubular pores; common pedotubules of very dark, gray color; few clean quartz grains (1-3 mm diameter); few, very altered lithorelicts (quartzitic sandstone?);

common red, hard, spheroidal sesquioxidic nodules (0.5-10 mm) with a sandy material inside; few fine roots; smooth gradual boundary.

B22cn: 75-97 cm depth

Reddish brown (5 YR 4/4), sandy loam; weak and moderate fine subangular blocky structure that breaks into weak fine granules; friable, slightly sticky; plastic; few fine tubular pores; few dark gray pedotubules; about 5% (by volume quartz grains) of (0.5-30 mm); common dusky red, hard, irregular sesquioxidic nodules enclosing yellowish brown earthy material, few fine roots, clear, wavy boundary.

B3cn horizon: 97-124 cm depth

Horizon consisting of layered sesquioxidic nodules 2-3 cm thick (iron pan); nodules are brown in the surface and enclose strong brown, dusky red and yellowish brown fine material; abrupt wavy boundary.

IIC horizon: 124-240 cm depth

Variegated pattern of dark reddish brown (2.5 YR 3/4) white (5 Y 8/2) and brown (7.5 YR 4/4) clay; platy, imbricated structure; friable; very sticky, very plastic; common planar pores are present and joint plane cutans of waxy appearance; few red nodules; no roots, no macroorganisms; no clean quartz grains.

SOIL PROFILE 8. FLOREN

LOCATION: Municipio Florencia; Caldas section. Florencia-Travesia road, San Luis farm; in the foothills of the Eastern Cordillera.

ALTITUDE: 500 m above sea level.

RELIEF: Steep, to hilly.

SLOPE: 25-30%.

POSITION OF THE PROFILE: Hillslope, local slope 25%.

EROSION: Laminar and gully in the nearby.

VEGETATION: Originally tropical rain forest; actually pastures (Panicum maximum).

PARENT MATERIAL: Mixed, gneiss, granites, colluvial and some pyroclastic materials.

WATER TABLE: Very deep.

DRAINAGE: Well drained.

MOISTURE CONDITIONS OF THE PROFILE: Moist, all profile.

DATE SAMPLED: July 6, 1972.

A1 horizon; 0-16 cm depth

Dark yellowish brown (10 YR 4/3.5); clay; very weak, fine subangular blocky and weak medium granular; soft, friable; sticky, plastic; many fine, common medium tubular pores; few angular and subangular quartz grains (1 mm); many fine roots; many earthworms; common ants; smooth clear boundary.

B21 horizon; 16-85 cm depth

Yellowish red (5 YR 4.5/6) with few fine faint yellowish brown (2.5 Y 6/4) mottles; clay; weak medium prismatic structure that breaks to moderate fine granular; friable, very sticky, very plastic; many fine, common medium, few coarse tubular pores; no films are present; few subrounded, subangular and angular quartz grains; few fine roots; diffuse boundary.

B22 horizon; 85-173 cm depth

Yellowish red (5 YR 5/6); clay; weak fine prismatic structure that breaks to moderate fine angular blocky; friable, very sticky, very plastic; many fine, common medium tubular pores; no evidence of films; angular and subangular, 1-5 mm diameter chert (smocky) and quartz grains (3% volume); common ant chambers; diffuse boundary.

B3 horizon; 173-208 cm depth

Yellowish red (5 YR 5/7) sandy clay; a tendency to rock fabric is observed and a weak medium and fine angular blocky and moderate fine granular; very friable, sticky, plastic, many fine tubular pores; few mica fragments, few chert and quartz grains (1-5 mm), few ant chambers; smooth, clear boundary.

C1 horizon; 202-228 cm depth

Horizon consisting of rock fabric (horizontal layering) and loose materials; yellowish red and red in the lower part; sandy clay; no roots; no macroorganism activity; smooth and clear boundary.

C2 horizon; 228-247 cm depth

Red (2.5 YR 4/6) sandy clay; weak medium angular blocky and weak fine granular; very friable, sticky, plastic; common fine tubular pores; in the lower part of the horizon there is a discontinuous layer of planar, dark red nodules; smooth, clear boundary.

C3 horizon; 247-350+ cm depth

Weathered, very altered gneissic rock with banded and variegated yellowish brown, yellowish red colors.

SOIL PROFILE 9. ASIS

LOCATION: Municipio Puerto Asis, Km 1 South Puerto Caicedo; foothills of Eastern Cordillera.

ALTITUDE: 250-300 m above sea level.

RELIEF: Rolling to hilly.

SLOPE: 12-25%.

POSITION OF THE PROFILE: Lower part of hillslope.

EROSION: Not apparent.

VEGETATION: Originally tropical rain forest cut 15 years ago, actually pastures.

PARENT MATERIAL: Miocene-Pliocene sediment mixed with colluvial and pyroclastic rocks.

WATER TABLE: Very deep.

DRAINAGE: Well drained.

MOISTURE CONDITIONS OF THE PROFILE: Moist, all profile.

DATE SAMPLED: July 9, 1971.

A1 horizon; 0-12 cm depth

Brown (10 YR 4/3) with common radicular dark brown (7.5 YR 4/4) mottles; sandy clay; weak fine subangular blocky structure and weak fine granular; hard, firm, sticky, plastic; many fine and medium tubular pores; many fine roots; few earthworms; smooth, clear boundary.

B2 horizon; 12-86 cm depth

Yellowish red (5 YR 4/6) with fine distinct pale brown (10 YR 6/3) around the root channels, clay; weak medium prismatic structure that breaks to moderate medium and fine subangular blocky and moderate fine granular; friable, very sticky, very plastic; many fine tubular pores; common medium and few coarse pores; common ants; few earthworms; few ant chambers; smooth, gradual boundary.

IIC1 horizon; 86-138 cm depth

Yellowish red (5 YR 4/6) with common fine distinct brown (10 YR 5/3) mottles and many small grayish brown "points" of weathered "rock fragments;" clay loam; there is a layered structure (rock fabric) with many "joint-planes" and hard blocky lithorelicts (aggregates of clay). In some parts the horizon is friable, sticky plastic; with clay loam to clay texture; few fine tubular pores; few angular and subangular quartz and chert grains, few sesquioxidic nodules; smooth and clear boundary.

IIC2 horizon; 138-214 cm depth

Horizon consisting of about 50% material with rock fabric (layered with joint-planes); variegated reddish brown (2.5 YR 4/4), dusky red (10 YR 3/4) white (10 YR 8/1.5), olive brown (2.5 Y 4/4) and dark chert grains; the faces of the fragments are coated by dark films. About 50% of the horizon has soil material with variegated colors, clay texture, weak medium subangular blocky structure, friable, sticky, very plastic, common fine tubular pores; common chert and quartz grains (1-5 mm) of oblate and angular shapes.

IIC3 horizon; 214-296 cm depth

More than 60% of the horizon has rock fabric, with variegated color pattern, brown, reddish brown, yellowish brown, white. In the "joint-planes" there are prominent red mottles and common black films.

The soil material has variegated colors, clay, textures, weak medium angular blocky structure films; sticky, plastic, few fine tubular pores. In the lower part of the horizon there is a black and red discontinuous layer, 2 cm thick, of Fe and Mn accumulation.

IIIC4 horizon; 296-350 cm depth

Very altered and weathered rock (probably feldspatic sandstone) with sandy loam texture; yellowish brown, gray with dark red mottles, some quartz and chert grains are present.

Appendix B. Micromorphology of Selected Horizons of the Amazonia Soils

					Pedological features		
Horizon & depth	Fabric analysis	Skeleton grains	Voids	Plasma fabric	Cutans	Nodules	Papules & others
Profile 1 - Miraf							
B21 60-80 cm	Porphyro-skelic, random unrelated	Sparse quartz; sparse acicular heavy minerals	Common irregular prolate very fine macro, meso, micro orthovughs; sparse single & dendroid orthochannels	Argillasepic; skelargillasepic; no plasma separation	None	Sparse irregular sharp, red brown & black nodules	None
B22 100-150 cm	Porphyro-skelic, random unrelated	Sparse quartz; very sparse acicular heavy minerals	Common irregular prolate, equant, medium to very fine macro, meso, & micro orthovughs; sparse single orthochannels	Argillasepic, skelargillasepic; sparse local areas of redder plasma, asepic	None	Sparse irregular sharp, dark brown to black nodules	None
B23 300-350 cm	Porphyro-skelic, random unrelated	Sparse quartz (well sorted)	Common irregular medium to very fine macro, meso, micro ortho & meta vughs, sparse dendroid orthochannels; sparse meta skew planes; very sparse metavesicles	Argillasepic, skelargillasepic (no plasma separation)	None	Sparse irregular sharp red to dark brown nodules	None

Horizon & depth	Fabric analysis	Skeleton grains	Voids	Plasma fabric	Pedological features		
					Cutans	Nodules	Papules & others
Profile 2 - Montan							
B1 37-64 cm	Porphyroskelic, random unrelated	Sparse quartz (poorly sorted); very sparse anatase & acicular heavy minerals	Common irregular, medium to very fine macro, meso, mitro ortho & meta vughs, sparse dendroid meta channels; very sparse metavesicles	Argillasepic, skelargillasepic; local areas of vomasepic	None	Sparse irregular sharp, reddish brown & black nodules	Very sparse papules
B21 104-124 cm	Porphyroskelic, random unrelated	Sparse quartz (poorly sorted); very sparse heavy minerals	Common irregular, medium to very fine macro, meso, micro vughs; common dendroid ortho channels; very sparse meta vesicles	Argillasepic, skelargillasepic; no plasma separation	None	Very sparse irregular reddish brown nodules	Very sparse ellipsoidal ortho-agrotabules, sharp boundary
B22 170-200 cm	Porphyroskelic, random unrelated	Sparse quartz (poorly sorted); very sparse heavy minerals	Common irregular, medium to very fine macro, meso, micro vughs; common dendroid ortho channels; very sparse meta vesicles with fine ramifications	Argillasepic, skelargillasepic; no plasma separation	None	Very sparse irregular red nodules (iron)	Very sparse papules with distinct boundaries; well developed parallel internal orientation (clay papules increase in amount with depth)

					Pedological features		
Horizon & depth	Fabric analysis	Skeleton grains	Voids	Plasma fabric	Cutans	Nodules	Papules & others
			Profile 3 - Naval				
B21 33-52 cm	Porphyroskelic, random unrelated	Common quartz; very sparse heavy minerals in random distribution pattern	Common irregular, equant, prolate fine macro, meso & micro ortho vughs; sparse dendroid orthochannels	Argillasepic + silasepic; very sparse localized areas of red plasma-asepic	None	Very sparse irregular, diffuse red nodules	None
B22 72-105 cm	Porphyroskelic with some agglomeroplasmic, random unrelated	Common quartz; very sparse heavy minerals; very sparse mica flakes	Common prolate irregular & equant fine to very fine macro, meso, micro, meta vughs; very sparse single meta channels	Argillasepic + silasepic & vosepic; sparse localized areas of red plasma, asepic	Common ped & vugh, thin argillans, sharp degree of separation	Sparse irregular sharp reddish brown to black nodules	None
B24 142-200 cm	Porphyroskelic, random unrelated	Abundant quartz (in silt fraction); very sparse heavy minerals	Common irregular & prolate, fine to very fine macro, meso, micro meta vughs; sparse single meta channels; sparse meta skew planes; very sparse meta joint planes	Argillasepic + silasepic; some vosepic; localized areas of red plasma asepic	Sparse & channel argillans & ferri-argillans, sharp degree of separation	Ped sparse irregular diffuse red nodules	None

					Pedological features		
Horizon & depth	Fabric analysis	Skeleton grains	Voids	Plasma fabric	Cutans	Nodules	Papules & others
			Profile 4 - Polvor				
B21 47-80 cm	Porphyroskelic, random unrelated	Common quartz (well sorted); very sparse acicular heavy minerals	Common irregular acicular medium to very fine macro, meso, micro ortho vughs & connected vughs; sparse dendroid ortho channels	Argillasepic, skelargillasepic; local areas of red plasma asepic	Sparse thin ped vugh, channel argillans, sharp boundaries	Sparse with irregular sharp diffuse boundaries, dark reddish brown to black colors	None
B22 120-157 cm	Porphyroskelic, random unrelated	Common quartz, (well sorted); very sparse heavy minerals	Common irregular fine, very fine macro, meso, micro ortho vughs; sparse to common dendroid ortho-channels; sparse skew planes	Argillasepic, skelargillasepic masepic; local areas of redder plasma asepic	Common thin ped, vugh skew plane argillans with sharp boundaries	Sparse irregular, sharp & diffuse boundaries dark reddish brown to black	None
C1 157-210 cm	Porphyroskelic, random unrelated	Common quartz (moderately sorted); very sparse heavy minerals; sparse mica flakes	Sparse irregular very fine macro, meso, micro ortho vughs; sparse skew planes; very sparse dendroid meta-channels	Argillasepic, masepic; local areas of redder plasma asepic	Common thin ped, skew planes; vughs ferriargillans & ferrands?	Sparse irregular sharp reddish brown to black nodules	None

Horizon & depth	Fabric analysis	Skeleton grains	Voids	Plasma fabric	Pedological features		
					Cutans	Nodules	Papules & others
			Profile 5 - Tacana				
B21 30-50 cm	Porphyroskelic, random unrelated	Common quartz; very sparse heavy minerals	Common irregular prolate, equant macro, meso, micro meta vughs; sparse single meta channels	Argillasepic skelargillasepic; local areas of red plasma asepic	None	Sparse irregular sharp reddish brown to black	None
B21 70-83 cm	Porphyroskelic, random unrelated	Common quartz; very sparse heavy minerals; very sparse mica flakes	Common irregular, prolate & equant macro, meso, micro meta vughs; sparse meta channels	Argillasepic local areas of red plasma asepic	None	Sparse irregular sharp, reddish brown to black	None
B22 83-140 cm	Agglomeroplasmic, random to weakly banded	Common quartz sparse heavy minerals; very sparse micas	Common irregular macro, meso, ortho vughs (interconnected vughs); sparse ortho channels	Argillasepic local areas of red plasma asepic	None	Sparse irregular sharp, dark reddish brown to black	None
			Profile 6 - Leguiz				
B21 20-80 cm	Porphyroskelic agglomeraplasmic, random unrelated	Common quartz (moderately sorted); sparse heavy minerals; very sparse mica flakes	Common irregular medium to very fine macro, meso ortho vughs & connected vughs; sparse dendroid ortho channels	Skelargillasepic; local latticepic	None	Sparse irregular sharp, dark reddish brown & black	Sparse reddish brown lithorelicts (internally parallel oriented)

					Pedological features		
Horizon & depth	Fabric analysis	Skeleton grains	Voids	Plasma fabric	Cutans	Nodules	Papules & others
Profile 6 - Leguiz (Cont.)							
B22 82-133 cm	Porphyroskelic, random unrelated	Common quartz; sparse heavy minerals & mica flakes	Common irregular, prolate fine macro, meso micro ortho & meta vughs; common dendroid meta channels	Skelargillasepic	None	Sparse irregular dark reddish, brown & black	Very sparse papules with boundaries
IIB23 133-173 cm	Porphyroskelic agglomeroplasmic; random unrelated (locally banded, slight parallel orientation)	Abundant quartz; sparse heavy minerals & mica flakes	Abundant irregular very fine macro, meso & micro vughs; common dendroid meta channels; sparse meta skew planes	Skelargillasepic & silasepic; locally redder banded plasma	Sparse thin vughy cutans rather sharp; continuous orientation	Sparse sharp irregular dark reddish brown	Very sparse isotubules; very sparse gray lithorelicts
Profile 7 - Guavia							
B21 47-75 cm	Intertextic & agglomeroplasmic; random unrelated	Abundant quartz (poorly sorted); very sparse rock fragments	Common irregular medium to very fine macro, meso, micro ortho vughs; sparse meta vesicles; sparse arched chambers	Argillasepic local areas of silasepic	None	Sparse irregular sharp dark reddish brown & black nodules	None

Horizon & depth	Fabric analysis	Skeleton grains	Voids	Plasma fabric	Pedological features		
					Cutans	Nodules	Papules & others
			Profile 7 - Guavia (Cont.)				
B22cn 75-97 cm	Porphyroskelic; local areas agglomeroplasmic; random unrelated	Abundant quartz (poorly sorted); very sparse rock fragments	Common irregular medium to very fine macro, meso, micro vughs & connected vughs; sparse meta vesicles	Argillasepic local areas of dark red plasma asepic in a yellowish red plasma	Very sparse thin vugh cutan, sharp separation	Sparse irregular sharp reddish brown to black nodules	None
IIC 124-240 cm	Porphyroskelic banded; parallel orientation	Sparse to common quartz	Sparse irregular & acicular very fine macro, meso, micro ortho & meta vughs; sparse dendroid meta channels & ortho joint planes & ortho skew planes	Argillasepic skelargillasepic, no plasma separation	None	None	None
			Profile 8 - Floren				
B21 16-85 cm	Porphyroskelic, random unrelated	Common quartz (poorly sorted); sparse heavy minerals; very sparse mica flakes; sparse rock fragments	Common irregular & acicular fine to very fine macro, meso, micro, ortho & meta vughs; sparse skew planes & craze planes	Skelargillasepic & silasepic	None	Sparse irregular sharp, dark reddish brown & black	Common brown & gray lithorelicts

Horizon & depth	Fabric analysis	Skeleton grains	Voids	Plasma fabric	Pedological features		
					Cutans	Nodules	Papules & others
			Profile 8 - Floren (Cont.)				
B22 53-173 cm	Porphyroskelic, random unrelated	Common quartz (moderately sorted); sparse heavy minerals; very sparse mica flakes	Common irregular fine macro, meso, micro ortho vughs & connected vughs; sparse dendroid ortho channels; sparse craze planes	Argillasepic, silasepic locally vosepic	Sparse thin vughy cutans; rather sharp boundaries; continuous orientation	Sparse irregular sharp reddish brown & black	Common brown & gray lithorelicts; sparse red papules with parallel orientation; rather diffuse boundaries
C1 208-228 cm	Agglomeroplasmic, random unrelated	Abundant quartz (very poorly sorted); sparse heavy minerals; very sparse mica flakes; sparse rock fragments	Common fine & very fine macro, meso, ortho vughs connected vughs; sparse single & dendroid ortho channels; sparse skew, craze planes; sparse meta vesicles	Silasepic skelargillasepic? local concentration of redder plasma asepic	Very sparse thin cutans with diffuse boundaries	Sparse irregular sharp reddish brown	Common gray lithorelicts

Horizon & depth	Fabric analysis	Skeleton grains	Voids	Plasma fabric	Pedological features		
					Cutans	Nodules	Papules & others
Profile 9 - Asis							
B2 12-86 cm	Porphyroskelic, random unrelated	Common quartz (poorly sorted); sparse heavy minerals; very sparse mica flakes; sparse rock fragments	Common irregular, equant & prolate, very fine macro, meso, micro, ortho vughs, sparse single & dendroid ortho channels; very sparse skew planes & vesicles	Argillasepic silasepic	Very sparse thin vughy & grain cutans	Sparse irregular sharp & diffuse, reddish brown	Sparse yellowish red papules internally parallel oriented; sparse lithorelicts
IIC 86-138 cm	Porphyroskelic, random unrelated	Common quartz (poorly sorted); very sparse heavy minerals acicular & rhombic; sparse mica flakes	Common irregular prolate, medium to fine macro, meso, micro ortho vughs & connected vughs	Argillasepic, silasepic local; concentration of red plasma	Very sparse subcutans (quasicutans)	Sparse irregular diffuse, red iron	Sparse gray lithorelicts; sparse red papules, weak parallel orientation
IIIC4 296-350 cm	Porphyroskelic, random unrelated	Common quartz & chert & rock fragments; sparse heavy minerals; very sparse mica	Common very fine macro, meso, micro ortho vughs; connected vughs; sparse meta vesicles	Argillasepic, skelargillasepic; some skel-silasepic	None	Sparse irregular diffuse reddish brown	Common gray & reddish lithorelicts with sharp boundaries; no internal orientation

Appendix C. Preliminary Characterization of the Soil Fertility Status by Greenhouse Studies

An attempt was made to characterize the fertility status of some soils of the Amazonia. Samples were taken from the 0-20 cm topsoil of soils 1, 3, 4, 8 and 9.

In the greenhouse studies the missing element technique as described by Martini[2] was used. Pots were filled with 1.5 kg of sieved soil (4 mm mesh). The treatments were applied in solution or suspension to the premoist soils. Liming treatments were done two weeks before nutrient application and barley seeds were planted one week after nutrient application. After six weeks of growth, the tops were cut, dried and weighed. All treatments were made in triplicate.

The sources and amounts of nutrients applied were as follows:

Nutrient	Amounts applied		Sources
	mg/pot[3]	Kg/ha[4]	
N	150	200	$CO(NH_2)_2$
P	375	500	$NaH_2PO_4\ H_2O$
K	150	200	KCl
Ca	375	500	$CaCO_3$
Mg	225	300	$MgCO_3$
S	75	100	Na_2SO_4
Cu	7.5	10	$CuCl_2\ 2H_2O$
Zn	15	20	$ZnCl_2$.
Mn	30	40	$MnCl_2\ 4H_2O$
Mo	7.5	10	$Na_2MoO_4\ 2H_2O$
B	7.5	10	$Na_2B_4O_7\ 10H_2O$

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[2] Martini, J. A. 1969. Caracterization del estado nutricional de los latosoles de Costa Rica, mediante la tecnica del elemento faltante en el invernadero. Turrialba 19:394-408

[3] 1.5 Kg soil/pot

[4] Assuming 2.000.000 Kg/ha

The amounts of lime applied were calculated based on the meq/100 g of exchangeable aluminum times 1.5 for treatment 3; and one-half of this amount for treatment 4 (complete plus one-half lime). The soil data before and after liming is as follows:

Soil	Before liming pH	Before liming Exch. Al meq/100 g	Limed to neutralize pH	Limed to neutralize All exch. Al meq/100 g	Limed to neutralize pH	Limed to neutralize 50% exch. Al meq/100 g
Soil 1 Miraf	4.5	2.61	5.3	0.35	5.9	0.0
Soil 3 Naval	4.5	4.68	5.6	0.95	7.0	0.0
Soil 4 Polvor	4.6	5.86	5.7	1.23	6.8	0.0
Soil 8 Floren	4.6	3.70	5.9	1.57	7.0	0.0
Soil 9 Asis	4.7	5.27	5.7	1.56	7.0	0.0

Yield of barley tops in greenhouse studies

Treatments	Soil 1 Miraf	Soil 3 Naval	Soil 4 Polvor	Soil 8 Floren	Soil 9 Asis
	g dry matter/pot				
1. Check	0.35	0.30	0.37	0.25	0.33
2. Complete	1.60	2.17	3.23	2.00	2.13
3. Complete + lime[5]	1.40	2.63	3.40	1.93	2.27
4. Complete + 1/2 lime[6]	1.15	2.23	2.57	2.03	2.16
5. Less N	1.16	1.30	2.53	1.87	1.90
6. Less P	0.76	0.66	0.90	0.80	0.83
7. Less K	1.10	1.70	2.90	0.60	2.00
8. Less Ca	0.77	1.36	2.63	1.80	1.70
9. Less Mg	1.05	1.57	2.33	2.20	2.30
10. Less S	1.20	2.23	2.85	2.10	2.10
11. Less Cu	1.00	2.30	3.40	2.10	2.35
12. Less Zn	1.20	2.23	3.10	2.43	2.25
13. Less Mn	1.20	2.23	2.70	2.20	2.90
14. Less Mo	1.70	2.43	2.65	2.15	2.35
15. Less B	1.23	2.60	3.00	----	2.75

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[5] Limed to neutralize all exchangeable aluminum (Exch. Al x 1.5)

[6] Limed to neutralize 50% of exchangeable aluminum (Exch. Al x 1.5/2)