CHARACTERIZATION, CLASSIFICATION AND USE INTERPRETATIONS OF A SEQUENCE OF SOILS ALONG THE TRANSAMAZON HIGHWAY, OF BRAZIL BETWEEN THE XINGU AND JACARE RIVERS

By

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ABSTRACT

CHARACTERIZATION, CLASSIFICATION AND USE INTERPRETATIONS OF A SEQUENCE OF SOILS ALONG THE TRANSAMAZON HIGHWAY, OF BRAZIL, BETWEEN THE XINGU AND JACARE RIVERS

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A sequence of four profiles (numbered from highest to lowest) was studied.

The soils were relatively shallow, and physical tests show that the two better drained profiles have plinthite in their subsoil horizons.

Chemical analyses show profiles 2 and 3 have high Al^{+++} saturation. All soils studied have low exchange capacity and percent base saturation.

Kaolinite comprised more than 95 percent of the total clay fraction. Aluminum saturation seems to have more influence on x-ray diffraction intensity than soluble iron oxides in the samples. Pretreatments of clay by dithionite and oxalate increased the kaolinite diffraction peaks in all subsurface samples; but, dithionite was most effective. Oxalate treatments were not effective on surface samples.

Taxonomically, these soils fit into Plinthic Paleudults (Profile 1), Plinthudults (Profile 2), and Aquic Paleudults (Profiles 3 and 4).

The two more poorly drained soils (Profiles 3 and 4) had severe limitation for all purposes, but the two better drained (Profiles 1 and 2) had less limitations for some purposes.

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I. INTRODUCTION

During the soil survey process along the Transamazon Highway, of Brazil, soils with plinthite have been mapped on several parts of the highway (Santos et al., 1973).

During the rainy season (January-July), these soil types have caused many problems to the traffic, because of the high water table in the soils of the lower parts and lateral movement of water in the soils of the higher parts of the slopes.

Some researchers have studied plinthic soils in Brazil. Nevertheless, they remain not well characterized in the soil survey of the transamazon highway, because some, by field observation of the profile recognize them as a plinthite feature, but some others do not. Therefore more study is necessary in order to clarify this problem. There is much controversy concerning the characterization of these soils in the field and by laboratory analyses.

The present study started in 1973 and was sponsored by Conselho Nacional de Desenvolvimento Cientifico e Tecnologico (CNPq). However, it stopped before completion because CNPq changed its policy. The main objective of this study is description, characterization, classification and interpretation, plus comparative evaluation among the profiles studied, in order to see how they vary.

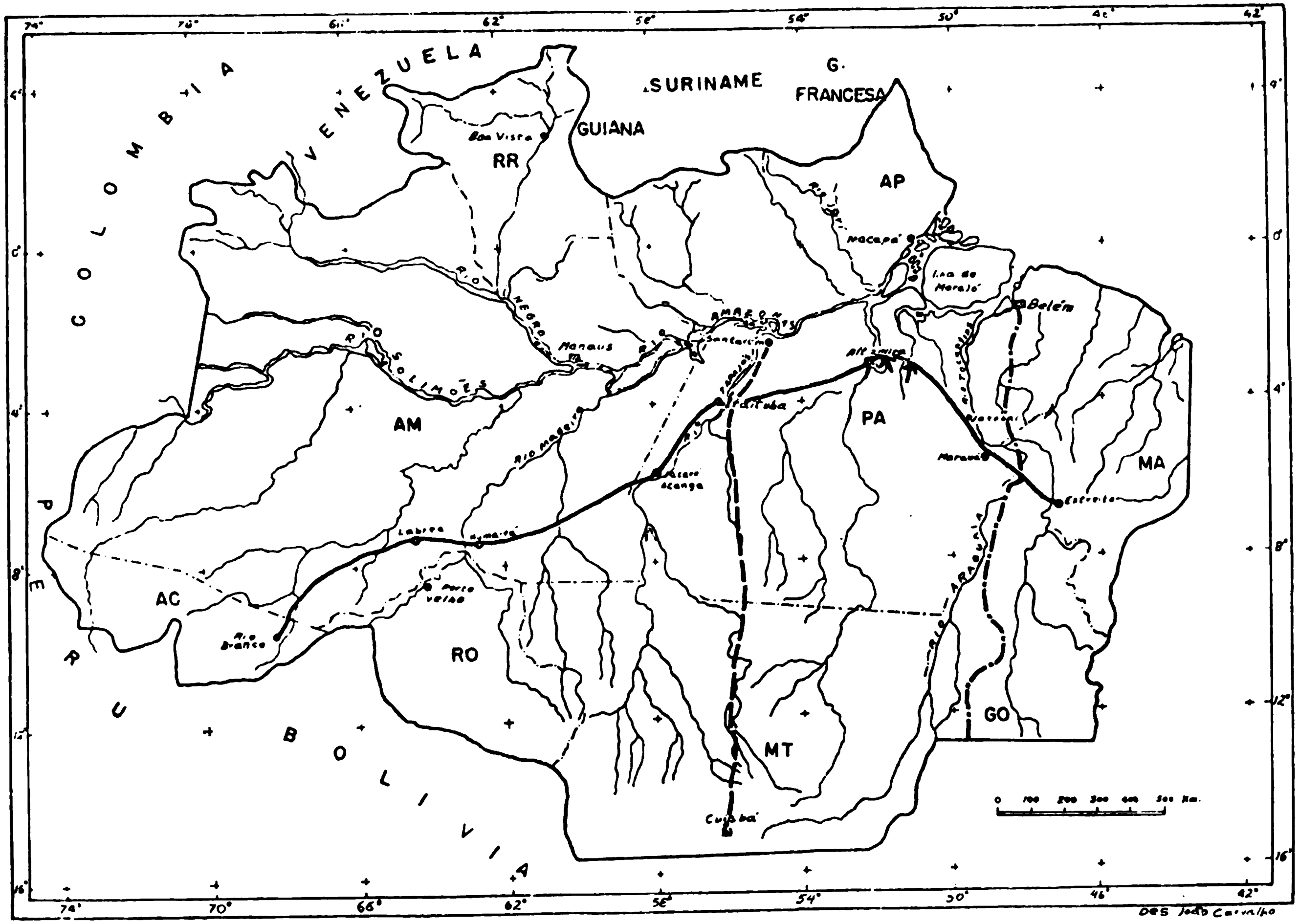
II. LITERATURE REVIEW

Historic

In 1965, the Ministry of Agriculture of Brazil, made an agreement with United States Agency for International Development (USAID) to make a Schematic (exploratory in some areas) Soil Survey of the North, Middle North and Central-West Regions of Brazil (Brailian Amazon region is included) which comprises approximately 6,000,000 sq km (Camargo, Freitas, et al., 1975). Legal Amazon Region showing Transamazon Highway and interval studied $\overline{\uparrow\uparrow}$, is showed in Figure 1.

Since Marbut and Manifold (1926), chiefly after the second World War, and creation of the SPVEA (Superintendência do Plano de Valorização Econômica da Amazônia), new data on the Brazilian Amazon soils have been gathered. The Amazon region in Brazil is part of the middle and lower parts of the Amazon River basin.

Some other soil researchers have done soil studies in the area, such as: Guerra (1952); Day (1958, 1959, 1961); Carneiro (1955); FAO by Sombroek, and Sampaio (1962): Sombroek (1962a, 1962b); and IPEAN-Secção de Solos by



Rodovia Transamazonica--Transamazon Highway

Rodovia Transamazonica Trecho Estudado--Transamazon Highway (Interval Studied)

Rodovia Santarem-Cuiaba--Santarem-Cuiaba Highway

Rodovia Belem-Brasilia--Belem-Brasilia Highway

Figure 1. Legal Amazon Region Showing Transamazon Highway and Interval Studied ↑↑.

Falesi, Vieria, Rodrigues da Silva, Santos, Rodrigues, among others.

The Soils

Upper Amazon River Basin

The soils of the Yurimaguas Region in the upper Amazon jungle of Peru, are classified as Reddish Brown Lateritic, Red Yellow Podzolic, Ground Water Laterite and azonal Alluvial Forest Soils (ONERN, 1967). In other areas of the Amazon Basin of Peru ONERN (1969) has mapped: Ground Water Laterites and Red Yellow Podzolic soils. They believed that these soils were developed from Tertiary sediments and may be very similar to those found near Yurimaguas (Tyler, 1975).

The most extensive well-drained soils of the Amazon Basin of Peru are, according to Sanches and Buol (1974): Typic Paleudults and the poorly drained soils are Typic Tropaqualfs or Tropaquepts. The Paleudults had predominantly kaolinitic mineralogy with small quantities of 2:1 minerals present. The poorly drained soils were predominantly montmorillinitic or of mixed mineralogy. The results indicate that morphologically the main soils of the upper Amazon Basin of Peru are very similar to many soils of the Upper Coastal Plain and Piedmont Regions of the Southeastern United States. Evidence of this relationship was published by Marbut and Manifold in 1926 but this information has been largely ignored.

More soils containing mainly kaolinite were studied in sediments from the Eastern Cordillera of Colombia in the upper Amazon Basin by Benavides (1973).

Middle and Lower Amazon
River Basin

Mainly Yellow Latosols are found in the middle and lower Amazon Basin. They are dystrophic, and mapped principally on level and gently undulating relief. Nevertheless they have also been mapped in rolling and hilly areas. Various soil textural classes are present and they are developed from sand clay sediments, similar to the Barreiras formation (Tertiary that occurs in Eastern Brazil), over Devonian shale and sandstones.

The second most extensive soils are Red Yellow Latosols developed from gneiss of acid character (Pre-Cambrian (CD)): dystrophic and eutrophic. Third in extent are Red and Yellow Sands.

Following without order are: Dark Red Latosols, Red Yellow Podzolic soils (eutrophic, dystrophic, and plinthic), Hydromorphic Soils, Terra Roxa Estruturada Eutrophic, Dusky Red Latosol (dystrophic and eutrophic) and other small units (Camargo, Freitas, et al., 1975).

Red Yellow Podzolic Plinthic vs. Red Yellow Podzolic.--The Red Yellow Podzolic plinthic soils differ from Red Yellow Podzolic class, by presence of plinthite in the Bt or C horizons, however, at least the first 30 cm of the

B horizon is free of plinthite and has the following characteristics: variable texture, usually low activity clay, low base saturation, high aluminum saturation and low natural fertility. These soils are susceptible to erosion and were developed from products of decomposition of crystalline rocks and sand clay sediments. The vegetation varies from deciduous to semi-evergreen with babaçu (dicotilo-palmaceas) and cerrado. The relief is gently undulating. The climate has a dry season but not too extensive. Their highest concentrations are in Rondônia Federal Territory and Mato Grosso State in Central West of Brazil (Camargo, Freitas, et al., 1975). This type of soil has been mapped in Northwest of Maranhão State (Rodrigues, Rodrigues da Silva, et al., 1971) as well as in Northeast area, states of Ceara, R. G. Norte, Pernambuco, semi-arid region (Jacomine et al., 1971, 1972, 1973a, 1973b).

Ground Water Laterite of the Bottom Lands.--These are soils chiefly poorly drained with the following sequence of horizons: A moderate, prominent or turfy, followed by well developed plinthite with or without a weathered textural B and C horizon. An A2 horizon may precede the plinthic Bt. The texture is widely variable either among profiles or within them; the neutral colors are dominant or condominant in the upper part of the profile or underlying it.

Ground Water Laterite of the Uplands.--Ground Water Laterite of the uplands are chiefly imperfectly drained, very similar to those of the bottom lands, however not so hydromorphic. The A horizon is moderate, occasionally prominent, normally have B horizon either textural, latosolic or cambic, thin and not plinthic, preceding the plinthic part situated just underlying (Camargo et al., 1975).

Planosol Plinthic.--Santos et al. (1973) define Planosols from Transamazon Highway as a sequence of soils with A1, A2 and B horizons having abrupt transition between A and B horizons; moderate A; textural B; dystrophic (low base saturation); low activity clay; alico; imperfectly drained; occur under semi-evergreen equatorial forest of the valley bottoms; level; altitude around 50 meters; parent material is sandy clay sediments of the decomposition alluvium-colluvium and contain plinthite.

Plinthite

Kellogg (1949) confined the term "laterite" to four principal forms of sesquioxide-rich material that either are hard or that harden upon exposure: (1) soft mottled clays that change irreversibly to hardpans or crusts when exposed; (2) cellular and mottled hardpans and crusts; (3) concretions or nodules in a matrix of unconsolidated material; (4) consolidated masses of such concretions or nodules. The Soil Survey Staff, 1960, proposed a new term, plinthie (Gk. plinthos, brick), for essentially the same concept, defining it as "the sesquioxide rich, humus poor, highly weathered mixture of clay with quartz and other diluents, which commonly occurs as red mottles, usually in platy, polygonal, or reticulate patterns; plinthite changes irreversibly to hardpans or irregular (hard) aggregates on repeated wetting and drying, or it is the hardened relicts of the soft red mottles." The term plinthite was introduced to avoid the confusion arising from use of the word "laterite" without precise definition for many widely divergent materials (Sivarajasingham, et al., 1962). The plinthite was sub-divided into two groups (by Sombroek, 1966), namely:

Soft plinthite (mottled clay, fleckenzone, argile tachete, horizon bariole):

A layer of soft (i.e., cuttable with knife), dense, usually clayey, humus poor mineral material with many, coarse, prominent mottles. The mottles are red or purple,[1] often with admixture of some yellow, and occur in a white or light grey matrix. In case of a predominance of the red or purple, the situation may be described as the occurrence of white and some yellow mottles in a red or purple matrix. The pattern of mottling varies. It may be reticulate (polygonal), vesicular (prismatic) or platy (laminar).

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[1]Actually usually weak red in the Munsell notation.

Hard plinthite (iron concretions, eisenkruste, laterite, cuirasse, ferruginous quartzite, canga, picarra): A slag-like (i.e., only breakable with hammer), humus poor mineral material, apparently largely consisting of indurated iron oxides; as well as the earth between this material, if present. The indurated elements vary in color (red to black), size (from fine gravels to enormous boulders and crusts), shape (pisolithic, platy, prismatic, massive, vesicular), nuclei (fine to very coarse elements, usually of quartz, around which the sesquioxides are cemented), and arrangement (vertical, horizontal, irregular).

Plinthite is formed in older tropical soils with hydromorphic characteristics (high water table or stagnating percolation). This is called plinthization which is characterized by mobilization, transport and final accumulation of iron compounds. In permanent moist conditions, plinthite is soft but when it dries (e.g., by decreasing in water table or upheaval of the land) the material hardens irreversibly by dehydration, and hard or indurated plinthite (<u>ironstone</u>) forms. The hard plinthite may occur in various types, such as concretions, cemented concretions and hardpans. (Fr. cuirasse; Ger. panzer.) Plinthization is not confined to Ferralitic soils; it may also occur in all older iron-rich tropical soils with recent or former influence of ground water (Buringh, 1970).

Plinthite is present where either there are high concentrations of iron in the parent rock or where iron is translocated into an area. It usually forms in conjunction with a fluctuating water table (Daniels et al., 1970; Alexander and Cady, 1962).

Sanches (1973) has pointed out that suspected material can be easily tested by wetting it to saturation and allowing it to dry. If after five to ten wetting and drying periods the material is still friable enough to be broken in one hand, it will not qualify for plinthite.

Alexander and Cady (1962) observed that wetting and drying for a period of 15 years caused a hard, slaglike crust, 1 to 2 cm thick to be formed. In addition they state that the principal factors that accelerate the hardening process are erosion and the removal of forest cover, and conclude that vegetation is the only agent that can prevent or reverse this hardening process.

The Soil Survey Staff (1975) proposed a new definition for plinthite

> Plinthite (Gr. plinthos, brick) is an iron-rich, humus-poor mixture of clay with quartz and other diluents. It commonly occurs as dark red mottles, which usually are in platy, polygonal, or reticulate patterns. Plinthite changes irreversible to an <u>ironstone</u> hardpan or to irregular aggregates on exposure to repeated wetting and drying, especially if it is exposed also to heat from the sun. The lower boundary of a zone in which plinthite occurs usually is diffuse or gradual, but it may be abrupt at a lithologic discontinuity. . . .
>
> . . . From a genetic viewpoint, plinthite forms by segregation of iron: probably there has been, in many places, addition of iron from other horizons or from higher adjacent soils. . . .
>
> . . . The red or dark red mottles are not considered plinthite unless there has been enough segregation of iron to permit irreversible hardening on exposure to

wetting and drying. Plinthite in the soil usually is firm or very firm when the soil moisture content is near field capacity and hard when the moisture content is below the wilting point. Plinthite does not harden irreversibly as a result of a single cycle of drying and rewetting. After a single drying, it will re-moisten, and then it can be dispersed in large part by shaking in water with a dispersing agent. In a moist soil, plinthite is soft enough that it can be cut with a spade. After irreversible hardening, it is no longer considered plinthite but it is called ironstone. Indurated ironstone materials can be broken or shattered with a spade but cannot be dispersed by shaking in water with a dispersing agent.

Daniels, Perkins, et al. (in press) have suggested redefinition of plinthite, because when the term was first introduced by Soil Survey staff (1960), the definition was somewhat vague about how to identify this material in the field. The major feature of plinthite is that it must harden irreversibly upon repeated wetting and drying. After several years of field and laboratory studies of plinthite, they suggest the following as a working definition within the meaning of Soil Taxonomy (1975). Consistency terms are defined in the Soil Survey Manual (Soil Survey Staff, 1951).

> Soil materials rich in iron oxides range from friable mottles to extremely firm or extremely hard (indurated) ironstone sheets or nodules. Plinthite occupies a position between these two extremes. Plinthite is separated from friable red mottles that never harden because it hardens irreversibly upon repeated wetting and drying, usually when exposed to air and especially to direct sunlight. Plinthite is separated from extremely firm or extremely hard (indurated) ironstone by being firm to very firm (barely crushable between thumb and forefinger) when moist and pieces less than 3 cm long can be broken by hand.

> Plinthite is a discrete body of firm to very firm when moist, hard or very hard when dry, material rich in iron oxides larger than 2 mm in diameter that can be separated from the surrounding matrix. It withstands moderate rubbing or rolling between the thumb and forefinger, yet it can be broken by hand. Plinthite does not slake within 2 hours when submerged in water even with periodic gentle agitation, but it may be brokendown if rubbed after being submerged for two hours or more. Plinthite may occur as discrete spherodial or irregular nodular bodies or as platy bodies. The hue of the color ranged from 10R to 7.5YR although the 5YR hue is more common. Plinthite commonly is associated with and surrounded by yellowish red to yellowish brown mottles or bodies that are brittle and friable or firm, but these bodies disintegrate when rolled between the thumb and forefinger and they slake in water. Bodies of plinthite feel less clayey than the surrounding material but laboratory evidence is inconclusive. Nodular plinthite apparently forms in or above soil layers that restrict vertical water movement; and platy plinthite apparently forms on level landscapes within a fluctuating zone of saturation. Nodular plinthite does not perch water but platy plinthite will perch a zone of saturation above it for short periods in soils with a udic moisture regime. Roots do not penetrate either nodular or platy plinthite but they follow the more friable zones surrounding bodies of plinthite.

According to Wood and Perkins (1976b), plinthite contains relatively large amounts of Fe, in contrast to red mottles and light-colored soil matrix with which it is associated and does not slake in water. Red mottles and other nonplinthic materials slake within a few seconds after being immersed in water. Since the introduction of the term plinthite, few investigations to specifically characterize plinthite have been reported and as a result, there is difficulty in the field identification of this soil feature.

Daniels, Perkins, et al. (in press) have established the above mentioned criteria for the identification of plinthite in the field and consistently separate nodular and platy plinthite from similar appearing materials that will not harden and from material that has already irreversibly hardened. They pointed out that nodular plinthite forms where lateral movement of water is a factor; while platy plinthite forms on level handscapes influenced by a fluctuating water table.

Measurement and Removal of Iron Oxides

A number of researchers have studied methods by which the free oxides of iron, aluminum, and manganese can be extracted from the soils. Mehra and Jackson (1960) developed a dithionite-citrate-bicarbonate method for extracting iron. Tamm (as in agrochemical methods in study of soils, 1965) used acid ammonium oxalate to determine free iron oxides. This procedure was later modified by McKeague and Day (1966). Deb (1950) used a method that involved the reduction of iron to the ferrous form.

Similar studies were also conducted by a number of researchers throughout the world and their results are well documented (Lundblad, 1934; Lajoie and Delong, 1945; Gorbunov, et al., 1961; Holmgren, 1967; McKeague et al., 1971; Dudas and Harward, 1971; Arshad et al., 1972; Pawluk, 1972).

Iron analysis of the particle-size separaters in bulk samples seems to be an indicator of plinthite presence. Horizons with red mottles (pseudo-plinthite) resembling plinthite have >90% of the iron associated with the sodium dispersed clay size fraction but sampled horizons with plinthite often have more than half of the iron associated with the sodium dispersed sand and silt size fractions.

An "active iron" ratio, oxalate extractable/citrate-bicarbonate-dithionite extracable iron, is a possible indicator of plinthite. Seventy percent of the samples called plinthite have "active iron" ratios <0.05 indicating that <5% of the iron is amorphous" (Daugherty, 1975).

McKeague and Day (1966), working with Canadian soils using dithionite and oxalate procedures extractable Fe and Al as aids in differentiating various classes of soils, concluded:

1. The oxalate extraction dissolved much of the iron and aluminum from the amorphous materials but very little from crystalline oxides, whereas the dithionite extraction dissolved a large proportion of the crystalline iron oxides as well as much of the amorphous materials.
2. Both oxalate and dithionite-extractable Fe and Al values are useful in studies of soil genesis and classification. The oxalate values give an approximation of the degree of accumulation of amorphous products of recent weathering in the horizons of soils formed from materials varying widely in texture, color, pH, organic matter, and total iron oxides.

Classification

The types of soil in this study have precipitate many discussions (disagreements) among soil surveyers (mappers) and soil classifiers in Brazil and all over the world. Some studies of correlation and classification done by Jacomine, Camargo et al. (1972) have proposed "if the profile has plinthite as deep as 75 cm and the drainage is not more restricted than imperfectly, the soil should be considered as Red Yellow Podzolic plinthic."

Jacomine, Camargo et al. (1973) proposed a differentiation between: "Red Yellow Podzolic plinthic and Ground Water Laterite soils. Tentatively it was established that when plinthite is just below the A horizon, the soil should be called Ground Water Laterite. When the upper part of the B horizon, free of plinthite, is 'thick' or a whole B horizon is free of plinthite, but the plinthite is present in the C horizon, the criteria designate the soil with 'substrata plinthic' e.g. Red Yellow Podzolic . . . substrata plinthic. If the upper part of the textural B, solonetzic B, latosolic B or incipient (B), is free of plinthite but the bottom part has plinthite, the best way is to classify the soil according to type of the B horizon and add the qualitative term plinthic, e.g. Red Yellow Podzolic plinthic. The same criteria is used for AC soils such as Alluvium and Regosols.

A soil taxonomy is a reflection of the current knowledge of soils and their genesis. A multiple categorical system in the United States is based on a hierarchy of chosen soil properties. The level of generalization of the chosen property is used in forming classes. Plinthite is presently used at two levels of generalizations: the great group, where a continuous phase or greater than 50 percent of the soil volume, within 1.25 m of the surface, is occupied by plinthite; and the subgroup with plinthite volume range of 5-50 percent, within different depths.

There are 185 great groups in this multiple category system, of which 9 use the presence of plinthite as a major property, for differentiation and only one has an established series in the United States, Puerto Rico or the Virgin Islands (Soil Survey Staff, 1975). There are presently 23 subgroups with plinthite and 20 have recognized series in the United States, Puerto Rico or the Virgin Islands. Table 1 summarizes the use of plinthite in soil taxonomy (Soil Survey Staff, 1975).

Daniels, Perkins et al. (in press), have suggested that slight adjustments in the amount of plinthite required for recognizing a plinthic soil must be made according to the form of plinthite present. For example:

> Ten percent or more discontinuous phase platy plinthite and its underlying reticulately mottled horizons will perch water in a humid climate for significant periods each year. The 5 percent plinthite by volume that is diagnostic for plinthic subgroups in Soil Taxonomy (Soil Survey Staff, 1975) is, on the basis of available data (Daniels, Gamble, et al., in press), too low to be recognizable for soils with platy plinthite. Neither the plinthite nor the underlying reticulately mottled horizons appear to have a significant effect on water movement, but its presence apparently does indicate that the underlying reticulately mottled horizons are restricting the downward flow of water. The 5 percent plinthite criterion seems appropriate for soils having nodular plinthite. Nodular and platy plinthite can occur in the same pedon, but one usually is clearly dominant and the classification should be based on the dominant condition.

Table 1.--Level of Plinthite in Soil Taxonomy.

Order[a]	Suborder[a]	Great Group[b]	Subgroup[c]
Alfisols	Aqualfs	Plinthaqualfs*	No subgroup or series in U.S.
	Udalfs	Paleudalfs	Grossarenic Plinthic Paleudalfs Plinthaquic Paleudalfs Plinthic Paleudalfs
	Ustalfs	Plinthustalfs*	No subgroup or series in U.S.
	Xeralfs	Plinthoxeralfs*	No subgroup or series in U.S.
Inceptisols	Aquepts	Plinthaquepts*	No subgroup or series in U.S.
		Tropaquepts	Plinthic Tropaquepts
Oxisols	Aquox	Plinthaquox*	No subgroup or series in U.S.
	Orthox	Acrorthox	Plinthic Acrorthox[d]
		Haplorthox	Plinthic Haplorthox[e]
Utisols	Aquults	Plinthaquults*	Oxic Plinthaquults
		Fragiaquults	Plinthic Fragiaquults Plinthudic Fragiaquults
		Paleaquults	Arenic Plinthic Paleaquults Plinthic Paleaquults
		Tropaquults	Plinthic Tropaquults
	Humults	Plinthohumults*	No subgroup or series in U.S.
		Palehumults	Plinthic Palehumults
	Udults	Plinthudults*	No subgroup or series in U.S.
		Fragiudults	Plinthaquic Fragiudults Plinthic Fragiudults
		Paleudults	Arenic Plintaquic Paleudults Arenic Plinthic Paleudults Grossarenic Plinthic Paleudults Plinthaquic Paleudults Plinthic Paleudults
		Tropudults	Plinthaquic Tropudults Plinthic Tropudults
	Ustults	Plinthustults*	No subgroup or series in U.S.
		Haplustults	Plinthic Haplustults

*No series have been established in the United States, Puerto Rico or the Virgin Islands (Soil Survey Staff, 1976).

[a]Plinthite is not a differentiating criterion at the order or suborder level.

[b]Plinthite must be continuous or >50% of the volume within 1.25 m of the surface.

[c]Plinthite is noncontinuous and 5-50% of the volume within 1.5 m of the surface.

[d]Plinthite is noncontinuous and 5-50% of the volume within 1.0 m of the surface.

[e]Plinthite is noncontinuous and 5-50% of the volume with 1.25 m of the surface.

III. MATERIALS AND METHODS

Soil Formation Factors

There are very few detailed studies available about soil formation (geology, climate, vegetation, and so on) along the Transamazon Highway that has only recently been built.

According to "Esbôço geologico preliminar and Perfil geologico preliminar by Campanhia de Recursos Minerais (C.P.R.M.), in Falesi (1972), this sequence of soils are related to undifferentiated Pre-Cambrian gneiss and migmatite-granites. The parent material of these soils are provided by the decomposition of these materials, followed by some local reworking of materials, except for Planosols Plinthic, which are formed from clayey and sandy, recent or subrecent, colluvial sediments.

The topography is gently undulating and elevations range from 40 to 80 meters.

The vegetation is semi-evergreen forest (tropical rain forest).

The climatic data at Altamira City, situated 70 km west from the Xingu River, are the nearest ones available to the sites studied.

According to Köppen, the climate of the area is the type Aw, having relatively high annual precipitation with a definite dry season (Bastos, 1972). This dry season generally occurs from July to October, having at least one month with less than 60 mm of precipitation. Climatic data are in Table 2.

Galvão (in I.B.G.E.-C.N.G., 1959), made the following comments about Altamira's climate. "Really its mean annual temperature is very high (26.0°C) ranging from 25.5°C in July to 26.6°C in October. Its extreme values registered are: absolute minimum, 12.4°C (08-08-1938) and the absolute maximum, 39.9°C (03-14-1933). The thermal amplitude is only 1.1°C which qualifies as a isothermic climate (Table 2). In spite of the fact that Altamira City is situated in the Am zone, in which annual total precipitation reaches 2000 mm in almost all meteorological stations, Altamira presents only 1700 mm. The hydrological balance is shown in Figure 2. In Köppen's diagram, Altamira is located very close to the diagonal which separates the climate types Am and Aw. This permits considering it as a transitional climate between these two types.

Field Studies

Field studies were made on two profile pits and two profile road cuts and comprised: morphological characterization and collection of soil samples, according to the standards established in the Soil Survey Manual (Soil

Table 2.--Climatic Data According to Thornthwaite (1955) Altamira, Pará, Brazil, Period 1931-1967.

	Tmax	Tmin	Tm	P_p	PE	RE
	---------°C--------			--------mm--------		
January	30.3	21.2	25.8	216	143	143
February	30.2	21.0	25.6	275	128	128
March	30.2	21.3	25.8	346	130	130
April	30.1	21.4	25.8	278	146	146
May	30.3	21.4	25.8	176	149	149
June	30.6	20.7	25.6	77	139	128
July	30.7	20.3	25.5	51	140	100
August	31.5	20.7	26.1	26	150	64
September	31.7	21.0	26.4	33	153	50
October	31.9	21.3	26.6	48	157	60
November	31.4	21.3	26.4	65	155	65
December	31.2	21.3	26.2	106	151	106
Year	30.8	21.1	26.0	1697	1741	1269

Tmax = maximum temperature; Tmin = minimum temperature; Tm = medial temperature; P_p = precipitation; PE = potential evapotranspiration; RE = real (actual) evapotranspiration.

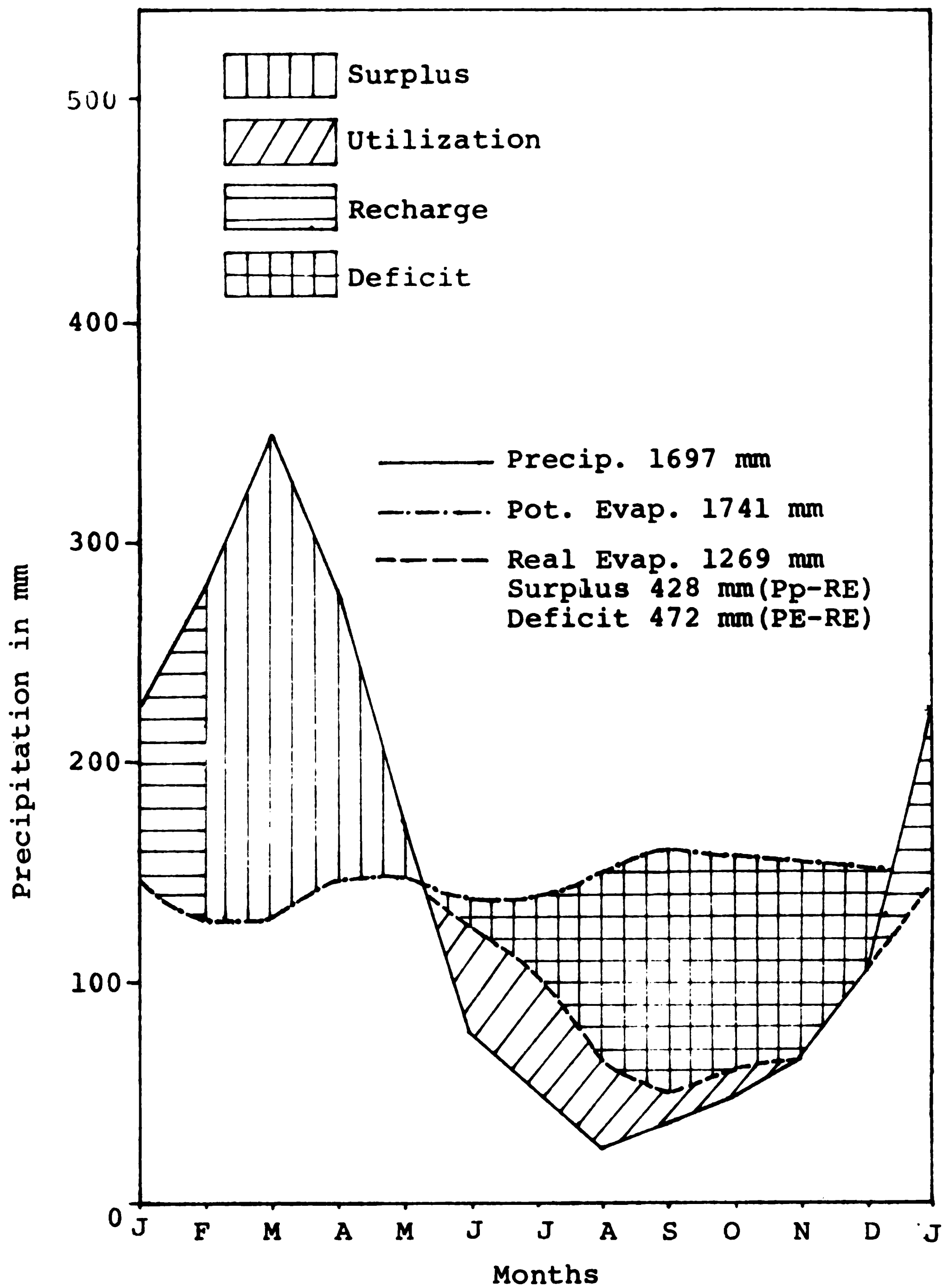

Figure 2. Hydrological Balance Registered at the Metereological Station at Altamira State of Pará, Brazil, for the period 1931-1967.

Survey Staff, 1951) and Manual de Metodo de Trabalho de Campo (Sociedade Brasileira de Ciência do Solo, 1973). The samples were then analyzed for physical, chemical, and mineralogical properties as described in the next section. The results of the field studies of each profile follows Figure 3 of the diagrams of profiles and altitude.

Profile 1

Classification in Brazil: RED YELLOW PODZOLIC ALICO[1] low activity clay, moderately drained, moderate A horizon, sandy/gravelly,[2] medium texture, semi-evergreen forest phase, plain relief, substrata plinthic.

Location: Municipality of Altamira, State of Pará; 19.6 km from Xingu River (Belo Monte) in direction to Maraba, to the left side of the highway, and 56.3 km before the Anapu River is reached.

Situation and Slope: Pit on the top of an elevation with 0-0.5% slope.

Altitude: 80 meters.

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[1]ALICO means Al^{+++} saturation greater than 50%, in Brazil.

[2]Follows the Brazilian criteria for gravelly materials according to Manual de Metodo de Trabalho de Campo (Sociedade Brasileira de Ciência do Solo, 1973), that is related to amount of coarse fragments (2-20 mm).

.very gravelly--has greater than 50 percent.
.gravelly--ranges from 15 to 50 percent.
.with gravel--ranges from 8 to 15 percent.

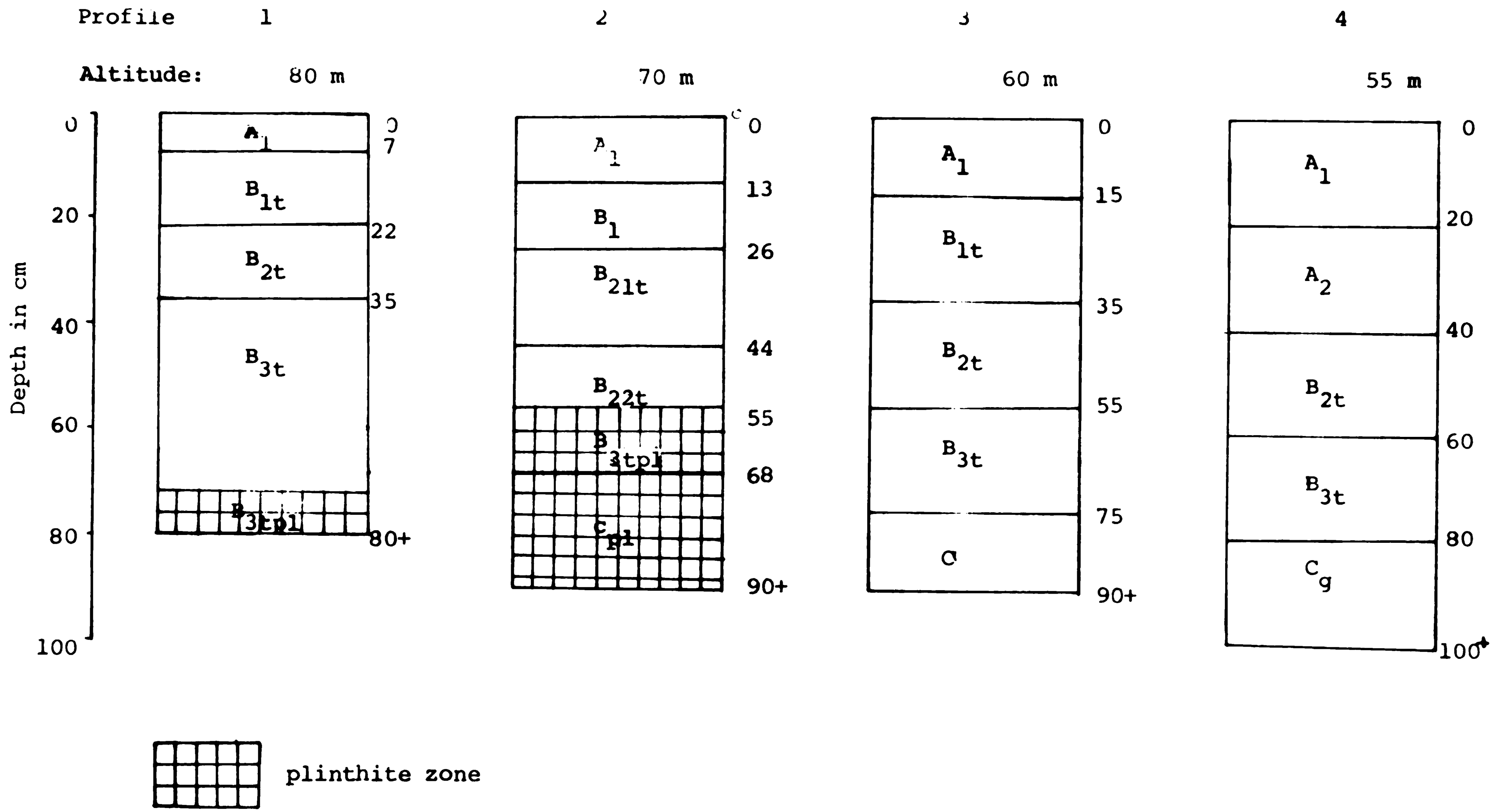

Figure 3. Scaled Diagrams of the Profiles Studied, with Altitudes in Meters.

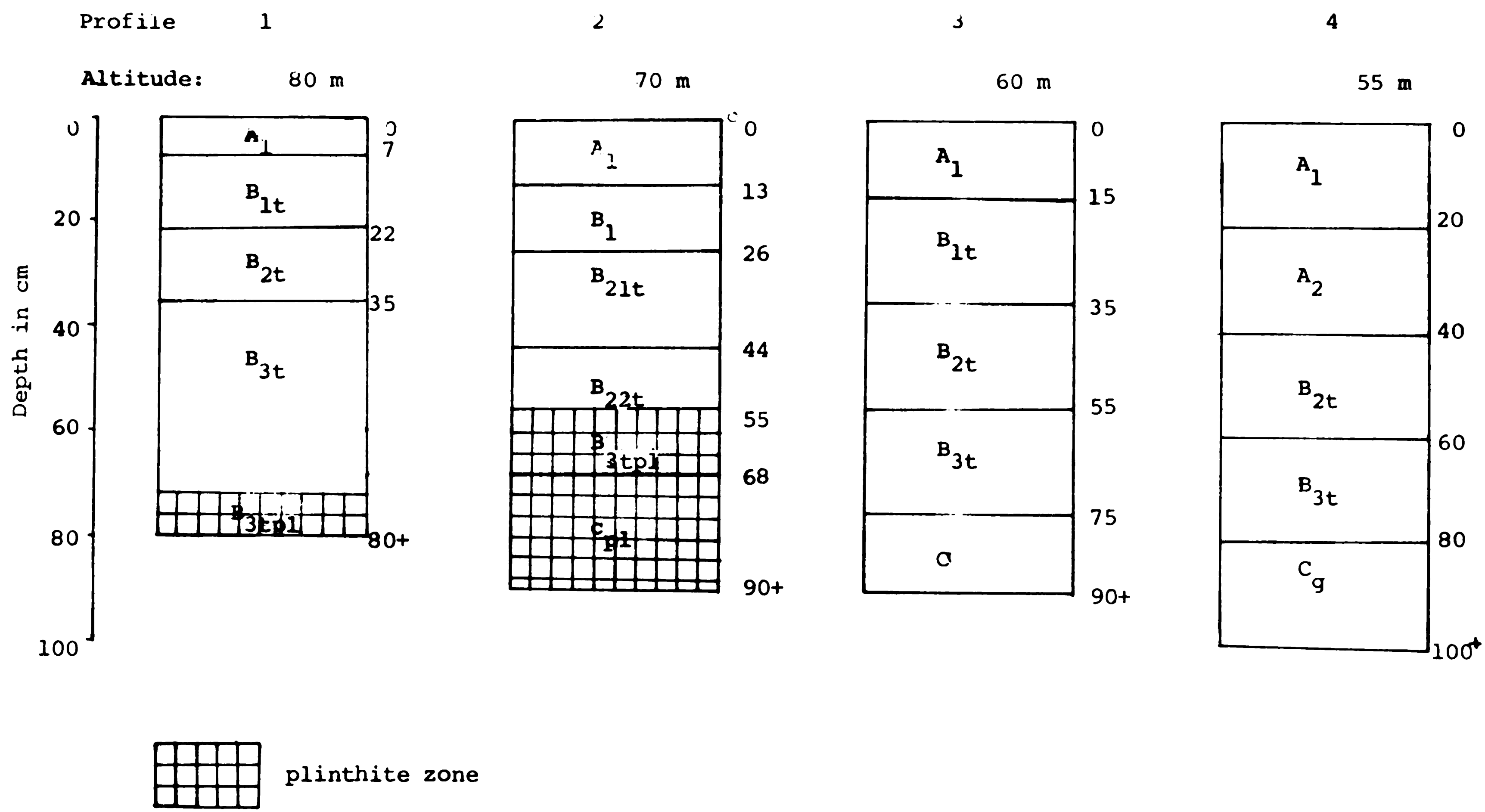

Figure 3. Scaled Diagrams of the Profiles Studied, with Altitudes in Meters.

Parent Material: Product of gneiss and migmatite-granite decomposition.

Relief: Level on the top of elevation.

Erosion: Slight laminar.

Drainage: Moderately drained.

Vegetation: Semi-evergreen forest.

A_1 - 0 - 7 cm, grayish brown (10 YR 5/2); sandy loam with gravel[3]; moderate fine to medium granular and moderate very fine to fine subangular blocky; many fine pores; slightly hard, friable, slightly plastic and non-sticky; clear smooth boundary.

B_{1t} - 7 - 22 cm, yellowish brown (10 YR 5.5/4); gravelly sandy loam; weak fine to medium subangular blocky with aspect of massive moderately coherent "in situ"; common fine pores; moderate common discontinuous clay skins; hard, very friable, plastic and very stickly; gradual smooth boundary.

B_{2t} - 22 - 35 cm, yellowish brown (10 YR 5/6), few fine distinct red (10R 4/6) mottles; gravelly sandy clay loam; weak fine to medium subangular blocky with aspect of massive moderately coherent "in situ"; common fine pores, moderate common discontinuous clay skins; hard, very friable, plastic and very sticky; abrupt wavy boundary.

B_{3tpl} - 35 - 80 cm+, brownish yellow (10 YR 6/8), red (2.5 YR 4/8), pale brown (10 YR 6/3) variegated with few coarse prominent brown (10 YR 5/3) mottles; clay; many fine pores; weak few discontinuous clay skins; 40% plinthite; hard, very friable, plastic and sticky.

Remarks: (a) A magnifying lens (10x) was used to check clay skins.

(b) The plinthite present is a noncontinuous phase.

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[3]See footnotes in Profile 1, page 23.

(c) The B_{2t} horizon contains some iron concretions.

(d) Roots: abundant at A_1, common at B_{1t}, few at B_{2t} and rare at B_{3tpl}.

(e) Distribution of color at B_{3tpl}: brownish yellow 45%; red mottles 5%, brown 5% and pale brown 5%, and plinthite 40%.

(f) The B_{3tpl} presented small amounts of material weakly weathered that showed the presence of parent material nearby.

(g) pl designated a horizon with more than 5% plinthite.

Profile 2

Classification in Brazil: RED YELLOW PODZOLIC ALICO[4] plinthic, low clay activity, moderately drained, moderate A horizon, sandy/gravelly clay texture, semi-evergreen forest phase, gently undulating relief.

Location: Municipality of Altamira, State of Pará; 19.8 km from Xingu River (Belo Monte) in direction to Maraba, to the left side of the highway, and 56.1 km before the Anapu River is reached.

Situation and slope: Pit on lower 1/3 of the elevation with 5% of slope.

Altitude: 70 meters.

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[4]Ibid.

Parent Material: Product of gneiss and migmatite-granite decomposition influenced locally by reworked material.

Relief: Gently undulating.

Erosion: Slight to moderate laminar.

Drainage: Moderately drained.

Vegetation: Semi-evergreen forest.

A_1 - 0 - 13 cm, dark brown (10 YR 4.5/3); loamy sand; moderate, fine to medium, granular and moderate, very fine to fine, subangular blocky; many fine pores; soft, friable, nonplastic and nonsticky; clear smooth boundary.

B_{1t} - 13 - 26 cm, brown (10 YR 5/3); sandy loam with gravel[5]; weak, fine to medium, subangular blocky, with aspect of massive moderately coherent "in situ"; weak, few, discontinuous clay skins; slightly hard, friable, plastic and slightly sticky; gradual smooth boundary.

B_{21t} - 26 - 44 cm, yellowish brown (10 RY 5/4); sandy clay loam with gravel; weak fine to medium subangular blocky with aspect of massive moderately coherent "in situ"; common very fine pores; weak, few, discontinuous clay skins; slightly hard, friable, plastic and slightly sticky; gradual smooth boundary.

B_{22t} - 44 - 55 cm, yellowish brown (10 YR 5.5/6), few fine distinct yellowish red (5 YR 5/8) mottles, brown (10 YR 5/3) mottles; sandy clay with gravel; weak, fine to medium, subangular blocky, with aspect of massive moderately coherent "in situ"; common very fine pores; weak, few and discontinuous clay skins; slightly hard, friable, plastic and sticky; clear wavy boundary.

B_{3tpl} - 55 - 68 cm$^+$, pale brown (10 YR 6/3), brownish yellow (10 YR 6/8), yellowish red (5 YR 5/8), red (2.5 YR 4/6) variegated color; gravelly clay; weak, medium to coarse, subangular blocky, with aspect of massive moderately coherent "in situ"; common very fine pores; weak few discontinuous clay skins;

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[5]Ibid.

greater than 50% plinthite; slightly hard, friable, plastic and sticky; abrupt wavy boundary.

C_{pl} - 68 - 90 cm^+, pale brown (10 YR 6/3), brownish yellow (10 YR 6/8), red (2.5 YR 4/8), yellowish red (5 YR 5/8) variegated color; clay with gravel; common very fine pores; greater than 50% plinthite; hard, friable, plastic and sticky.

Remarks: (a) The plinthite present in a continuous phase.

(b) A magnifying lens (10x) was used to check clay skins.

(c) Roots: Many in A_1; common in B_{1t}; few in B_{21t} and rare in B_{3tpl} and C_{pl}.

(d) pl designates a horizon with more than 5% plinthite.

Profile 3

Classification in Brazil: GROUND WATER LATERITE ALICA[6] (with textural B) low clay activity, abruptic, imperfectly drained, moderate A horizon, gravelly medium texture/gravelly clayey, semi-evergreen forest phase gently undulating relief.

Location: Municipality of Altamira, State of Pará; 21.9 km from Xingu River (Belo Monte) in direction to Maraba, to the right side of the highway, and 52.4 km before the Anapu River is reached.

Situation and Slope: Road cut on lower 1/3 of the elevation with 5% of slope.

Altitude: 60 meters.

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[6] Ibid.

Parent Material: Product of granite decomposition influenced locally by reworked material of sandy clay nature.

Relief: Gently undulating.

Erosion: Slight laminar.

Drainage: Imperfect.

Vegetation: Semi-evergreen forest.

A_1 - 0 - 15 cm, brown (10 YR 5/3); sandy clay loam with gravel[7]; weak, fine to medium, subangular blocky; many fine and medium pores; slightly hard, friable, plastic and sticky; clear wavy boundary.

B_{1t} - 15 - 35 cm, yellowish brown (10 YR 5/4), common fine prominent strong brown (7.5 YR 5/6) mottles, few fine prominent black (5 YR 2/1) mottles; gravelly clay; moderate, fine to medium, angular blocky; common very fine pores; hard, firm, plastic and sticky; clear smooth boundary.

B_{2t} - 35 - 55 cm, pale brown (10 YR 6/3), common medium prominent red (2.5 YR 5/6) mottles, common district prominent strong brown (7.5 YR 5/8) mottles; clay with gravel; moderate, medium, angular blocky; common very fine pores; weak, few, discontinuous clay skins; hard, firm, plastic and sticky; clear wavy boundary.

B_{3t} - 55 - 75 cm, pale brown (10 YR 6/3), red (2.5 YR 4/6), reddish yellow (5 YR 6/8) variegated color; clay with gravel; moderate, medium, angular blocky; few very fine pores; weak, fine, discontinuous clay skins; hard, friable, plastic and sticky; abrupt wavy boundary.

C - 75 - 90 cm+, very pale brown (10 YR 7/4), yellow (10 YR 7/6), red (2.5 YR 4/8), light brownish gray (10 YR 6/2) variegated color; clay with gravel; less than 5% plinthite, hard, friable, nonplastic and non-sticky.

Remarks: (a) A magnifing lens (10x) was used to check clay skins.

(b) The plinthite present is a noncontinuous phase.

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[7] Ibid.

(c) Roots: common in the A_1, few in the B_{1t} and B_{2t} and rare in the B_{3t}.

Profile 4

Classification in Brazil: PLANOSOL plinthic, low clay activity, imperfectly drained, moderate A horizon, medium/clay with gravel texture, semi-evergreen forest of the bottom valley phase, level relief.

Location: Municipality of Altamira, State of Pará; 53.2 km from Xingu River (Belo Monte) in direction to Maraba City, to the right of the highway, and 22.9 km before Anapu River is reached.

Situation and Slope: Road cut on level relief.

Altitude: 55 meters.

Parent Material: Clayey and sandy, recent or subrecent, colluvium-alluvium sediments.

Relief: level (plain).

Erosion: None.

Drainage: Poorly drained.

Vegetation: Semi-evergreen forest.

A_1 - 0 - 20 cm, grayish brown (10 YR 5/2.5); sandy loam; many fine and very fine pores; friable, and nonplastic and nonsticky; clear smooth boundary.

A_2 - 20 - 40 cm, brown (10 YR 5/3), few fine faint yellowish brown (10 YR 5/6) mottles; sandy loam; many fine and very fine pores; friable, nonplastic and nonsticky; clear smooth boundary.

B_{2t} - 40 - 60 cm, pale brown (10 YR 6/3); common fine faint yellowish brown (10 YR 5/4) mottles; sandy clay loam with gravel,[8] common fine and very fine pores; friable, plastic and slightly stickly; abrupt smooth boundary.

B_{3t} - 60 - 80 cm, very pale brown (10 YR 7/4), common fine prominent red (10 R 4/6) mottles, few fine distinct grayish brown (10 YR 5/2) mottles; sandy clay with gravel; less than 5% plinthite; friable, plastic and slightly sticky; abrupt smooth boundary.

C_g - 80 - 100 cm+, light gray (10 YR 7/1); many medium prominent red (2.5 YR 4/6) mottles; gravelly sandy clay; friable, plastic and sticky.

Remarks: (a) The plinthite is present in a noncontinuous phase.

(b) The profile was very wet.

(c) Roots: common in the horizons A_1, A_2, and B_{2t}, few in the B_{3t} and rate in the C_g.

Laboratory Studies

The soil samples were air dried, crushed and passed through a 2 mm sieve.

The fraction greater than 2 mm was separated into 20-2 mm (cascalho) and (calhaus) greater 20 mm fractions. The part less than 2 mm comprised the air dried fine earth.

Physical Analyses[9]

Granulometric analyses: by sedimentation in a Koettgen cylinder, using NaOH as the dispersion agent and

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[8] Ibid.

[9] The chemical and physical analyses were done by the laboratory of the Serviço Nacional de Levantamento e conservação de Solos (S.N.L.C.S.) da Empresa Brasileira de Pesquisa Agropecuaria (E.M.B.R.A.P.A.), Rio de Janeiro, Brazil.

shaking in high rotation. Four fractions were separated according to the classification of the International Method, and using 0.05 mm as upper limit of silt. They are: 2.0-0.2, 0.2-0.05, 0.05-0.002 and less than 0.002 mm.

Natural clay or clay dispersed by water: is the percentage of clay obtained by shaking with distilled water.

Flocculation degree: was obtained by comparing natural clay content with clay content (total) after dispersion with NaOH, by the following formula

$$\frac{\text{total clay} - \text{clay dispersed by water}}{\text{total clay}} \times 100$$

Moisture equivalent: was determined by the method of Briggs and McLane, centrifuging the moistened earth at 1000g for 40 minutes.

Chemical Analyses[10]

Organic carbon, C: was determined by oxidation of the material with potassium bichromate, 0.4 N (method of Tiurin).

Total nitrogen, N: was determined by digestion with sulphuric acid, catalyzed with copper and potassium sulphate. After transformation of all N into ammonia, it was collected in a solution of 4% boric acid and titrated with 0.01 N HCl.

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[10]Ibid.

pH-H_2O and pH-KCl: were determined potentiometrically using a soil paste with ratio of soil to water or salt solution of approximately 1:1, using a glass electrode.

Available phosphorus, P: was extracted with a solution of 0.050 N HCl and 0.025 N H_2SO_4 (North Carolina). The phosphorus was colorimetrically determined by reducing of the phosphorous molybdate complex with ascorbic acid, in presence of the bismuth salt.

H_2SO_4(d=1.47) soluble fine earth: under a reflux cooler, 2 g of air dried fine earth were boiled for an hour with 50 ml H_2SO_4, d=1.47. After boiling, the material is cooled, diluted and filtered into a receiver of 250 ml capacity.

a. SiO_2: The residue of the sulphuric acid treatment is boiled for half an hour with 200 ml of 5% Na_2CO_3. The mixture is filtered, and in a measured part of the filtrate, the dissolved silica is precipitated by an excess of concentrated H_2SO_4 and heated in a sand bath until smoking. The silica is determined colorimetrically.

b. Al_2O_3, total aluminum: 50 ml of the filtrate from the sulphuric acid treatment are used for the determination of total aluminum subsequent to the separation of heavy metals by the addition of an excess of 30% NaOH. An aliquot of this filtrate is gradually neutralized with HCl and the aluminum determined volumetrically with EDTA.

c. Fe_2O_3, total iron: was determined on 50 ml aliquot of the filtrate of the sulphuric acid treatment by the bichromate method, using diphenylamine as the indicator and tin chloride as the reducing agent.

d. TiO_2: was determined in the filtrate of the sulphuric acid treatment by the colorimetric method of H_2O_2, after elimination of the organic material by heating with several drops of concentrated $KMnO_4$.

e. P_2O_5, total phosphorus: was determined colorimetrically on the filtrate of the sulphuric acid treatment, by reduction of the phosphorous molybdate complex with ascorbic acid in the presence of bismuth salt.

Values Ki (SiO_2/Al_2O_3 ratio), Kr ($SiO_2/(Al_2O_3+Fe_2O_3)$ ratio) and Al_2O_3/Fe_2O_3: were calculated on a molecular basis from the data obtained from sulphuric treatment. It is assumed that Al and Fe are determined totally with the sulphuric acid treatment as described above. The data for these two constituents therefore represent the sums of the portions of Fe and Al occurring in exchangeable form, the portions occurring as free sesquioxides--including concretions--and the portions that are constituents of the silicate clay minerals. The determined Si comprises all that of the silicate clay minerals and also that which is present in free colloidal form. Quartz and other primary minerals are not, however, attacked, even when of clay-size.

The determination of the Ki and Kr on the fine earth fraction generally gives the same results as the internationally used determination on the clay fraction (Vettory, 1959). The Kr may be slightly different if concretions are present (Sombroek, 1966).

Exchangeable metallic cations:

a. The sum of exchangeable metallic cations, S: S represents the sum of the separately determined Ca^{++}, Mg^{++}, K^{+} and Na^{+}.

b. Exchangeable calcium, Ca^{++}, magnesium, Mg^{++}, and aluminum, Al^{+++}: Extractant was a normal solution of KCl at a proportion 1:10. An aliquot of this solution is used for the determination of exchangeable Al^{+++} by titration of the acidity using Brometymol blue as the indicator. The same aliquot is subdivided into two equal portions, for determining Ca^{++} and $Ca^{++} + Mg^{++}$ by EDTA.

In fact, the aluminum (Al^{+++}) determination gives the "active acidity." Experience at SNLCS has however shown that the exchangeable aluminum, determined colorimetrically with aluminon after extraction with 1 N KCl is practically equal to the active acidity.

c. Exchangeable potassium, K^{+}, and sodium, Na^{+}: are determined flame photometrically directly in the percolate of 0.05 N HCl.

Potential acidity, exchangeable, $H^{+} + Al^{+++}$: is determined by extraction with normal calcium acetate at pH 7 and titration of the resultant acidity with 0.1 N NaOH using phenolphtalein as the indicator.

This value represents the "potential acidity." It includes the "active acidity," or the exchangeable aluminum, Al^{+++}. H^{+} alone represents the pH-dependent acidity.

The exchangeable H^{+}: is calculated by subtracting exchangeable Al^{+++} from the $H^{+} + Al^{+++}$.

Cation Exchange Capacity, T(CEC): Not determined separately but obtained by the addition of S (page 35) and $H^{+} + Al^{+++}$ (page 35). As such, it is equivalent to the cation exchange capacity according to the NH_4OAC method at pH 7.

$$T(CEC) = S+H^{+} + Al^{+++}$$

Base saturation, BS: is obtained by formula,

$$BS = 100S/T(CEC)$$

Aluminum saturation percentage: $100Al^{+++}/Al^{+++}+S$

Mineralogical Analyses

The coarse fragments,[11] The >20 mm and 20-2.0 mm, and sands (coarse and fine), were studied mineralogically. Identification of mineral species was by optical methods (Fry, 1933; Winchell and Winchell, 1959), using a polarizing microscope and counting the species over lined millmetered plates or lined millmeter paper. Amounts less than 0.5% by weight are indicated as "trace," tr.

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[11] The analyses of sands and coarser fragments were done by Professor Franklin dos Santos Antunes.

Some chemical microtests (Feigl, 1954) were made for some opaque or weathering minerals. Qualitative analyses and estimation of dominance of mineralogical components for coarse fractions, >20 mm and 20-2.0 mm.

Sand fractions (coarse and fine),[12] obtained by granulometric analysis, were divided in two other samples with different densities by heavy liquid separations, using bromoform with density 2.83 and a Brogger funnel.

The heavy minerals are concentrated in the group whose density is greater than 2.83 and the other fraction, with density less than 2.83 are where quartz and feldspars are concentrated with other constituents when present.

The sample separation by density facilitates, the counting and morphological description and allows heavy mineral identifications whose percentages are very small in the sands of these soils.

After homogenizing, the description and the counting of the mineral species are conducted using a stereoscopic microscope. Mineral identification was verified by petrographic microscope with transmitted light (Fry, 1933; Winchell and Winchell, 1959).

Clay fractions and X-ray diffraction: Three methods were used: first clay samples were x-rayed without any pretreatment, second they were x-rayed after removing the organic matter and free iron oxides, and third they were

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[12] Ibid.

x-rayed after treatment with acid NH_4-oxalate. The removal of iron oxide was done by Dithionite-Citrate System Buffered with Sodium Bicarbonate as proposed by Mehra and Jackson (1960), and the acid ammonium oxalate treatment is as modified by McKeague and Day (1966).

X-ray diffractometer: A Norelco X-ray unit with wide-range goniometer, and Brown recorder, was adjusted to 20 milliamperes at 35 kilovolts and used for scanning parallel oriented samples on glass slides.

The X-ray tube contained a tungsten filament and a copper target. A nickel filter was used to filter out radiation of shorter wavelengths than the copper Kα1 radiation of 1.54 A°.

To obtain the necessary measurements, the goniometer was set at a scanning speed of 2°(2θ) per minute, and the sample was rotated to 28° (2θ).

a. Without any pretreatment four grams of soil (8g for A_1 of profile 2, because it has very low clay content) were suspended in distilled water, mixed thoroughly, allowed to sediment for 24 hours, and pipetted onto a clean glass slide and air dried at room temperature. The dried material was then subjected to x-ray diffraction analysis.

b. After removing the organic matter and free iron oxides

1. Removal of organic matter: Used about 4g of soil (less than 2 mm) and added 4 ml of distilled water to the sample to bring the soil water ratio to 1:1 (8g for A_1 of profile 2, because it has very low clay content). Five ml of 30% hydrogen peroxide solution was then added to the sample to oxidize the organic matter. A further addition of 5 ml hydrogen peroxide was also done. The sample was heated (digested) on the hot plate (about 70°C) for 15 minutes. Heating above this temperature caused decomposition of the hydrogen peroxide. The excess of liquid was evaporated to a thin paste (approx 1:1 ratio), but not to dryness. Distilled water was added to the sample to dilute the hydrogen peroxide present and it was evaporated again to about 1:1 ratio and then centrifuged for 20 minutes at 7,000 rpm. The supernatant liquid was decanted and the sample was washed twice with distilled water and centrifuged. At the end of each washing, the supernatant was discarded (Kunze, 1965).

2. Removal of free iron oxides: With dithionite citrate, 40 ml of 0.3 M sodium citrate and 5 ml of 1 N sodium bicarbonate were added to the wet soil. Four grams of soil were used except for A_1 of profile 2, because it has very low clay content, 8 g were used. The suspension was carefully warmed to 75-80°C in a water bath, about 1g of sodium dithionite (sodium "hydrosulfide" $Na_2S_2O_4$) was added to the suspension, it was stirred continuously for about one minute, and occasionally during a period of 15

minutes. After this, the suspension was cooled and cen fuged. The supernatant was decanted and the sample was washed twice with distilled water and centrifuged. At the end of each washing, the supernatant was discarded. Only sample B_{3tp1} from profile 1 needed additional treatment with sodium dithionite, because after first treatment the supernatant remained yellow.

With acid ammonium oxalate; 200 ml of 0.2M acidified ammonium oxalate solution* (the pH of the solution had been adjusted to 3.0 with oxalic acid) were added to 2g of oven-dried, less than 2 mm soil (in plastic bottles) except for A_1 of profile 2, because its very low clay content, 4g were used. The suspension was then shaken continuously for 4 hours in the reciprocating shaker. The suspension was centrifuged. The supernatant was decanted and the sample was washed twice with distilled water and centrifuged. At the end of each washing, the supernatant was discarded.

Separation of clay fractions and preparation of slides: After treatments above, the soil sample was put in a 400 ml bottle, and after sodium carbonate (Na_2CO_3) was added until pH 9 and it was shaken for 24 hours in the reciprocating shaker. After this dispersion, the suspension

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*McKeague and Day (1966) have shown that ammonium oxalate at pH 2.0 and 3.0 can extract approximately the same amount of Al and Fe, but pH 4.2 extracted somewhat less Fe and Al from most of the samples they tested. However, pH 3.0 caused less breakdown of silicate minerals than pH 2.0.

was transferred to a 1,000 ml sedimentation cylinders graduated at 100 ml intervals, through a 300 mesh screen. The volume was completed with distilled water, stirred, and the suspension allowed to stand for 24 hours. At the end of this time, according to the depth determined by Stokes law for less than 2μ clay, the suspension above this was siphoned into a bottle. Then a portion of the suspension was pipetted onto a glass slide placed over two leveled glass rods. The slide was allowed to air dry overnight and then subjected to x-ray diffraction analysis.

Laboratory and Field Methods for Plinthite Identification

The methods by Wood and Perkins (1976a) and Daniels, Perkins et al. (in press), were only partially used.

In the field, red mottles and plinthite were measured together.

In the laboratory, the samples were soaked in water for 2 hours; also 15 cycles of drying and rewetting, were used.

IV. RESULTS AND DISCUSSIONS

Physical Properties

The distribution of the separates (coarse fragments, sand, silt, and clay) in four profiles is given in Table 3.

Amounts of coarse fragments are less than 22 percent, and they increase from the surface to the lower horizons. In the greatest amounts are in the two surface horizons of profiles 1 and 3, and in the smallest amount is in the lowest horizon of profile 3.

The distribution of the silt in profile 1 showed a tendency to increase and in profile 4 to decrease with depth. Its percentage ranges from 12 to 23.

The clay contents increase from the surface to lower horizons, in all cases. From an examination of each profile, it is evident that there was an accumulation of clay in the lower horizon of the sola. Clay movement was evident by clay skins present in the subsoil of all profiles. Some researchers have also found that the clay content of similar soils decreases below a maximum in the B horizon, in the Amazon Region (Falesi, 1972 and Sombroek, 1966).

Table 3.--Some Physical Properties of the Soils Studied.

Horizon		Air Dry Sieves			Granulometric analysis (NaOH)				Natural Clay %	Degree of Floc-culation %	% silt / % clay	Moisture equiva-lent
Symbol	Depth cm	>20 mm	20.2 mm	<2 mm	2-0.2 mm	0.2-0.05 mm	0.05-0.002	<0.002 mm				
						Profile 1						
A_1	0-7	3	10	87	45	32	12	11	6	45	1.09	10
B_{1t}	7-22	0	16	84	32	32	19	17	13	24	1.12	15
B_{2t}	22-35	1	16	83	36	23	18	23	3	87	0.78	16
B_{3tpl}	35-80+	0	3	97	18	15	23	44	0	100	0.52	27
						Profile 2						
A_1	0-13	0	7	93	46	36	10	8	6	25	1.25	8
B_{1t}	13-26	0	10	90	39	32	14	15	13	13	0.93	12
B_{21t}	26-44	0	12	88	34	28	14	24	0	100	0.58	16
B_{22t}	44-55	2	15	83	31	21	13	35	0	100	0.37	19
B_{3tpl}	55-68	2	18	80	29	18	12	41	0	100	0.29	22
Cpl	68-90+	0	8	92	22	16	15	47	0	100	0.32	25
						Profile 3						
A	0-15	0	14	86	27	28	19	26	19	27	0.73	18
B_{1t}	15-35	0	18	82	17	21	19	43	0	100	0.44	24
B_{2t}	35-55	0	8	92	16	15	17	52	0	100	0.33	28
B_{3t}	55-75	0	9	91	16	14	17	53	0	100	0.32	27
C	75-90+	0	13	87	18	9	22	51	0	100	0.43	26
						Profile 4						
A_1	0-20	0	6	94	34	33	21	12	11	8	1.75	12
A_2	20-40	0	6	94	32	29	22	17	16	6	1.29	14
B_{2t}	40-60	0	9	91	29	26	20	25	24	4	0.80	16
B_{3t}	60-80	0	12	88	27	21	16	36	0	100	0.44	20
C_g	80-100+	0	22	78	33	13	13	41	0	100	0.32	22

Table 3 shows considerable differences among these soils: depth to clay greater than 40 percent is 35 cm, 55 cm, 15 cm, and 80 cm, respectively, from profile 1 to 4; degree of flocculation of clay varies from 4 to 100 percent and depth to flocculation greater than 85 percent is 22 cm, 26 cm, 15 cm, and 60 cm, respectively, from profile 1 to 4; and the percentage of silt/clay ratio varies from 1.75 to 0.29 and decreases with depth in each profile, but the maximum is 1.09, 1.25, 0.73 and 1.75 in profile 1 to 4.

Moisture equivalent is consistent with clay content. It varies from 8 (8% clay to 28 (52% clay).

Chemical Properties

Table 4 shows the pH, available P, and exchangeable cations of the profiles studies. The pH values, percent exchangeable bases and available P of the four profiles, were quite low. In each case there was not much variation with depth. Only profile 4 showed a slightly higher pH, available P, and base saturation in comparison to the others.

Some investigators have used pH values as a measure of the approximate degree of base saturation, but at a given pH it may differ in soils of similar origin as has been demonstrated by Pierre and Scarseth, 1931.

In all profiles the exchangeable hydrogen predominates in the exchange complex. The second most abundant exchangeable cation is Al^{+++}, except in profiles 1 and 4

Table 4.--Some Chemical Properties (pH, exchangeable cations, and available P) of the Soils Studied.

Horizon: Symbol	Horizon: Depth (cm)	pH: H_2O	pH: KCl	Exchangeable cations (meq/100g soil): $Ca^{++}+Mg^{++}$	K^+	Na^+	S(Sum)	Al^{+++}	H^+	T(CEC)	Base saturation $\frac{100S}{T(CEC)}$	Al^{+++} Saturation $\frac{100Al^{+++}}{Al^{+++}+S}$	P (ppm)
Profile 1													
A_1	0-7	4.9	3.4	0.8	0.07	0.02	0.9	0.6	2.3	3.8	24	40	3
B_{1t}	7-22	4.7	3.6	0.4	0.06	0.02	0.5	0.6	2.2	3.3	15	55	<1
B_{2t}	22-35	4.7	3.7	0.6	0.06	0.02	0.7	0.5	1.8	3.0	23	42	<1
B_{3tpl}	35-80+	4.6	3.7	0.5	0.10	0.03	0.6	0.7	2.0	3.3	18	54	<1
Profile 2													
A_1	0-13	5.0	3.5	0.7	0.09	0.02	0.8	0.4	2.8	4.0	20	33	4
B_1	13-26	4.6	3.4	0.3	0.05	0.02	0.4	0.6	2.1	3.1	13	60	1
B_{21t}	26-44	4.4	3.4	0.3	0.04	0.03	0.4	0.8	2.0	3.2	13	73	<1
B_{22t}	44-55	4.5	3.5	0.3	0.04	0.03	0.4	0.9	2.0	3.3	12	69	<1
B_{3tpl}	55-68	4.4	3.5	0.3	0.05	0.03	0.4	1.0	1.9	3.3	12	71	<1
Cpl	68-90+	4.7	3.8	0.4	0.04	0.02	0.5	1.0	2.1	3.6	14	67	<1
Profile 3													
A_1	0-15	4.5	3.8	0.2	0.05	0.05	0.3	1.0	2.7	4.0	8	77	1
B_{1t}	15-35	4.6	3.8	0.2	0.05	0.04	0.3	1.3	2.7	4.3	7	81	<1
B_{2t}	35-55	4.6	3.9	0.2	0.04	0.03	0.3	1.4	2.7	4.4	7	82	<1
B_{3t}	55-75	4.5	3.9	0.3	0.05	0.04	0.4	1.4	2.5	4.3	9	78	<1
C	75-90+	4.6	3.9	0.3	0.05	0.05	0.4	1.3	1.8	3.5	11	76	<1
Profile 4													
A_1	0-20	5.2	4.2	0.9	0.05	0.04	1.0	0.2	2.2	3.4	29	17	3
A_2	20-40	5.2	4.1	0.9	0.05	0.12	1.1	0.3	2.1	3.5	31	21	2
B_{2t}	40-60	5.0	4.0	0.9	0.08	0.07	1.1	0.6	2.1	3.8	29	35	2
B_{3t}	60-80	4.9	3.9	0.8	0.07	0.05	0.9	1.0	1.7	3.6	25	53	2
Cg	80-100+	5.0	4.0	0.9	0.07	0.06	1.0	0.9	1.7	3.6	28	47	3

where Ca^{++} + Mg^{++} was greater. Too much aluminum saturation for good plant growth is common. Profile 4 was not classified as "alico."[1] Although profile 1 and 2 had surface horizons low in Al^{+++} saturation, those profiles were classified as "alico" because their B horizons had an average of greater than 50 percent Al^{+++} saturation. Profile 3 is the highest in Al^{+++} saturation and CEC values but has the lowest base saturation.

The generally low cation exchange capacity varies little, from 3.0 to 4.4 m.e./100 grms of soil.

Table 5 shows some other chemical data for these profiles. Organic carbon and nitrogen are very low in each case and decrease with depth in all profiles.

The acid soluble silica/alumina ratios are pretty close to 2 in each profile. These figures are consistent with kaolinite contents of the clay fractions.

Amazon Yellow Latosols have high SiO_2/Al_2O_3 ratios near 2 (Falesi, 1972; Sombroek, 1966), whereas the Latosols from the central part of Brazil show lower ratios, around 1 (Freitas, 1970). This shows that the Amazon soils, including the ones in this study, are not the most weathered soils of Brazil.

The acid soluble Al_2O_3/Fe_2O_3 ratios of profile 2 reflect the relatively lower amounts of Fe_2O_3 in that profile.

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[1]This Brazilian term designates Al^{+++} saturation greater than 50 percent.

Table 5.--Some Chemical Properties (carbon, nitrogen and acid soluble components) of the Soils Studied.

Horizon Symbol	Depth cm	C %	N %	C/N	H_2SO_4 (d=1.47) Acid soluble five earth % SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	SiO_2/Al_2O_3 (Ki)	SiO_2/R_2O_3 (Kr)	Al_2O_3/Fe_2O_3
						Profile 1						
A_1	0-7	0.84	0.09	9	4.9	4.0	1.0	0.28	0.02	2.08	1.80	6.22
B_{1t}	7-22	0.41	0.06	7	8.5	7.0	1.4	0.37	0.02	2.07	1.83	7.80
B_{2t}	22-35	0.36	0.05	7	11.1	9.1	1.5	0.44	0.02	2.07	1.88	9.49
B_{3tpl}	35-80+	0.26	0.04	7	25.9	22.5	4.7	0.57	0.02	1.96	1.73	7.50
						Profile 2						
A_1	0-13	0.73	0.08	9	3.9	3.0	0.7	0.22	0.02	2.21	1.92	6.68
B_{1t}	13-26	0.41	0.05	8	7.0	5.4	0.8	0.30	0.02	2.21	2.02	10.58
B_{1t}	26-44	0.36	0.05	7	11.1	8.8	1.3	0.40	0.02	2.14	1.96	10.65
B_{22t}	44-55	0.32	0.04	8	15.8	13.3	1.5	0.44	0.02	2.02	1.88	13.87
B_{3tpl}	55-68	0.33	0.04	8	17.8	15.5	2.0	0.46	0.02	1.95	1.80	12.16
Cpl	68-90+	0.22	0.04	6	22.4	19.5	2.6	0.53	0.02	1.95	1.80	11.73
						Profile 3						
A_1	0-15	0.50	0.05	10	11.9	9.5	2.2	0.58	0.02	2.13	1.86	6.75
B_{1t}	15-35	0.45	0.05	9	18.5	16.6	3.9	0.64	0.02	1.89	1.65	6.67
B_{2t}	35-55	0.44	0.04	11	22.7	20.0	4.6	0.70	0.02	1.93	1.68	6.81
B_{3t}	55-75	0.37	0.05	7	23.8	20.7	4.1	0.74	0.02	1.96	1.74	7.93
C	75-90+	0.22	0.02	11	27.7	24.2	5.2	0.74	0.02	1.95	1.71	7.30
						Profile 4						
A_1	0-20	0.41	0.04	10	5.9	4.5	1.4	1.17	0.03	2.23	1.86	5.01
A_2	20-40	0.31	0.03	12	7.9	6.2	1.7	1.05	0.03	2.17	1.84	5.74
B_{2t}	40-60	0.34	0.03	11	11.8	9.1	2.0	1.06	0.03	2.21	1.93	7.14
B_{3t}	60-80	0.25	0.04	6	15.7	12.9	2.3	1.10	0.03	2.07	1.86	8.78
Cg	80-100+	0.21	0.03	7	18.6	15.3	3.0	1.06	0.04	2.07	1.84	7.78

Mineralogical Properties

Coarse fragments (greater than 20 mm only in profiles 1 and 2; and 20-2 mm in all profiles as shown in Table 6): Quartz was the dominant primary constituent in both fractions. The grains look like quartzite fragments when crushed. Some horizons presented iron oxide concretions with inclusions of quartz. Greater than 20 mm fractions in B horizons have more ferruginous concretions than quartz. Plates of mica in ferruginous clay fragments in the B_{2t} and B_{3t} horizons of profiles 1 and 2 were noted in the 20-2 mm fractions.

Sands (2-0.2 mm and 0.2-0.05 mm as shown in Table 7).

Heavy fractions (d>2.83): Heavy fractions were composed by heavy minerals resistant to weathering such as: zircon, ilmenite, and magnetite among others. One exception was the B_{21t} horizon of the profile 2, that showed a small amount of biotite (6.7%). A lithologic discontinuity could be inferred from this factor or perhaps preservation of a less resistant mineral in concretions could have occurred.

Iron concretions are also common secondary components of the coarse sands in the heavy fractions, particularly those from the better drained profiles 1, 2, and 3 are commonly the most abundant constituents of the heavy fractions. These are less abundant in the light fraction of the coarse sands and in the heavy fractions of the fine sands. Ferruginous clay fragments may also occur in the lighter sand fractions of profiles 1 and 3.

Table 6.--Mineralogical Analyses, Coarse Fragments.

Profile 1

A_1 >20 mm

broken quartz, showing signs of crushing, reddish grains due to iron oxide.

20-2 mm

Large percentage of transparent and milky quartz, less reddish grains due to iron oxide; several grains show signs of crushing; subrounded grains of hematite, ferruginous concretions; fragments of clay-ferruginous material, red, several with inclusions of transparent quartz; fragments of clay-milky material; rare goethite concretions; rare fragments of coal and roots.

B_{1t} 20-2 mm

Large percentage of quartz, crushed grains, reddish due to iron oxide; rounded ferruginous concretions; fragments of the clay-iron material with inclusion of transparent quartz; rare fragments of coal; creamy clay material with spots (stained by iron oxide).

B_{2t} >20 mm

Ferruginous concretions; crushed quartz, reddish grains due to iron oxide, the grains look like fragments of quartzite.

Table 6.--Continued.

	20-2 mm Large percentage of quartz, crushed grains; reddish due to iron oxide; fragments of the iron-clayey material with inclusions of quartz; material with clayey aspect, white and red mottles; rare ferruginous concretions; fragments of the iron-clay material with inclusions of very small plates (blades) of weathering mica.
B_{3tpl}	20-2 mm White and milky quartz, several of them are crushed; fragments of the iron-clayey material with inclusions of quartz; fragments of the iron-clayey material with inclusion of plates (blades) of weathering mica; fragments of the material with clayey aspect with white and red mottles.
	Profile 2
A_1	20-2 mm Large percentage of quartz, some grains are crushed and the majority are colored by iron oxide; rounded ferruginous concretions with inclusion of quartz; rare fragments of detritus; rare fragment of coal.
B_1	20-2 mm The same as above.

Table 6.--Continued.

B_{21t}	20-2 mm Large percentage of quartz, some grains are crushed and the majority are colored by iron oxide; rounded ferruginous concretions with inclusions of quartz; rare grains of quartz are rounded and subrounded.
B_{22t}	>20 mm Ferruginous concretions (like Bir horizon); quartz colored by iron oxides. 20-2 mm Large percentage of quartz, several grains are crushed, the majority are of milky appearance, and some are colored by iron oxides; ferruginous concretions, some are rounded with inclusions of quartz; fragments of iron-clayey material, some with inclusions of quartz, others with inclusion of plates (blades) of weathering mica. Observation: The crushed grains of quartz look like fragments of quartzite.
B_{3tpl}	>20 mm Ferruginous concretions with few quartz grains included (look like Bir horizon); crushed quartz colored by iron oxide (look like fragments of quartzite). 20-2 mm The same as above.

Table 6.--Continued.

Cpl	20-2 mm
	Quartz, the majority of the grains have a milky appearance, many crushed (some of them look like fragments of quartzite); ferruginous concretions, and some are rounded; rare rounded and subrounded grains of quartzite; rare fragments of iron-clayey material with inclusions of quartz; rare fragments or mottled iron-clayey material.
	Profile 3
A_1	20-2 mm
	Large percentage of quartz, many grains are colored by iron oxide, when crushed look like quartzite fragments; few grains of milky quartz or quartzite like fragments. Presence of fragments of quartz with appearance of secondary origin. Some grains of quartz subrounded. Some fragments of red clayey-iron material, with inclusions of crushed quartz and transparent quartz not crushed.
B_{1t}	20-2 mm
	Milky-quartz like, crushed, grains colored by iron oxide; fragments of ferruginous material with inclusion of crushed quartz.
B_{2t}	20-2 mm
	Crushed milky quartz-like, crushed quartz spotted (stained) by iron oxide; fragments of ferruginous

Table 6.--Continued.

	material with inclusions of crushed milky-quartz like; rare ferruginous concretions.
B_{3t}	20-2 mm
	The same as above.
C	20-2 mm
	Crushed milky-quartz like, fragments of ferruginous material some with inclusion of quartz; fragments of clayey-iron material with red and white color (mottles). This material is not consistent.
	Profile 4
A_1	20-2 mm
	Large percentage of quartz, the majority are milky-quartz like, some look like quartzite fragments, others slightly colored by iron oxide; rare ferruginous concretions with inclusions of quartz.
A_2	20-2 mm
	Large percentage of quartz, the majority are milky-quartz like, many of them crushed, some look like quartzite fragments, other grains slightly colored by iron oxide.
B_{2t}	20-2 mm
	The same as above.
B_{3t}	20-2 mm
	Large percentage of quartz, some grains crushed, some look like quartzite fragments. The majority

Table 6.--Continued.

	of grains are milky-quartz like; some ferruginous concretions.
Cg	20-2 mm
	Large percentage of quartz, many grains milky-quartz like, some slightly colored by iron oxides, some grains crushed, look like quartzite fragments.

Table 7.--Mineralogical Analyses, Sands.

Horizon	Heavy Fraction (d>2.83)	% by Weight	Medium and Light Fraction (d<2.83)	% by Weight
		Profile 1		
		Coarse Sand (2-.2 mm)		
A_1	Ferruginous concretions	51.9	Quartz	88.0
	Ilmenite (magnetic) and magnetite	25.0	Ferruginous concretions	7.1
	Quartz	17.8	Clay-ferruginous concretions	4.8
	Apatite and zircon	5.0		
	Epidote	x		
B_{1t}	Ferruginous concretions	94.0	Quartz	88.0
	Ilmenite and magnetite	3.1	Ferruginous concretions	7.2
	Zircon and apatite	2.0	Clay-ferruginous concretions	4.8
	Cyanite	x		
B_{2t}	Ferruginous concretions	50.0	Quartz	97.0
	Magnetic ilmenite and magnetite	26.7	Concretions	2.9
	Quartz	23.3		
B_{3tpl}	Ferruginous concretions	100.0	Quartz	80.0
	Magnetite	x	Clay-ferruginous concretions	20.0
	Ilmenite	x	Clay concretions	x

x means trace--less than 5 percent.

Table 7.--Continued.

Horizon	Heavy Fration (d>2.83)	% by Weight	Medium and Light Fraction (d<2.83)	% by Weight
		Fine Sand (.2-.05 mm)		
A_1	Magnetic ilmenite and magnetite	86.8	Quartz	91.0
	Quartz	10.4	Ilmenite	8.5
	Zircon and apatite	2.7	Detritus	x
	Muscovite	x	Ferruginous concretions	x
	Rutile	x		
	Ferruginous concretions	x		
B_{1t}	Magnetic ilmenite and magnetite	80.0	Quartz	81.8
	Quartz	18.0	Clay-ferruginous concretions	9.6
	Apatite and zircon	2.0	Ilmenite	8.5
	Muscovite	x	Clay-milky concretions	x
	Tourmaline	x		
B_{2t}	Magnetic ilmenite and magnetite	79.0	Quartz	89.0
	Quartz	18.7	Clay concretions	
	Zircon	2.0	Clay-ferruginous concretions	
	Apatite	x	Ilmenite and detritus	3.5
	Rutile	x		
	Muscovite	x		
	Iron oxide	x		
B_{3tpl}	Ferruginous concretions	80.0	Quartz	43.9
	Quartz	10.0	Clay-ferruginous concretions	35.2
	Ilmenite and magnetite	10.0	Clay-milky concretions	17.0
			Ilmenite	3.0

Table 7.--Continued.

Horizon	Heavy Fraction (d>2.83)	% by Weight	Medium and Light Fraction (d<2.83)	% by Weight
	Profile 2			
	Coarse Sand (2-.2 mm)			
A_1	Quartz	40.0	Quartz	100.0
	Magnetite	30.0	Detritus	x
	Ilmenite	29.0		
B_1	Hematite-ferruginous concretions	95.0	Quartz	100.0
	Ilmenite	5.0		
B_{21t}	Ferruginous concretions	80.0	Quartz	100.0
	Ilmenite	10.0	Detritus	x
	Biotite	6.7		
	Zircon	2.4		
B_{22t}	Ferruginous concretions	85.0	Quartz	100.0
	Ilmenite	10.0		
	Magnetite	5.0		
	Quartz	x		
	Clay-ferruginous concretions	x		
B_{3tpl}	Ferruginous concretions	84.0	Quartz	100.0
	Ilmenite	7.2	Coal	x
	Quartz	3.5	Ferruginous concretions	x
Cpl	Ferruginous concretions	48.0	Quartz	100.0
	Quartz	29.6		
	Ilmenite	22.0		

Table 7.--Continued.

Horizon	Heavy Fraction (d>2.83)	% by Weight	Medium and Light Fraction (d<2.83)	% by Weight
		Fine Sand (.2-.05 mm)		
A_1	Ilmenite and magnetite	63.0	Quartz	100.0
	Quartz	31.0	Detritus	x
	Zircon and apatite	6.0		
	Concretions	x		
B_1	Ilmenite and magnetite	57.0	Quartz	94.0
	Quartz	33.0	Ilmenite	6.0
	Apatite and zircon	9.0		
B_{21t}	Ilmenite and magnetite	57.0	Quartz	94.0
	Quartz	30.0	Ilmenite	6.0
	Apatite and zirconite	7.0		
	Ferruginous concretions	5.0		
B_{22t}	Quartz	46.0	Quartz	95.0
	Magnetite and ilmenite	26.0	Ilmenite and concretions	5.0
	Ferruginous concretions	23.0		
	Zircon and apatite	6.0		
	Rutile	x		
B_{3tpl}	Quartz	41.0	Quartz	98.0
	Ferruginous concretions	27.0	Concretions	2.0
	Magnetite and ilmenite	20.0		
	Zircon and apatite	12.0		
Cpl	Quartz	45.0	Quartz	94.0
	Ilmenite and magnetite	30.0	Ilmenite	6.0
	Ferruginous concretions	21.0		
	Zircon and apatite	4.0		
	Rutile	x		
	Biotite	x		

Table 7.--Continued.

Horizon	Heavy Fraction (d>2.83)	% by Weight	Medium and Light Fraction (d<2.83)	% by Weight
		Profile 3		
		Coarse Sand (2-.2 mm)		
A_1	Ferruginous; limonite goethite, and principally hematite concretions	90.0	Quartz	100.0
			Detritus	
			Biotite	x
	Magnetic ilmenite, zircon and staurolite	10.0	Chestnut lamellae	x
B_{1t}	Ferruginous; hematite, limonite, and goethite concretions	85.0	Quartz	98.0
	Ilmenite, magnetite, and zircon	10.0	Ferruginous concretions, biotite, clayey concretions	2.0
	Quartz	5.0	Detritus	x
B_{2t}	Ferruginous; limonite and goethite concretions	90.0	Quartz	98.0
	Ilmenite, magnetite, and quartz	10.0	Clay-ferruginous concretions	2.0
			Detritus	x
B_{3t}	Ferruginous; limonite hematite and goethite concretions	90.0	Quartz	98.0
	Ilmenite, magnetite, and zircon	5.0	Ferruginous concretions	2.0
	Quartz	5.0	Detritus	x
C	Ferruginous; limonite, hematite, and goethite concretions	100.0	Quartz	90.0
			Ferruginous concretions and clay-ferruginous concretions	10.0

Table 7.--Continued.

Horizon	Heavy Fraction (d>2.85)	% by Weight	Medium and Light Fraction (d<2.83)	% by Weight
		Fine Sand (.2-.05 mm)		
A_1	Ilmenite and magnetite	50.0	Quartz	100.0
	Hematite	20.0	Detritus	x
	Quartz	20.0		
	Zircon and apatite	10.0		
	Detritus	x		
	Epidote	x		
B_{1t}	Quartz and biotite	48.0	Quartz	98.0
	Ferruginous: limonite hematite, and goethite concretions	40.0	Clay-ferruginous concretions	2.0
			Detritus	x
	Ilmenite and magnetite	10.0	Biotite	x
	Zircon and apatite	2.0		
B_{2t}	Ferruginous: limonite, hematite, and magnetite concretions	50.0	Quartz	90.0
			Clay-ferruginous concretions	10.0
	Quartz	30.0		
	Ilmenite	17.0		
	Zircon, biotite and apatite	3.0		
B_{3t}	Ferruginous: limonite, hematite, and goethite concretions	60.0	Quartz	90.0
			Clay-ferruginous concretions	10.0
	Ilmenite and magnetite	20.0	Detritus	x
	Quartz	15.0		
	Zircon	5.0		

Table 7.--Continued.

Horizon	Heavy Fraction (d>2.83)	% by Weight	Medium and Light Fraction (d<2.83)	% by Weight
C	Limonite, hematite, and goethite concretions	75.0	Quartz	90.0
	Ilmenite	10.0	Hematites concretions and clay-ferruginous concretions	10.0
	Quartz	10.0		
	Zircon	5.0		
		Profile 4		
		Coarse Sand (2-.2 mm)		
A_1	Ilmenite	83.0	Quartz	100.0
	Magnetite	10.0	Detritus	x
	Zircon	5.0	Ilmenite	x
	Hematite concretions	2.0		
A_2	Ilmenite	85.0	Quartz	100.0
	Magnetite	10.0	Detritus	x
	Zircon	3.0		
	Ferruginous concretions	2.0		
B_{2t}	Ilmenite	85.0	Quartz	100.0
	Magnetite	5.0	Detritus	x
	Zircon	5.0		
	Quartz	5.0		
B_{3t}	Ilmenite	90.0	Quartz	100.0
	Magnetite	5.0	Magnetite and Muscovite	x
	Zircon	5.0		
	Hematite	x		
Cg	Ilmenite	88.0	Quartz	100.0
	Magnetite	5.0	Detritus	x
	Quartz	5.0	Ilmenite	x
	Zircon	2.0		

Table 7.--Continued.

Horizon	Heavy Fraction (d>2.83)	% by Weight	Medium and Light Fraction (d<2.83)	% by Weight
		Fine Sand (.2-.05 mm)		
A_1	Ilmenite	65.0	Quartz	100.0
	Magnetite	25.0	Detritus	x
	Zircon	5.0	Opal	x
	Quartz	5.0	Ilmenite	x
A_2	Ilmenite	60.0	Quartz	99.0
	Magnetite	25.0	Magnetite and ilmenite	1.0
	Zircon	10.0	Detritus	x
	Quartz	5.0		
B_{2t}	Ilmenite	70.0	Quartz	99.0
	Magnetite	10.0	Ilmenite and magnetite	1.0
	Zircon	10.0	Detritus	x
	Ferruginous concretions	5.0		
	Quartz	5.0		
B_{3t}	Ilmenite	85.0	Quartz	99.0
	Zircon	10.0	Ilmenite and magnetite	1.0
	Magnetite	5.0	Detritus	x
	Detritus	x		
Cg	Ilmenite	88.0	Quartz	100.0
	Magnetite	5.0	Detritus	x
	Zircon	5.0	Ilmenite	x
	Quartz	2.0		

Iron concretions were not observed in the A horizon of the profile 2, even in the heavy sand fractions. In profile 4, the most poorly drained, iron concretions were observed only in the heavy coarse sand of the A horizons and the heavy fine sand of the B_{2t} horizon.

Apatite is an infrequent heavy mineral observed in the coarse and fine sand fractions of the A_1 and B_{1t} horizons of profile 1; in the fine sand fractions throughout profile 2; and in the A_1, B_{1t}, and B_{2t} of profile 3. Biotite was also observed in the heavy fine fractions of the B_{1t} and B_{2t} horizons of profile 3.

Medium and light fractions ($d<2.83$). The medium and light fractions are the predominant components in both the coarse and fine sands.

More than 90 percent by weight of the medium and light fractions were quartz. Quartz could thus be considered the dominant constitutent of these sand fractions in all four profiles. However, small amounts of ilmenite were also observed in the fine sand fractions of profiles 1, 2, and 4.

Secondary products were found in the light fractions of some horizons only. Thus, iron concretions and ferruginous clay fragments were observed in the coarse sands of profile 1, iron concretions were observed in the coarse sands of the subsurface horizons of profile 3, and ferruginous clay fragments were observed in some of the fine sand fractions of the subsurface horizons of profiles 1 and 3.

Clays Fractions: For this purpose, only X-ray diffraction analyses of total clay fractions were used, from 9 of the 20 horizons in the four profiles. The results are tabulated in Table 8.

Two pretreatments were used: the first with dithionite-citrate-bicarbonate and the second using ammonium oxalate.

Besides the clay mineral characterization, the purpose of using these two treatments was to try to make some comparisons with the amount of the exchangeable Al^{+++} and acid soluble Fe_2O_3 on the differences in X-ray diffraction peak heights. Figure 4 shows X-ray tracings of total clay.

The dithionite treatment is supposed to dissolve much of the iron from amorphous as well as from crystalline materials and the oxalate treatment is supposed to dissolve only iron from amorphous materials. The height figures on the table refer to the scale of the X-ray diffraction recording charts.

The samples were X-rayed at three different times and they showed different peak intensities. Differences in intensities of X-ray diffractions (peak), probably are due to differences in amount of clay mineral, mineral particle orientation, and with the position of the mounted sample in the diffractometer.

The following comparisons and conclusions seem warranted: First, it was evident that all profiles were

Table 8.--Clay Contents, Selected Soil Analyses from Tables 2 to 4 and Heights of Kaolinite Diffraction Peaks of Clay Fraction With or Without Pretreatments.

						Dithionite-Citrate-Bicarbonate Treatment, Peak Heights or Ratios				Ammonium-Oxalate Treatment, Peak Heights or Ratios		
Pro-file No.	Hori-zon	Total Clay %	Degree of Flocc-ulation %	Al^{+++} sat. %	Acid sol. Fe_2O_3 %	No treat-ment (a)	After treat. (b)	c_1 = b-a	c_1/b[1]	After treat. (d)	c_2 = d-a	c_2/d
1	B_{3tpl}	44	100	54	4.70	53	100	57	0.52	59	+6	0.11
						100	180	80	0.44	87	-13	-0.13*
						60	125	65	0.52	61	+1	+0.02
2	A_1	8	25	33	0.70	50	70	20	0.29	20	-30	-0.60*
						71	90	19	0.26	29	-42	-0.59*
						47	65	18	0.28	19	-28	-0.60*
	B_{21t}	24	100	73	1.30	17	75	58	0.77	--	--	--
						27	115	88	0.77	--	--	--
						17	80	63	0.77	--	--	--
	Cpl	47	100	67	2.60	37	96	59	0.61	50	+13	0.26
						53	127	74	0.58	64	+11	0.17
						37	100	63	0.63	48	+11	0.23
3	A	26	27	77	2.20	68	100	32	0.32	32	-36	-0.53*
						88	125	37	0.30	39	-49	-0.56*
						64	92	28	0.30	31	-33	-0.52*
	B_{2t}	52	100	82	4.60	25	85	60	0.71	49	+24	0.49
						35	129	94	0.73	61	+26	0.43
						27	98	71	0.72	46	+19	0.41
4	A_1	12	8	17	1.40	70	35	-35	-0.50[1]	23	-47	-0.66*
						108	39	-69	-0.64[1]	29	-79	-0.73*
						77	32	-45	-0.58[1]	21	-56	-0.73*
	B_{2t}	25	4	35	2.00	15	33	18	0.55	21	+6	0.27
						22	55	33	0.42	30	+8	0.27
						17	44	27	0.61	24.5	+7.5	0.31
	Cg	41	100	47	3.00	23	121	98	0.81	45	+22	0.49
						31	142	111	0.78	61	+30	0.49
						23.5	108	84.5	0.78	45	+21.5	0.48

[1] c_1 was divided by (a) only in the A horizon of profile 4, because it was the higher peak.

*c_2 was divided by (a) because it was the higher peak.

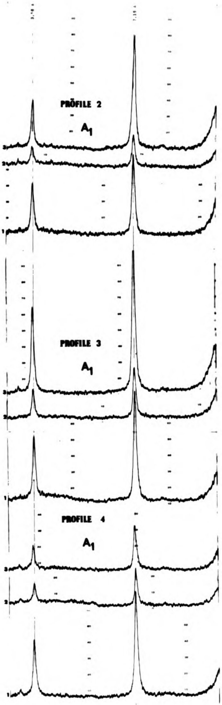
Figure 4. X-ray Tracings of Total Clay of Selected Soil Horizons.

Treatment: (1) No Treatment

(2) Ammonium Oxalate Procedure

(3) Dithionite-Citrate System Buffered With Sodium Bicarbonate

Scale factor is 32 for all tracings.


PROFILE 2
A_1
PROFILE 3
A_1
PROFILE 4
A_1

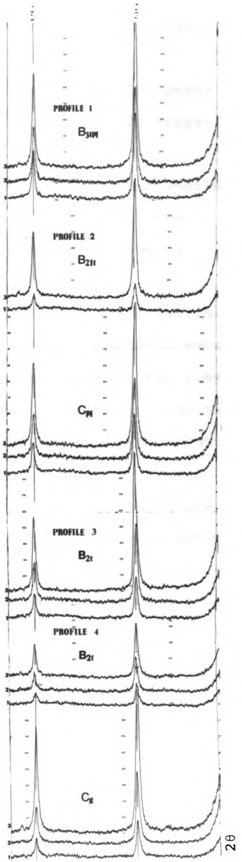

PROFILE 1
$B_{3t(P)}$
PROFILE 2
B_{21t}
C_{P}
PROFILE 3
B_{2t}
PROFILE 4
B_{2t}
C_g
2θ

Figure 4

Figure 4. X-ray Tracings of Total Clay of Selected Soil Horizons.

Treatment: (1) No Treatment

(2) Ammonium Oxalate Procedure

(3) Dithionite-Citrate System Buffered With Sodium Bicarbonate

Scale factor is 32 for all tracings.

mostly kaolinitic (greater than 95%), as shown by diffraction peaks at 7.18A°.

After dithionite treatment, the diffraction peaks showed greater heights than they did after oxalate treatment in all horizons.

After oxalate treatment, the A horizons had smaller diffraction peaks than with no treatment. That is the reason for their negative ratios in the last column of Table 8.

The A_1 of the profile 4 showed the highest kaolinite peak with no treatment. This horizon had the smaller amount of exchangeable Al^{+++} saturation, 17 percent, and the clay had a low degree of clay flocculation, 8 percent. Even the dithionite treatment decreased the diffraction peak height of this sample.

The relative order of increase of the intensities of the kaolinite peaks in the subsurface horizons is about the same for the two treatments, but the dithionite treatment was most effective. The B_{2t} sample from profile 4 had the lowest peak height without treatment. Both treatments increased the peak heights more of this sample than would have been expected from its lack of flocculated clay, its low Al^{+++} saturation, and low soluble iron content.

<u>Plinthite Characterization</u>

A great limitation for plinthite characterization in the laboratory, was the amount of soil samples in undisturbed (natural) conditions. Even so, some conclusions can be made from the results of the slaking and fifteen wetting and drying cycles in the laboratory.

Table 9 shows the results of the distinction between red mottles and plinthite after slaking (being immensed in water for 2 hours) and the test of hardness after 15 drying and wetting cycles.

These tests should be made in the field, but it was impossible. For the slaking test, it does not make any difference. But for the drying and wetting cycles it probably does because the investigators mention that soil material hardens especially if it is exposed also to heat from the sun.

From the table it is evident that the most red material is actually plinthite in the better drained profiles (1 and 2), but they harden only after 15 cycles. Sanches (1973), has indicated from 5-10 cycles should be sufficient.

Classification of These Soils

Table 10 shows the classification of the soils in this study according to the systems of classification used in Brazil, FAO/UNESCO, and the U.S. Soil Taxonomy.

Currently, in soil surveys carried out by SNLCS in Brazil, plinthite has tentatively been considered necessary to quality for a Ground Water Laterite. But, probable some

Table 9.--Distinction Between Red Subsoil Mottles and Plinthite (in Laboratory).

Profile	Horizon	% of Red Material	Immersed in Water (Dry or Moist Sample) for 2 Hours				Hardness After 15 Cycles of Drying and Wetting of Plinthite or Red Mottles
			Plinthite		Red Mottles		
			% of Plinthite	% of Sample	% of Red Mottles	% of Sample	
1	B_2	5	0	0	100	5	no
	B_{3tpl}	45	85	38	15	7	hard
2	B_{22t}	5	0	0	100	5	no
	B_{3tpl}	55	>95	53	<5	2	hard
	Cpl	55	>95	53	<5	2	hard
3	B_2	10	0	0	100	10	no
	B_3	30	0	0	100	30	no
	C	25	<5	1	>95	24	no
4[a]							

[a]No laboratory test was made with profile 4 because undisturbed samples were not available.

Table 10.--Classification of the Soils According to the Systems Used in Brazil, FAO/UNESCO, and U.S. Taxonomy.

Profile	Classes of Soil Being Used in SNLCS/EMBRAPA/BRAZIL[a]	FAO/UNESCO (1973)	U.S. Taxonomy (1975)
1	Red Yellow Podzolic Alico,[b] low activity clay, moderate A, sandy/gravelly medium texture, substrata plinthic.	Plinthic Acrisols	Plinthic Paleudult fine-loamy, siliceous, isohyperthermic
2	Red Yellow Podzolic Alico, plinthic, moderately drained, moderate A, sandy/gravelly clay texture.	Plinthic Acrisols	Plinthudult, fine-loamy, siliceous, isohyperthermic
3	Ground Water Laterite Alico, (with textural B), low activity clay, abruptic, imperfectly drained, moderate A, gravelly medium/gravelly clay texture.	Ferric Acrisols	Aquic Paleudult, clayey, kaolinitic, isohyperthermic
4	Planosol plinthic, low activity clay, poorly drained, moderate A, sandy/medium with gravel texture.	Ferric Acrisols	Aquic Paleudult, fine-loamy, siliceous, isohyperthermic

[a]Phases can used too (vegetation, relief, stoniness, rockiness, etc.). SNLCS--Serviço Nacional de Levantamento e Conservação do Solo EMBRAPA-Empresa Brasileira de Pesquisa Agropecuaria.

[b]Definitions for terms "Alico" and gravel classification in Brazil--see footnotes of profiles descriptions.

of these soils already mapped could not be classified as Ground Water Laterite because tests for identifying plinthite and its measurements have not been done. For example, profile 3, was previously classified as a Ground Water Laterite in the field, because of the presence of red mottles. After laboratory tests it has less than 5 percent of what could be called plinthite. Likewise profile 4, called Planosol plinthic does not fit well into this class of soils. It also has less than 5 percent that could be called plinthite. These two soils show the evidence that plinthite develops more in better drained soil conditions.

Profile 1 was classified as Red Yellow Podzolic . . . substrata plinthic, due to presence of plinthite below 75 cm at the bottom of the Bt. Profile 2 is Red Yellow Podzolic plinthic, because plinthite is within that depth and occupies a large part of the B horizon.

In regards to the FAO/UNESCO system, all profiles fit into Acrisols. The plinthic soils are classified as plinthic Acrisols and the non-plinthic as Ferric Acrisols.

Finally, in U.S. Soil Taxonomy 3 profiles (1, 3, and 4) were classified as Paleudults because the clay content increased from the surface to the lower horizons. Profile 2 fits in Plinthudult, with plinthite as a continuous phase. The U.S. Taxonomy has not differentiated any subgroups for this great group. However, profile 2 could be classified as an Oxic Plinthudult, because it shows a high degree of clay flocculation and a low activity clay (after correction for carbon).

Bennema, 1964 indicated that one gram of carbon often is equal to approximately 4.5 millequivalents of cation exchange capacity. The equation for 100 grams of clay based on CEC and carbon (C) of a sample is:

$$\text{CEC 100 grams clay} = \text{CEC} - (\text{grms.Cx4.5}) \frac{100}{\%\text{clay}}$$

Current Land Uses

This sequence of soils has not had any agricultural use in the Amazon Region. However, Plinthic Paleudults and Aquic Paleudults, have been mapped in Sierra Leone, west Africa and some indications of their value for agricultural uses have been recognized (Odell et al., 1974). Plinthic Paleudults are used for both annual and perennial crops, such as: upland rice, maize, groundnuts, cassava, coffee, oil palm, and citrus. Dry season irrigation is desirable, but not feasible in most places. The Aquic Paleudults are used for swamp rice during the rainy season, with bunding and water control; and vegetables are grown during the dry season. With supplementary drainage a variety of crops can be grown.

At the family level, the Plinthic Paleudults in Sierra Leone are fine-loamy over clayey-skeletal, mixed, isohyperthermic. The Amazon soils are in the fine-loamy, siliceous, isohyperthermic family. The Aquic Paleudults are in the clayey, kaolinitic, isohyperthermic family, in both areas.

Plinthic Paleudults have also been mapped in Puerto Rico, but they are in oxidic, instead of siliceous, families. They present very severe limitations for cultivated crops.

Agricultural uses are not recommended for the Brazilian soils, because of the high investment that would be required and the large area of relatively better soils in the Amazon Region that could be so used.

Interpretations for Engineering Purposes*

These interpretations provide information about engineering properties of soils, Table 11; the suitability of soils as source materials, and the factors affecting various engineering uses of soils, Table 12. The soils also are related as to their degree of limitation for residences, recreational facilities, as well as farm crops, farm trees, structures for light industry, trafficways, and gardens, Table 13. The purpose of these interpretations is to give ideas about the potential uses for the soils represented in four profiles.

Estimated soil properties significant to engineering interpretations, are given in Table 11. Explanation of

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*Basically from guide for Interpretations for Engineering Uses of Soils by S.C.S.-U.S.D.A. and Michigan Agricultural Experiment Station.

Table 11.--Estimated Soil Properties Significant to Engineering.

Soil No.	Seasonal High Water Table	Horizon	USDA-Text	Unified	AASHO	Percent Less Than 3 Inches Passing Sieve				Reaction	Corrosivity Uncoated Steel
						No. 4 4.7 mm	No. 10 2.0 mm	No. 40 .42 mm	No. 200 .074 mm		
1	>90	0-7	sandy loam	S M	A-2-4	100	100	60-70	30-40	4.5-5.0	Low
		7-22	sandy loam	S M	A-2-4	100	100	60-70	30-40	4.5-5.0	Low
		22-35	sandy clay loam	S C	A-2-6	100	100	80-90	35-55	4.5-5.0	Mod
		35-80	clay	M H	A-7	100	100	90-100	75-95	4.5-5.0	M-H
2	>90	0-13	loamy sand	S M	A-2-4	100	100	50-75	15-30	4.5-5.0	Low
		13-26	sandy loam	S M	A-2-4	100	100	60-70	30-40	4.5-5.0	Low
		26-44	sandy clay loam	S C	A-2-6	100	100	80-90	35-55	>4.5	Mod
		44-55	sandy clay	S C	A-7	100	100	85-95	45-60	4.5-5.0	M-H
		55-68	sandy clay	S C	A-7	100	100	85-95	45-60	>4.5	H
		68-90	clay	M H	A-7	100	100	90-100	75-95	4.5-5.0	H
3	>30	0-15	sandy clay loam	S C	A-2-6	100	100	80-90	35-55	4.5-5.0	Mod
		15-35	clay	M H	A-7	100	100	90-100	35-55	4.5-5.0	H
		35-55	clay	M H	A-7	100	100	90-100	35-55	4.5-5.0	H
		55-75	clay	M H	A-7	100	100	90-100	35-55	4.5-5.0	H
		75-90	clay	M H	A-7	100	100	90-100	35-55	4.5-5.0	H
4	0[a]	0-20	sandy loam	S M	A-2-4	100	100	60-70	30-40	5.1-5.5	L-M
		20-40	sandy loam	S M	A-2-4	100	100	60-70	30-40	5.1-5.5	M
		40-60	sandy clay loam	S C	A-2-6	100	100	80-90	35-55	4.5-5.0	M-H
		60-80	sandy clay	S C	A-7	100	100	85-95	45-60	4.5-5.0	H
		80-100	sandy clay	S C	A-7	100	100	85-95	45-60	4.5-5.0	H

[a]Subject to flooding.

terms: Depth to seasonally high water table--Listed is the shallowest depth to which free water rises at least once a year, generally during the winter (in Amazon region this is about 6 months).

Depth from surface--the depths given in this column correspond to the top of the soil horizons.

USDA texture--the texture indicated corresponds to the textures given in the technical description of each soil profile of the sequence (USDA Handbook No. 18, SOIL SURVEY MANUAL).

Unified Classification[2]--The Unified Soil Classification system is based on identification of soils according to their texture and plasticity and their performance as engineering construction material (Corps of Engineers, U.S. Army, Technical memorandum No. 3-357, vol. 1, March, 1953). In this system, soil material is divided into 15 classes: 8 classes are for coarse-grained material (GW, GP, GM, GC, SW, SP, SM, SC), 6 for fine-grained (ML, CL, OL, MH, CH, OH), and 1 for organic material (Pt).

AASHO Classification[2]--Most highway engineers classify soil materials according to the system approved by the American Association of State Highway Officials. (Highway Research Board Proceedings of the 25th Annual Meeting,

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[2]Unified and AASHO classifications were taken from guide sheet 15--General relationship of systems used for classifying soil samples (USDA-Soils Memorandum--45 Rev. 2). Guide for Interpreting Engineering Uses of Soils.)

1945). This classification is based on the gradation, liquid limit, and plasticity index of the soil. Highway performance has been related to this system of classification. All soil materials are placed in seven principal groups. The groups range from A-1 (gravelly soils of high bearing capacity, the best soils for subgrades) to A-7 (clay soils having low strength when wet, the poorest soils for subgrades).

Percent of Material Passing Sieve[3]--The measured or estimated percentages of material passing the numbers 4, 10, 40, and 200 sieves are given for each major horizon. When there is very little gravel size material (No. 4 and 10 sieves) present, the percent passing the 200 sieve approximates the amount of silt and clay.

Soil Reaction--soil reaction or the intensity of soil acidity or alkalinity is expressed in pH--the logarithm of the reciprocal of the H-ion concentration. A pH of 7 is neutral, lower values indicate acidity and higher values show alkalinity.

Shrink-Swell Potential--indicates the volume change to be expected of the soil material with changes in moisture content. It is low in all cases.

Table 12, part A, presents a summary of the Engineering Interpretations for topsoils, sand, and gravel, or road fills.

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[3]Percent of Material Passing Sieve were taken from guide sheet 2 of the same Soils Memorandum 45 previously mentioned.

Table 12.--Engineering Interpretations.

Soils No.	(A) Suitability as Source of . . .		
	Topsoil	Sand and Gravel	Road Fill
1	Poor: coarse fragments; low organic matter content	Improbable source. Poor.	Fair: kaolinitic clay subsoil.
2	Poor: sandy; low organic matter content.	Improbable source. Poor.	Fair: kaolinitic clay subsoil.
3	Poor: coarse fragments; low organic matter content; high clay content.	Improbable source. Unsuited; no sand.	Fair: kaolinitic clay, wet
4	Poor: low organic matter content; seasonal high water table.	Improbable source. Unsuited; no sand.	Poor: poorly drained.
	(B) Soils Feature Affecting . . .		
	Local Roads and Streets	Reservoir Areas	Agricultural Drainage
1	Slight to moderate: clay substrata.	Plinthite, perched water.	Moderately well drained; perched water.
2	Moderate: clay subsoil.	Plinthite, perched water.	Moderately well drained; perched water.
3	Severe: wetness, subject to flooding.	High water table.	Imperfectly drained.
4	Severe: soils subject to flooding.	High water table.	Poorly drained.

Explanation of Items: Topsoil--The organic matter content, thickness, texture, and natural fertility of the surface layer determine the suitability of a soil for use as topdressing for slopes, road shoulders, and other earth structures that require a plant cover for protection. The rating terms used are: GOOD, FAIR, POOR, AND VERY POOR.

Sand and gravel--This column gives information about the soil as a possible source of sand and gravel for construction purposes. The ratings are: Probable source (GOOD, AND FAIR), AND IMPROBABLE SOURCE (POOR, AND UNSUITED).

Road fill--This column rates the soil material of the solum (surface layer and subsoil) and of the substratum. Road fill is subgrade material that is used to support the subbase and base, or surface course. Soil properties considered in making the ratings are soil texture and its effect on compressibility, shrink-swell potential, and moisture content. The suitability of a road fill depends largely on its texture, moisture content, and location. Normally wet, plastic, clay is rated poor for road fill, and sand is rated poor or fair, depending on its location. Sand is difficult to compact and needs close control of moisture during compaction.

Table 12, part B, summarizes soil features affecting local road or streets, reservoir areas, and agricultural drainage.

Explanation of Terms: Local roads and streets--The limitation ratings given in this column apply to use of soils for construction and maintenance of improved local roads and streets. Consist of: (1) underlying local soil material, whether cut or fill, that is called "the subgrade"; (2) the base material of gravel, crushed rock, lime-stabilized soil, or soil-cement-stabilized soil; (3) the actual road surface or street pavement that is either flexible (asphalt), rigid (concrete), or, in some rural areas, gravel with binder in it. Major factors considered are: soil drainage class, flooding hazard, slope, depth to water table, and shrink-swell potential.

Reservoir areas--consideration is given primarily to the sealing potential of the soil, but shallowness to bedrock and the susceptibility to overflow in flood plains are also considered; so the reservoir areas of farm ponds are adversely affected by rapid permeability, seepage, and flooding.

Agricultural drainage--Among the soil features listed are natural drainage, permeability of the soil in place, susceptibility to flooding, and the presence of a seasonal high water table.

Limitation of Soils for Town and Country Planning

These limitations are summarized in Table 13. The following explanations apply to that table.

Explanation of Items for: Residences--Residences refer to dwellings of three stories or less. They may be single houses or in a large subdivision. The limitations

Table 13.--Limitations of Soils for Town and Country Planning.

Soils No.	(A) Residences with . . .	
	Public or community sewage systems	Septic tank filter fields
1	Slight	Severe: moderately slow permeability in plinthite zone.
2	Slight	Severe: the same as above.
3	Severe: seasonal high water table.	Severe: seasonal high water table.
4	Severe: seasonal high water table; flooding.	Severe: seasonal high water table; flooding.

Soils No.	(B) Recreational facilities . . .		
	Campsites	Intensive play areas	Picnic grounds
1	Slight	Slight	Slight
2	Slight	Slight to moderate: slope.	Slight
3	Slight	Slight	Slight
4	Moderate: wetness.	Moderate: wetness.	Moderate: Wetness.

Table 13.--Continued.

Soils No.	(C) Other uses				
	Farm crops	Farm trees	Structures for light industry	Trafficways	Gardens
1	Severe: low natural fertility	Moderate	Moderate: high concrete corrosion	Slight	Moderate: low productivity
2	Severe: low natural fertility	Moderate	Moderate: high concrete corrosion	Slight	Moderate: low productivity
3	Very severe: low natural fertility; seasonal high water table.	Moderate to severe	Moderate: seasonal high water table.	Moderate: seasonal high water table.	Severe: seasonal high water table.
4	Very severe: low natural fertility; seasonal high water table; flooding.	Severe: low natural fertility; seasonal high water table; flooding.	Severe: seasonal high water table; flooding.	Severe: seasonal high water table; flooding.	Severe: seasonal high water table; flooding.

[a]For this section, the summer time (6 months, less amount of rain) was considered only because during the winter (6 months of strong rain) recreation is practically impossible in these soil types.

are rated for dwellings served by public or community sewage system and for dwellings that are served by septic tank filter fields. The significant soil properties are bearing strength, shrink-swell potential, depth to seasonal high water table, flood hazard, and slope. Flooding is a major limiting factor. If a septic tank filter field is required, a high water table and slow percolation rate are major limitations.

Increase in slope makes the soil less desirable for construction of sewage disposal fields. Slopes over 12 percent have severe limitations for the layout and construction of sewage disposal fields. Side-hill seepage is a problem on sloping areas. Very sandy soils may allow unfiltered effluent to enter and contaminate shallow water supplies. Clayey soils and soils with a high water table may become saturated during wet periods and prohibit proper functioning of the filter field.

Recreational facilities:[4] Campsites--are they suitable for tents and camping trailers. It is assumed that little site preparation is needed. Suitability for septic tanks is not a requirement. Soils properties that affect this use are depth to seasonal high water table, flood hazard, permeability, surface soil texture, and slope.

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[4]For this section, the summer time (6 months, less amount of rain) was considered only, because during the winter (6 months of strong rain) recreation is practically impossible in these soil types.

Intensive play areas--ratings apply to areas to be developed for playgrounds, athletic fields, and organized games such as volleyball and tennis. All areas are subject to heavy foot traffic. They require nearly level surfaces, good drainage, freedom from flooding during use periods, and a texture and consistence that provides a firm surface. Areas should be free of coarse fragments and rock outcrops.

Picnic grounds--ratings apply to areas to be used for picnic areas and extensive play areas. Ratings are based on soil features only and do not include other features such as presence of trees or ponds, which affect the desirability of a site. The same properties as for intensive play areas are significant, although wider variation within some properties can be permitted.

Other uses: Farm crops--soils are rated in terms of their limitations for common farm crops and pasture. Properties of the soil, erosion hazard, wetness hazard, climate, slope, and general fertility are items considered in this evaluation of the soils.

Farm trees--ratings apply to the use of trees for ornamental production. Available water capacity, depth to root restricting layers, and natural drainage are major factors in determining the limitation of the soil.

Structures for light industry--include buildings that are used for stores, offices, and small industries; none of which are more than three stories high nor require more than moderate bearing strength. It is assumed that sewage disposal facilities are available. The properties important in evaluating soils for this use are slope, depth to seasonal high water table, flood hazard, bearing strength, shrink-swell potential, and erosion potential.

Trafficways--refer to low-cost roads and residential streets. It is assumed that construction involves limited cut and fill and limited preparation of subgrades. The properties important in evaluating soils for such trafficways are slope, depth to seasonal high water table, flood hazard, shrink-swell potential, and traffic supporting capacity.

Gardens--include the production of both vegetables and flowers for homes. Properties important in evaluating soils for this use are productivity, depth to seasonal high water table, flood hazard, droughtiness, tilth, slope, erodibility, and permeability.

Soil Survey Interpretations in Brazil (For Reconnaissance Surveys)[5]

The soil survey interpretation system for reconnaissance surveys developing in Brazil comprise:

a. A list of properties of soils and environment, such as: mapped area, occurrence, climate, altitude, parent material and lithology, natural vegetation, relief, erosion, and so on;

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[5]Bennema; Beck and Camargo, 1964.

b. Soil limitations for plant growth and agricultural use;

c. Land capability classification.

Estimated degree and major kinds of limitations affecting farm uses shown in Table 14 are used as a guide for determining suitability classes of soils, under both Primitive and Developed Management. Explanations of the items considered are discussed next.

Estimation of Items: Deficiency of native fertility--in this case meaning chemical fertility, depends on:

1. The availability of the macro- and micro-nutrients in the soil, and

2. The absence or presence of toxic substances. Usually only soluble salts, and especially sodium salts, are regarded. Other important toxic substances, such as soluble aluminum and manganese, may depress the availability of some mineral nutrients. These toxicities are considered as part of point 1.

Deficiency of water--generally is determined as a function of the amount of available water to the plants and of the climatic conditions, especially, precipitation and transpiration. The climatological factors are the only factors of importance, in extreme cases as in the desert and in some super-humid areas, but in the other cases soil factories also have an influence.

Table 14.--Guide Table for Determining Suitability Class of Soils Under Both Primitive and Developed Management in Brazil.

	Limitation of Soils for Farm Uses				
Suitability Classes	Deficiency of Native Fertility	Deficiency of Water	Excess of Water	Susceptibility to Erosion	Use for Agricultural Machinery
			Management System, Primitive, A		
Good, G	None to slight	Slight and moderate	None and slight	None and slight	Slight
Fair, F	Moderate	Moderate	Slight to moderate	Moderate	Moderate
Restricted, R	Severe	Severe	Moderate to severe[x]	Severe	Severe
Inapt, I	Very severe	Very severe	Severe	Very severe	Very severe
			Management System, Develop, B (Without Irrigation)		
Good, G	None[1]	Slight[n] and moderate	Slight (1)	None[1]	None[1] Slight (1)
Fair, F	Slight (2)	Modernate[n]	Slight (2) Moderate (2),x	Slight (1)	Slight (2) Moderate (1)
Restricted, R	Moderate (2)	Severe[n]	Moderate[n]	Slight (2)	Moderate[n]
Inapt, I	Severe[n]	Very severe[n]	Severe[n]	Moderate[1]	Severe[n]

[x]Permitted limitation in this class of suitability, when the soils present susceptible to overflow.

[n]Without feasibility of improvement.

[1]Easily feasible, with restricted input of capital and technical know-how.

[2]Feasible, but with considerable capital or technical know-how (but still within the reach of economic possibility.

(1) and (2) These numbers with brackets indicate that limitations cannot be completely removed.

In well-drained soils this is especially the amount of available water which can be stored, and this amount depends on a set of single soil properties, among which are texture, kind of clay, carbon content and effective soil depth.

Excess of water or deficiency of oxygen--is mostly related to the drainage class, which is the result of climatological conditions (precipitation and evaporation), local relief, and soil properties. In soils with low water table the more important are: structure, permeability, and depth to a less permeable layer, if present. The depth of water table, in soils with high water table, is important too. It is evident that, in general, a direct relation must exist between drainage class and deficiency of oxygen, because the drainage classes are essentially defined in terms of excess of water. Some discrepancies may, however, exist in practice because the essential point in the classes of deficiency of oxygen is the reaction of plant-life, while in the drainage classes soil profile characteristics are taken to determine the drainage class. This relationship does not persist if the soil is artifically drained.

Susceptibility to erosion--consideration is given here to erosion by water, only. Susceptibility to erosion by water depends, besides climate, on topography and soil, also on the land use, and on the vegetation of the land. The standard for susceptibility to erosion is the erosion which would occur if the land would be used for cultivated agriculture, such as growing crops which are not soil protectors and neglecting to take measures to prevent erosion.

Use for agriculture machinery--This agricultural factor depends on slope, absence or presence of stones or rocks, absence or presence of extreme shallowness of the soil, at least if underlain by consolidated material or by material unfavourable if ploughed up, bad drainage conditions, and extreme in properties of the soil material, such as clayey texture with the presence of 2:1 layer silicate clays (often together with drainage conditions), organic soils, or loose sandy soils.

In the case of mechanization, it should be noted that an area which has no impediments to mechanization should have a minimum size to be of importance.

Table 15 lists the estimated degree and major kinds of limitations for farm uses of soils, and how these relate to suitability classes with primitive or developed management systems.

MANAGEMENT SYSTEM, PRIMITIVE, A

This system is characterized by using traditional methods of tiallage which reflect a low level of technical operational knowledge. There is no capital input (investment) for fertilizers and corrective applications, as well as for maintenance and improvement of soil conditions and of the tillage. The land use is not permament, because it

Table 15.--Estimated Degree and Major Kinds of Limitations Affecting Agricultural Uses by Management Systems, of the Soils.

Profile No.	Deficiency of Native Fertility		Deficiency of Water		Excess of Water		Susceptibility to Erosion		Use of Agricultural Machinery		Suitability Classes by Management Systems	
	A	B	A	B	A	B	A	B	A	B	A	B
1	Severe, low nutrient contents. <50% Al^{+++} sat.	Slight (2)	Slight	Slight	Slight	Slight	Slight	None[1]	Slight to moderate sand and gravel.	Slight (1)	R	F
2	Very severe, low nutrient contents; >50% Al^{+++} sat.	Moderate (2)	Slight	Slight	Slight	Slight	Slight to moderate	None[1]	Slight to moderate, sand and gravel.	Slight (1)	I	R
3	Very severe, low nutrient contents. >50% Al^{+++} sat.	Moderate (2)	None	None	Moderate, imperfectly drained.	Slight (2)	Slight	None[1]	Slight to moderate, gravel.	Slight (2)	R	F
4	Severe, low nutrients contents. <50% Al^{+++} sat.	Slight (2)	None	None	Severe, poorly drained.	Moderate (2)	None	None	Slight to moderate, sandy.	Slight (2)	R	F

Note: See footnotes to preceding figure.

is native fertility dependent, so when the production goes down, the land is abandoned for recuperation.

Animal power and only the more simple farm implements are used.

Suitability classes

CLASS 1--GOOD, G.

None of the soils of the sequence was classified in this class;

CLASS 2--FAIR, F.

None of the soils of the sequence was classified in this class;

CLASS 3--RESTRICTED, R.

The soil conditions present moderate limitations for growing a large number of climatically adapted crops. It is possible to foresee a medium harvest during the first years, but they rapidly decrease to a low level within a 10 year period; and

CLASS 4--INAPT, I.

The soil conditions present severe and very severe limitations for growing a large number of climatically adapted crops. It is possible to foresee low to very low harvest in the first years already.

MANAGEMENT SYSTEM, DEVELOPED, B (without irrigation).

This system employs a high level of technical-operational knowledge, including experimental data. There is a high input of capital for maintenance and improvement of soil conditions and of the tilth. If necessary and feasible, artificial drainage and erosion control are done as well as the employing of fertilizers, correctives of the acidity, insecticides, and herbicides. The tractor which includes the whole set of power-operated equipment is used.

Suitability classes

CLASS 1--GOOD, G.

None of the soils of the sequence was classified in this class;

CLASS 2--FAIR, F.

The soil conditions present <u>slight</u> limitations for growing a large number of climatically adapted crops. It is possible to foresee that <u>good</u> harvest can be obtained in most areas, but the option for crops, income maintenance, and a selection of management practices are restricted by one or more not feasible limitation of correction or can be partially corrected only;

CLASS 3--RESTRICTED, R.

The soil conditions present <u>moderate</u> limitations for maintenance of climatically adapted crops. The harvests are seriously reduced and the option for crops is very restricted by one or more limitations that cannot be removed;

CLASS 4--INAPT, I.

None of the sequence was classified in this class.

V. CONCLUSIONS

Four Ultisols of a soil sequence in the warm, humid tropics of Brazil were studied.

The parent material varied from granite-gneiss to relatively recent sandy-clay colluvium or alluvium sediments. In soils of the slopes, some reworked materials have had an influence in soil formation.

The soil sequence has been developed under very acid conditions. They are dystrophic and have low activity clays.

The low cation exchange capacity, low exchangeable calcium, magnesium, and potassium, low base saturation, and relatively high amounts of free iron oxides (as well as extractable Al^{+++}) all indicate strongly weathered soils. Variations among profiles in this sequence are accounted for by differences in topography and parent materials.

Coarse fragments are composed mostly of quartz and quartz is prevalent in the coarse and fine sands. Some horizons also contain iron concretions and ferruginous clay fragments.

Kaolinite is the predominant clay mineral (greater than 95%). This is consistent with the observations of

Sanches and Buol on well drained soils in the upper Amazon Basin in Peru.

Dithionite pretreatment was more effective than ammonium oxalate in removing coatings from the clays in the subsoil horizons. This is shown by greater increases in X-ray diffraction peaks of kaolinite, in comparison with no treatment.

In the A horizons dithionite normally increased the kaolinite peaks much less than in the B horizons in comparison with no treatment. The A_1 of profile 4 showed higher peaks with no treatment than with dithionite. In the A horizons ammonium oxalate decreased the kaolinite diffraction peaks, in comparison to no treatment. Increasing of the peak heights was associated with high percentages of Al^{+++} saturation and high degrees of clay flocculation.

Presence of plinthite was confirmed only in the two better drained soils. Thus, in the future during soil descriptions, better observations should be made by soil scientists where plinthite is suspected to be present. Plinthite must be separated from red mottles and the amount present measured or estimated.

Profiles 1, 3, and 4 were classified as Paleudults, due to the clay increase from the surface to the lower horizons. Profile 2 fits in Plinthudults, due to plinthite forming a continuous phase. The U.S. Taxonomy has not differentiated any subgroups for this great group. However, profile 2 could be classified as an Oxic Plinthudult, because it shows a high degree of clay flocculation and a low activity clay (after correction for carbon). Profile 1 is in the Plinthic Paleudult subgroup due to more than 5 percent Plinthite in a non-continuous phase. Profiles number 3 and 4 are in the Aquic Paleudults.

The soils with more restricted drainage (profiles 3 and 4), present moderate and severe limitations for agricultural uses. Under primitive management systems profiles 1 to 4 fit into restricted, inapt, restricted, and restricted classes. Under developed management systems they can improve only one class. Profiles 1 to 4 then fit into fair, restricted, fair, and fair classes, respectively.

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