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THESIS

SOILS OF THE COLOMBIAN LLANOS ORIENTALES

COMPOSITION AND CLASSIFICATION OF SELECTED SOIL PROFILES

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ABSTRACT

GUERRERO, RAMIRO. Soils of the Colombian Llanos Orientales - Composition and Classification of Selected Soil Profiles. (Under the direction of STANLEY WALTER BUOL).

Seven soil profiles of the Llanos Orientales (Eastern Plains) of Colombia, near Orocué and south of the Meta River, were selected to study their composition and classification. Additional samples of alluvial materials were taken within the same area to establish the mineralogical influence of wind-blown materials brought south of the Meta River by strong northeast-trade winds.

The area studied is representative of the tropical, treeless, non-flooded, savannas of Colombia. They are located approximately 4°50' north latitude and have an annual average temperature of 28°C and annually receive 1,734 mm of rainfall. The parent material for all soils were mixed alluvial acid sediments.

Within the soil profiles, clay content increased with depth, particularly the finer clay fraction ($<.2\mu$), but clay skins and argillic horizons were absent. Complete soil dispersion was possible only when the free iron was removed. Water-dispersible clay content decreased abruptly to less than 4 percent below the third horizon. Higher sand content in the soil profiles nearer the Meta River suggests greater influence of the wind blown sands, but mineralogical specie differences were not found to change with proximity to the river.

The soils are very acid, have a very low cation exchange capacity, very low base retention, low percent of base saturation, high amount of

exchangeable aluminum, and relatively high contents of free iron oxides, and organic carbon. Surface layers are very low in available phosphorus and low in micronutrient content.

Kaolinite was the predominant clay mineral in the very fine and fine clay fractions of selected horizons. Intergradient 2:1-2:2 clay minerals and pyrophyllite were present in most samples and minor amount of mica, feldspars and a "vermiculite-mica stratification" pattern were found in some subsoil samples. Quartz was predominant in the silt and sand fractions.

The chemical data and the absence of weatherable minerals in the upper horizons, but their presence in trace amounts in the bottom horizons, indicated advanced weathering of the soil solums. Depletion of bases and mineral transformation appear to be the main pedogenic processes. No relationship was found between water table level, soil color, free iron oxide content and plinthite-like formations.

According to the Comprehensive Soil Classification System - 7th Approximation, subsoil horizons meet the requirements for oxic horizons. Therefore, the soils are classed as Oxisols, although some intergrade to Ultic subgroups.

SOILS OF THE COLOMBIAN LLANOS ORIENTALES - COMPOSITION AND CLASSIFICATION OF SELECTED SOIL PROFILES

by

RAMIRO GUERRERO

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APPROVED BY:

Chairman of Advisory Committee

BIOGRAPHY

The author was born in Cali, Colombia, South America. He attended the Faculty of Agronomy of Palmira (National University) where he obtained the Degree of Ingeniero Agrónomo in 1950. After graduation, he worked in the Colombian Soil Survey Program for five years. In 1956, he spent nine months in the Center for Evaluation of Natural Resources, Río de Janeiro, Brazil, as an O.E.A. fellow. In 1958, he was appointed as Associate Edaphologist at the Instituto Colombiano Agropecuario, ICA (formerly DIA) in the Palmira Agricultural Experimental Station.

In 1961, he went to the Department of Soil Science in Cornell University for studies leading to the degree of Master of Science in 1963. From 1963 to 1968, he worked at the Tibaitatá Experimental Station (Bogotá) where he was promoted to Head of the Soil Section. Finally, in September of 1968, he was enrolled in the Graduate School of North Carolina State University at Raleigh. The author is married to the former Cecilia Arango and they have three children.

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Special acknowledgments are made to the Instituto Colombiano Agropecuario, I.C.A. for granting a leave of absence and to the Rockefeller Foundation whose fellowship enabled the author to pursue graduate studies at North Carolina State University at Raleigh.

The author also expresses his sincere gratitude to Dr. James M. Spain who served as Honorary Committee member and to Dr. Fernando Peñaranda C., for their encouragement to continue his education in the United States.

To the many other faculty, staff, and fellow graduate students of the Department of Soil Science, North Carolina State University at Raleigh, the author extends his thanks for their assistance and counsel. Specific appreciation is extended to Mr. Ellis Edwards and Mrs. Bertha Crabtree for their assistance in some laboratory work.

Finally, the author expresses deep appreciation to his wife, Cecilia, and children, Cecilia, Pilar and Ramiro, whose patience made this study possible and meaningful.

DEDICATION

To my wife and children, for their tireless efforts in support of this study; and,

To Dr. James M. Spain, whose pioneer research in the Llanos Orientales of Colombia inspired this work.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The Llanos Orientales (Eastern Plains) of Colombia represent a significative portion of the country (Figure 1). Although the whole area is one of the most underdeveloped parts of the country, there has been an increasing interest to develop the area both by semi-official institutions and private enterprise. In 1965, FAO (FAO, 1965) made a comprehensive general soil survey of approximately 13,000,000 hectareas, which included semi-detailed soil surveys of twelve "pilot zones" within the area. Present cattle and rice industries in the area make significant contributions to the national economy. It is believed that the development of the beef cattle industry, under modern management, processing, and marketing techniques, could signify a permanent source of meat supply both for internal consumption and for exportation. There is also the possibility to grow and/or to process the products of such crops as peanuts, African palm oil, cashew, yucca, and/or fruit trees as citrus, avocado, and mango. Good physical characteristics, good tillage conditions, flat topography, absence of flooding, low price of the land, short distance to Bogota--the main consumer center of the country--and presence of some navigable rivers connected to the Atlantic Ocean are some advantages of the area studied.

Available information (largely personal communications) indicate that the soils are at advanced stages of weathering in which most of the plant nutrients have been leached out from the upper horizons and the only remaining minerals are quartz and other highly insoluble primary minerals, hydrated oxides of iron and aluminum, and kaolinite type clays. There exists the possibility that a "pedoplasmation"

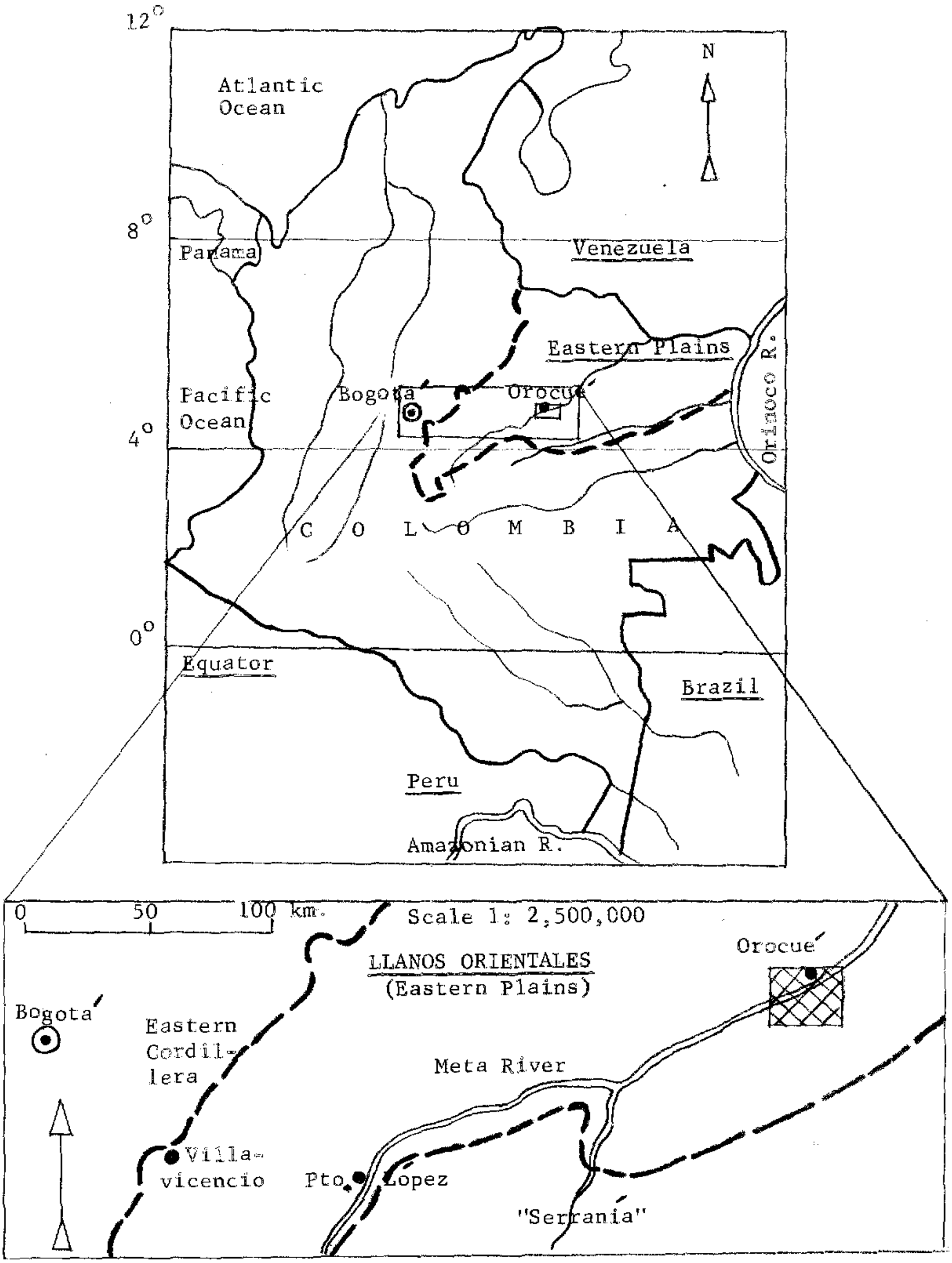

Figure 1. General location of the area (Orocue, 4° 50' N. lat., 71° 20' West long.) (after FAO, 1965)

process (the formation of soil plasma) proposed by Flach et al. (1968) is taking place in such a way that the weathering products retain a replica structure of the original rock (saprolite), but as it is destroyed a soil B horizon having soil structure is formed. During the transition from the saprolite to the B horizon mineralogical components, surface area and cation exchange capacity remain nearly constant and a kaolinitic oxic (latosolic B horizon) or montmorillonitic cambic (structural B) horizon (depending on the original composition) form. Drying and wetting, root action, and local alluvium transport are likely forces in this transition.

Leon (1964), studying the chemical and mineralogical properties of some Colombian soils, included a surface sample of a well-drained soil of the Llanos and concluded that the content of plant nutrients was extremely low. X-ray diffractograms of the soil particles less than 2 microns in diameter showed their composition to be approximately 50-60 percent kaolinite, 20-30 percent vermiculite-chlorite, 10 percent talc, and 10 percent iron oxides.

More recently Leon (1968), studying the chemical and mineralogical properties of some acid soils of Colombia, included some soil samples from approximately the same site as profile I reported in the present study and found that vermiculite-chlorite intergrades, kaolinite, geothite, quartz, and amorphous sesquioxides were the predominant clay minerals.

FAO (1965) classified some of the soils in the area studied as Oxisols. Comerma (1968) and Westin et al. (1968) working on the characterization of some Venezuelan soils of the savannas (Llanos) developed under similar conditions of physiography, climate, topography, and vegetation as those studied here, reported similar chemical characteristics and classified them as Ultisols and Oxisols. Likewise, Obeng and Quagraine (1960) considered similar soils of the savannahs of Ghana, West Africa, developed from granites and phyllites that presented well-drained, moderate acid, structureless, and poor nutrient conditions in which kaolinite was the predominant clay as Latosols.

Santamaria (1965) stated that about 3.1 million hectareas of the higher Llanos (savannas) of Venezuela have "arrecife" (pavement) that is a compacted gravel horizon cemented by Fe oxides after merging into the hard-pan horizon, having porous structure and easily destroyed by mechanical action. However, for the area studied here, the "arrecife" was not observed.

Classification of the soils of the tropics has been a subject of controversy (Wambeke, 1967). Bennema et al. (1959) and Bennema (1966) discussed the main morphological characteristics and the chemical and physical properties of the mineral soil mass that should be considered for Latosols. Harris (1963) examined the ideas involved in the classification of Latosols and well-drained tropical brown earths and suggested some definitions for Latosols and other acid soils. Maigniem (1964) proposed two groups of soils to classify the African ferralitic tropical soils based on their relationships to pedogenetic processes. Botelho da Costa and Cardoso-Franco (1965), discussing the concepts of ferralitic soils and Oxisols, concluded that the classification in use for soils of Portuguese dependencies do not correspond to either Ultisols or Oxisols as defined in the 7th Approximation.

Aubert and Segalen (1966), working on a scheme of classification for ferralitic soils, proposed three subclasses based on pH, cation exchange capacity, and percent base saturation. They further divide each subclass in three groups to account for the elimination of clay from the profile and for other modifications of the upper horizons.

Based on the dependence of the predominant clay mineral of the soil to other chemical and physical properties, Fieldes (1968) suggested a "Kaosol" group for Australian soils in which kaolinite block-type clay was dominant. The United States system of Soil Taxonomy (Soil Survey Staff, 1967, 1970) recently established the criteria to classify the Oxisols. All of these classifications indicate how soil horizonation, field and laboratory texture, structure, color, mottlings, presence of plinthite, consistence, clay increase with depth, presence of clay skins, type and amount of clay minerals present in soil particles of different size, percentage of weatherable minerals, cation exchange capacity, base retention, percent of base saturation, pH in water and in KCl, free iron oxide content, and water-dispersible clay, among other factors, can be used in determining the classification of the soils.

Apparently, some of the soil profiles included in the present study do not show some of the characteristics that have been reported for typical Oxisols. For instance, the field textures usually agreed quite closely with the laboratory textures. Brittliness of peds and absence of fine granular structure were quite noticeable in practically all the subsoil horizons; presence of pockets or tongues of organic matter were present in many subsoil horizons. Soil reaction was lower in KCl than in water. The presence of soft to weakly indurated plinthite-like red nodules, probably iron accumulations, was rather erratic, that is with or without apparent relationship to the drainage conditions, or to the occurrence of moderately high but fluctuating water table mentioned by the Soil Survey Staff (1967) and Daniels et al. (1971) to be common or necessary for plinthite formation. Presence of true laterite as that described by Sivarajasingham et al. (1962) was not observed in any of the soils sampled. However, hardened plinthite surfaces with small red nodules were exposed and observed on the gentle slopes of the southern "Serramia" and on the eroded river bank bordering the north of the area studied.

Maigniem (1964) discussing the formation of iron concretions in some tropical soils of West Africa which have varied conditions of climate, parent material, and vegetation attributed their origin to illuvial clay horizons developing with the immobilized of iron sesquioxides into concretions and crust. Wambeke et al. (FAO, 1965, p. 14) suggested the symbol "gcn" for soft non-indurated plinthite which can be cut with a spade and that has a dominance of grey colors in the matrix with strong and partially indurated mottlings. The hydromorphy of ferralitic soils having mottling and plinthite horizons was studied by Martin (1966) and Sys (1968). They described their formation and properties and suggested their use as criterion in the classification of ferralitic soils.

The implications of wind-blown materials deposited onto the study area from the adjacent Meta River and the occurrence of past events which modified the present landscape have only been partially investigated.

Arnold (1968) has emphasized the importance of the presence or absence of a lithological discontinuity in sampling soil horizons, to establish previous soil development and time-soil development relationships, and to evaluate the effects of soil forming factors. Likewise, Bettenay (1968) stressed the role of understanding periodicity in landscape and soil-geomorphological relationships to provide a major tool for broad scale soil mapping and to establish evidences of polygenetic horizons.

With these previous assumptions in mind, this study has the following purposes:

1. To characterize the physical, chemical, and mineralogical properties of seven soil profiles of the area in order to get information for soil correlation and soil classification.
2. To establish geomorphic relationships, determine if lithologic discontinuities are present and the implications of wind-blown materials brought to the area, if any.
3. To provide basic information for agricultural research programs underway.

The soil profiles are representative of an extensive area on which detailed soil information is very scarce and where I.C.A.[1] and C.I.A.T.[2] are presently conducting agricultural research.

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[2] Personal Communication: C.I.A.T., Centro Internacional Agricultura Tropical, Apartado aereo 67-13, Cali, Colombia, South America.

General Description of the Area

The area studied is located in the non-flooded high plains of the Llanos Orientales (Eastern Plains) of Colombia. It is approximately 4°51' north latitude, near to Orocue and south of the Meta River (Figure 1) at about 250-300 meters (800-1,000 feet) above sea level. The term "Llanos" is broadly applied to the whole area where the rivers drain into the Orinoco River (Orinoquia); roughly speaking it is bounded on the south by the Vichada River, on the west by the Colombian Eastern Cordillera, and continuing eastward into the Republic of Venezuela.

Although little detailed information is available on the area, FAO (1965) has compiled the main characteristics of the Colombian Llanos on which most of the information presented in this portion of the thesis is based.

The climate according to the Koeppen-Geiger classification is Av. or savanna climate. The average annual rainfall is about 1,734 mm (approximately 68 inches) distributed in a long rainy season from April to November followed by a short almost dry period from December to March. The average annual temperature is about 28°C (82°F) and practically uniform throughout the year. There are more variations between the daily maximum and minimum temperatures than between the mean monthly temperatures. The relative humidity averages 80 percent during the rainy season and 50-60 percent during the dry period. The potential evapotranspiration is higher at the end of the dry period when the temperature is higher, relative humidity lower, and the soil water storage decreases to minimum values, particularly in February and March. Figure 2 shows the average annual rainfall and temperature at Orocue.

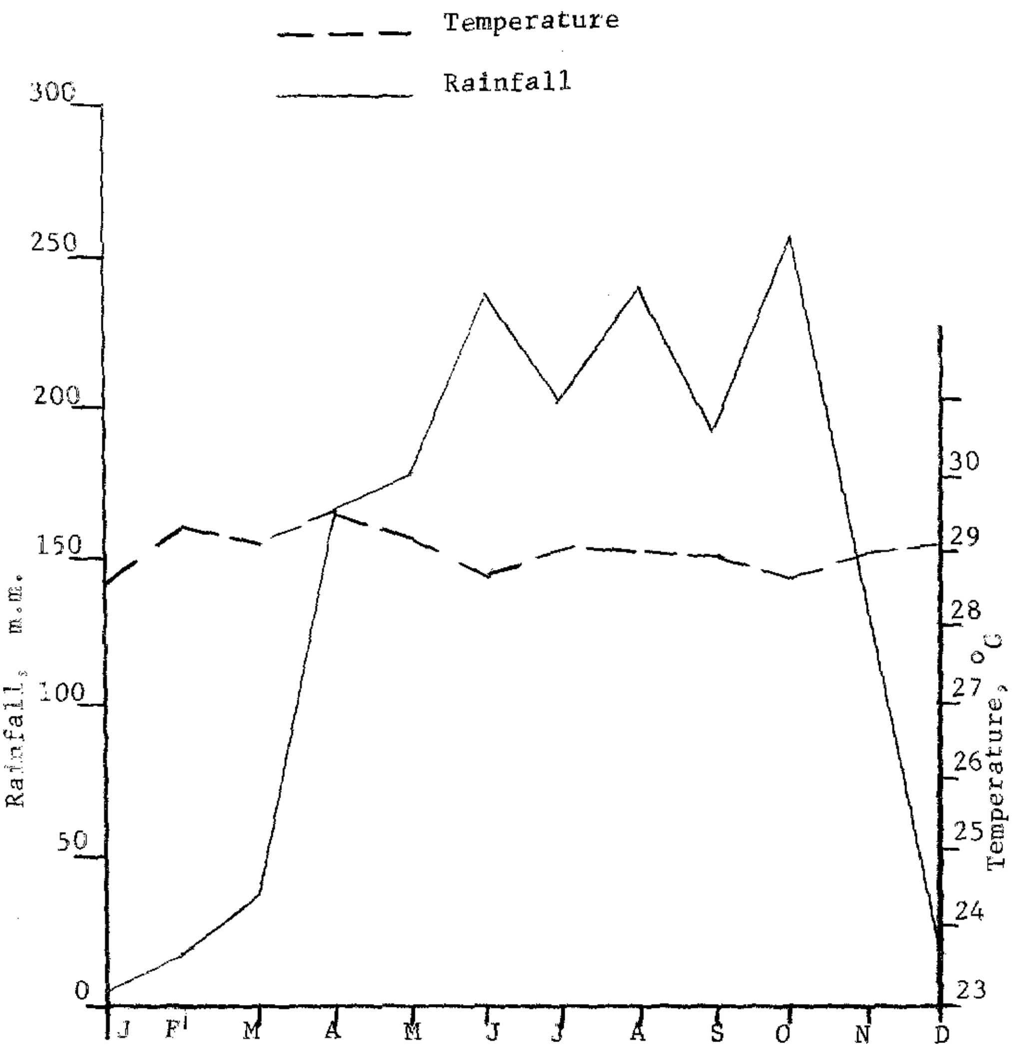

Figure 2. Mean annual rainfall and mean annual temperature at Orocue, Colombia (seven years data), (after Marin and Cano, 1964)

The parent material consists of mixed alluvial sediments, perhaps deposited during the Pleistocene. According to FAO (1965), all surface sediments in the Llanos Orientales come from the Eastern Cordillera and the intensity of the sedimentation process is probably connected to the various phases of glaciation, to tectonic movements and consequent erosion in the Cordillera. Probably in the middle of the Tertiary, the Cordillera began to lift and there followed a very active period of mountain building lasting through the Early Pleistocene, before the last glaciation. Toward the end of the Pleistocene, the greatest upheaval took place. The approximate composition of the various formations of the Cordillera is given below.

Upper Middle Tertiary	Sandstones and congomerates
Lower Tertiary	Sandstones and argilaceious schists
Upper Cretaceous	Sandstones
Middle Cretaceous	Shales with limestone beds
Lower Cretaceous	Shales
Paleozoic, Carboniferous	Argilaceous schists plus limestone
Intrusive Rocks	Granodiorites

Where the Cordillera was higher, erosion was greater, and the lower strata were also exposed to erosion. Actually the depositon of sediments followed the reverse order of the original strata, that is the upper sediments were deposited first and deeper. Thus, different strata affected the composition of the materials. Likewise, a large number of faults occurred parallel to the Cordillera and the area some kilometers to the east bank. The Meta area presents a large number of parallel and transverse faults, each representing a movement during the

Early Pleistocene on both sides of the fault. The eastern limit of the subsidence is the valley of the Meta River. The presence of higher cliffs on the south side of the river than on the north following almost straight line evidences a fault line along the river itself. The presence of the "Serrania" south of the study area in a dissected landscape and of terraces at several levels gives evidence of the original surface being subjected to an erosional process which has been interrupted several times. There also occurred several climatic changes in which wind-blown sands and loess were deposited. Presently materials blow from the beaches and islands of the Meta River during the dry season.

The relief is essentially flat to slightly convex and most of the area is well drained, but a catenary situation is present in which soils close to the depressions have a high fluctuating water table, especially during the rainy season. The fault line borders the northern part of the study area either as an almost vertical cliff or as a steep bank approximately 25-35 meters (roughly 80-115 feet) high (Figure 3). This bank, essentially acting as a dam, explains the occurrence of low flooded plains to the north and non-flooded high plains to the south of the Meta River. The particular landscape considered here is a portion of the physiographic region which has been called "High Plains" (FAO, 1965, pp. 30-31). Although these plains are considered alluvial sediments, "There is not much evidence of this on the surface. There are no old channels, natural levees or depressions. The surface is very smooth as though all irregularities had been covered and flattened out. This is probably due to wind action during the dry season.

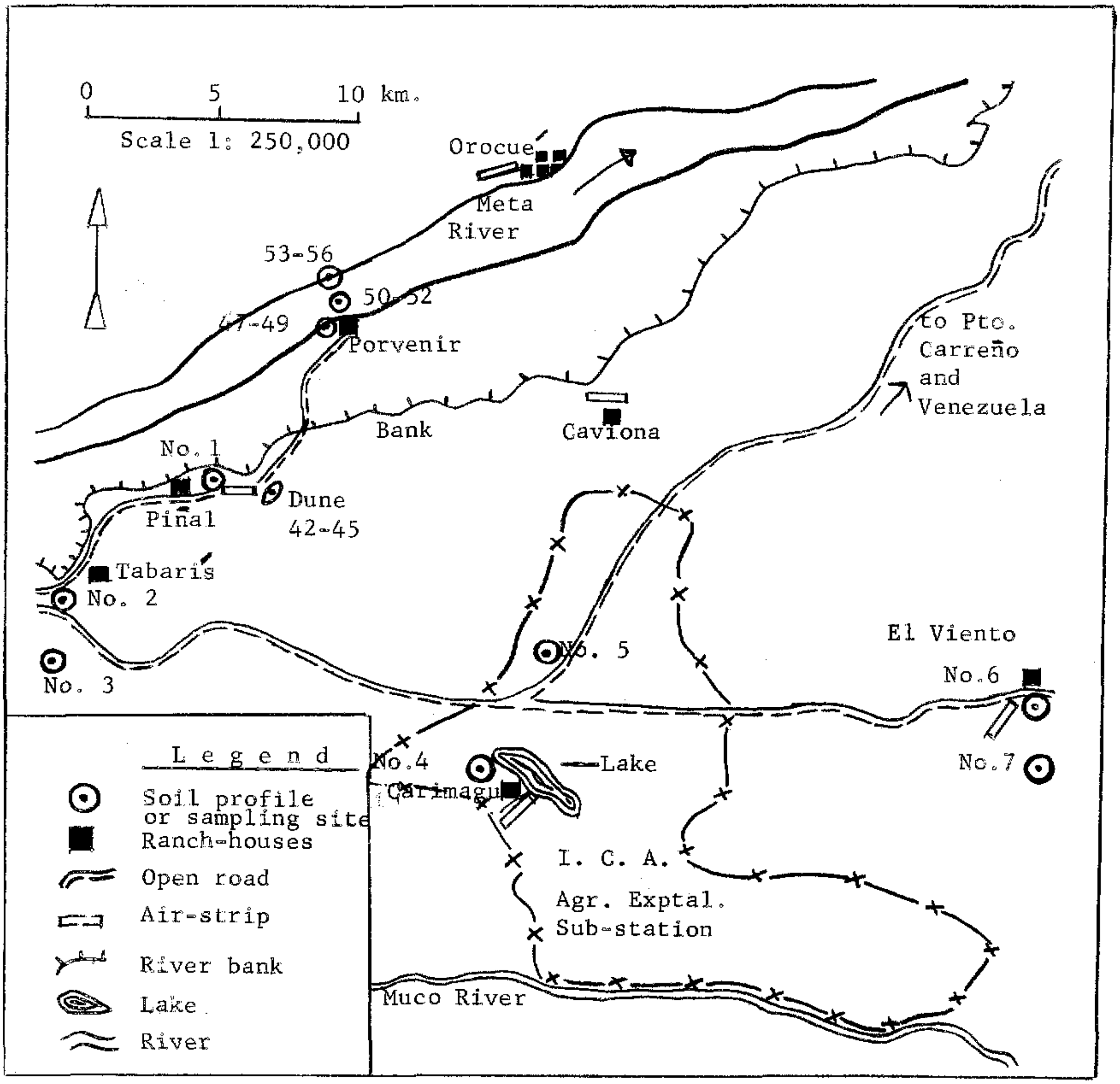

Figure 3. Map showing profile sites and some river bank sites

The surface material bears a strong resemblance granulometrically to loess."

The type of vegetation is characteristic of "tropical savanna." About 95 percent of the area consists of immense treeless plains covered almost exclusively by short bunch grass, mainly Trachypogon sp. and Axonopus sp. The remaining area is occupied with "esteros" (groves of "moriche" palms) and gallery forests along the drainages. At some places ant mounds less than 20 cm (8 inches) high are present over the surface of the soil. Termites are scarce on the high plains.

Population density is less than 2 persons per square kilometer for the area studied. Land transportation by cars and trucks is possible any time of the year within this area, but interrupted at some places by the lack of bridges on the esteros. The Meta River is navigable and used to transport cattle or supplies for about 7 1/2 months of the year.

The land is almost totally used for cattle breeding, but cattle population is less than 0.1 head per hectarea, usually under very primitive management practices. A typical ranch may have 2,000 head of cattle but some have over 20,000 head.

Since land has long been available for the taking ranches are extensive. A 10,000 hectare ranch is not considered large and commonly they encompass 10,000-20,000 hectareas. Most of the ranchers have no title to the land and usually they do not live on the ranch. Upland rice acreage has increased in the last years under fair agriculture techniques. Some small areas of subsistence crops, such as plantain, yucca, corn, or fruit trees of citrus, mango, and cashew are grown adjacent to the ranch houses. Some nomadic Indians grow yucca and corn in a shifting cultivation system. Lately, I.C.A. and C.I.A.T. started to test new agricultural techniques in field trials at the recently bought Carimagua Agricultural Experiment Station (Figure 3).

MATERIALS AND METHODS OF ANALYSIS

Seven soil profiles were described and sampled at representative sites in a transect south of the Meta River near Orocue (Figure 3). To select the sites, consideration was given both to relative position in the landscape (apparently "well drained" and "moderately well drained" members of a catena) and also to distance from the river (Figure 4). In order to test the influence that may be created in the profiles by material blown south from the river bed during the dry season, some additional samples of river beach material, both from the north bank, the islands, and from sand dunes to the south of the river were taken for mineralogical comparison with the material in the soil profiles.

Sampling

Profile descriptions and sampling were done in hand dug pits during August 1969 according to the procedures and terminology described in the Soil Survey Manual (Soil Survey Staff, 1951).

Figure 4 schematically diagrams the relative position of the profiles and additional samples. Soil horizons on which special determinations were made are also indicated. Samples were treated with methyl bromide by U. S. Customs officials upon entry to the United States.

Particle Size Distribution

Particle size distribution was done by two methods: (a) The Calgon-pipette method (Kilmer and Alexander, 1949): Twenty grams of air-dry soil were treated with hydrogen peroxide, in an 80°C water bath, to destroy organic matter, dispersed with 10 ml of 10 percent

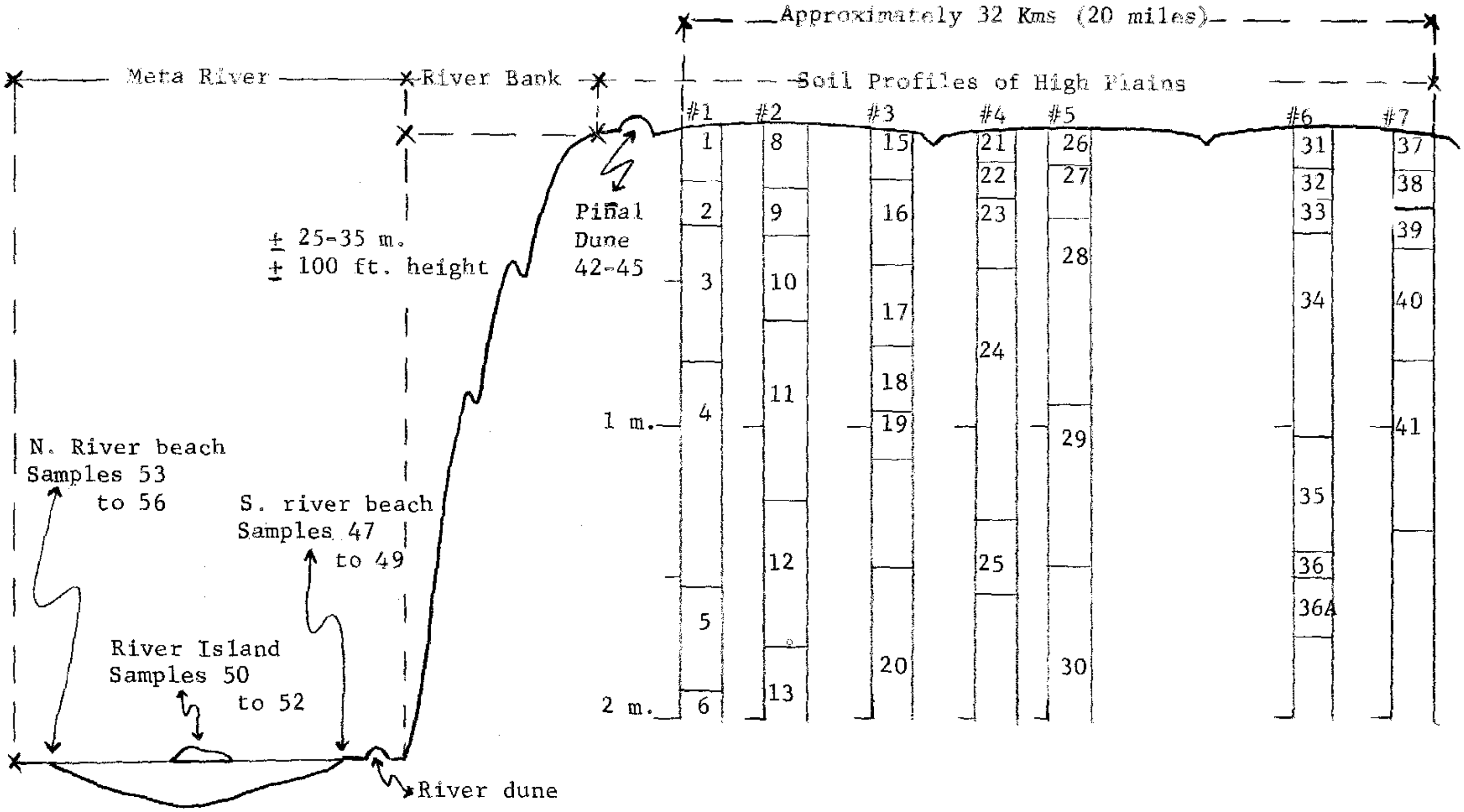

Figure 4. Schematic cross-section showing profiles, sample sites and sample numbers (profiles at exaggerated scale)

sodium-hexametaphosphate (Calgon) and stirred for 15 minutes with a Hamilton milk stirrer. The sand was separated with a 300 mesh-sieve, oven dried, and weighed. The clay was determined by sedimentation.

(b) Centrifugation (Kittrick and Hope, 1963): The organic matter was removed with hydrogen peroxide and the free iron with sodium-dithionite. Five fractions were separated: sand (2,000-50μ); coarse silt (50-20 μ); fine silt (20-2 μ); coarse clay (2-0.2 μ); and, fine clay (smaller than 0.2 μ). From 20 to 28 centrifugations for about 34 minutes each at 2,400 rpm were needed for the fraction smaller than 0.2 μ and from 12 to 22 centrifugations of 4 minutes each at 750 rpm were needed to obtain the 0.2-2 μ fraction.

Water-Dispersible Clay

Twenty grams of air-dry soil in approximately 500 ml of demineralized water were stirred with a malted milk stirrer for 15 minutes, transferred to a cylinder, and completed to 1,000 ml volume. The amount of water-dispersible clay was determined from an aliquot taken by pipette at a depth of 5 cm after the appropriate settling time (Kilmer and Alexander, 1949).

Clay Content by the 15-Bar Method

The water content at 15-bars pressure was determined by pressure membrane equipment (Soil Survey Staff, 1967). The clay percentage was calculated by multiplying the weight percentage of water retained by the factor 2.5.

Free-Iron Oxides

Free iron was extracted by the citrate-dithionite method as described by Kittrick and Hope (1963). Iron was determined by atomic absorption spectrophotometry.

Soil Reaction

Soil reaction was measured by using a glass-electrode pH meter and 20 grams of soil in 1:1 soil-water and 1:1 soil-N KCl ratios. Before reading the suspensions, the samples were mixed and allowed to equilibrate for about 30 minutes.

Organic Carbon

The organic carbon was determined by the methods described by Peech and Walkley, (Soil Conservation Service, 1967) with acid dichromate digestion and titrations with $FeSO_4$.

Exchangeable Hydrogen and Exchangeable Aluminum

Exchangeable hydrogen and exchangeable aluminum were determined by extraction with 1 N KCl and titration of the leachate with 0.1 N NaOH, and 0.1 HCl, using phenolphtalein as indicator, as described by Chapman (1965).

Exchangeable Bases, Base Retentions, and Base Saturation

Exchangeable Ca, Mg, K, and K were extracted in ammonium-acetate leachate. An atomic absorption spectrophotometer was used to determine Ca and Mg;; K and Na were determined by Flame Photometry.

The base retention was the sum of exchangeable bases plus exchangeable aluminum. Base saturation percentage was calculated as percentage of bases retained (Ca, Mg, K, Na) of the cation exchange capacity obtained by the sum of cations.

Soil Fertility Tests[1]

Basic cations (Ca, Mg, and K) and phosphorus were extracted with 0.05 N H Cl--0.025 N H_2SO_4 "North Carolina" solution and determined by atomic absorption. The Walkley-Black dichromate method with a 1.72 X conversion factor was used to determine organic matter content. A 1:1 soil-water suspension was used to determine pH values.

Micronutrients[2]

Copper, zinc, iron, and manganese were determined by two methods. (1) Five cc. of soil were treated with 25 ml of the North Carolina extracting solution. The micronutrients were determined in the extract by atomic absorption spectrophotometer. (2) The Hunter-Pratt method was also used where first 15 ml of H_2O were added to 2.5 ml of soil, then 2 ml of concentrated H_2SO_4 were added to the sample. The suspension was allowed to cool, and an additional 25 ml of H_2O was added. The suspension was filtered and the micronutrients determined by atomic absorption spectrophotometry. Boron was determined in hot water extraction at the Soil Testing and Plant Analysis Laboratory of the University of Georgia, Athens.

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[1] Appreciation is expressed to Dr. D. W. Eaddy, Director of the North Carolina Soil Testing Laboratory, North Carolina Department of Agriculture for these analyses.

[2] Appreciation is expressed to Dr. A. H. Hunter for his assistance in these determinations.

Clay and Silt Fraction Mineralogy

Four iron-free separates (less than 0.2 μ, 0.2-2 μ, 2-5 μ, and 5-20 μ) were prepared as oriented specimens on glass slides. Diffractograms of these particles were obtained for the following treatments: Mg-saturation at room temperature, Mg-saturation plus ethylene glycol solvation, K-saturation at room temperature, at 350°C, and at 550°C, according to the procedure described by Jackson (1956).

A General Electric XRD-5 x-ray diffractometer unit was used with nickel-filtered copper Kα radiation at the scanning rate of 2° 2 θ per minute. A semi-quantitative estimation of the clays was made by visually comparing the height and width of the peaks.

Sand Fraction Mineralogy

Both oil mountings in various refractive index oils and permanent slides on Canada balsams were used to identify quartz, feldspar, rock fragments, micas, heavy and opaque grains in the fine and very fine sand separates.

Thin Section Preparation

Thin sections were prepared from oven-dried (110°C) peds. Sample impregnation was under vacuum with castolite or laminac resins and styrene as described by Buol and Fadness (1961). Micropedologic features were described following the terminology suggested by Brewer (1964).

RESULTS AND DISCUSSION

The number of samples selected for each determination varied according to the nature of the determination. For several determinations, data were obtained only for those samples selected for x-ray analysis. Results obtained will be discussed for each site and also in relationship to its particular location with the area.

Particle Size Distribution

Table 1 shows the particle size distribution with and without organic matter and iron removal. Free iron and O.M. removal increased clay contents from 50 percent to more than 100 percent. Usually this was seen as the dispersion of silt-sized aggregates. This suggests that before removing organic matter and iron, most of the clay was present as stable iron-organic matter cemented aggregates in the silt fraction, since the clay increase was primarily at the expense of the silt content and the sand content showed only minor variations.

Wambeke (1962) established the use of silt/clay ratio as one of the criteria to estimate the age and weathering of some African tropical soils in which kaolinite was dominant clay and textural B horizons were absent. He proposed a ratio less than 0.15 for older and advanced weathered soils. This ratio was also used by Webster (1965) to estimate the weathering stage of some African Latosols. It is noted that in the Llanos soils studied, silt clay ratios were found to be greater than 0.3 thus not indicating extensive weathering or old age.

Also, some Brazilian "Latosols" (Comissao do Solos, 1960), some Brazilian Oxisols (Moura, 1968), and some Colombian Oxisols (FAO, 1965)

Table 1. Some physical and chemical properties

Soil no.	Sample no.	Depth	Calgon-pipette with O.M. removed			With organic matter and free iron removal							H_2O dispersible		H_2O at 15-bars	Clay by 15-bars	Fe_2O_3
			Sand 2mm -50μ	Silt 50μ -2μ	Clay < 2μ	Sand 2mm -50μ	Coarse silt 50-20μ	Medium silt 20-5μ	Fine silt 5-2μ	Coarse clay 2-.2μ	Fine clay <.2μ	Total clay	Clay	Sand			
		cm	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
1	1	0-18	32	49	19	--	--	--	--	--	--	--	15	40	8.6	22	--
	2	18-30	32	48	20	--	--	--	--	--	--	--	19	34	8.1	20	--
	3	30-80	31	46	23	--	--	--	--	--	--	--	21	30	9.1	23	--
	4	80-160	28	46	26	--	--	--	--	--	--	--	3	29	12.2	31	--
	5	160-185	28	45	27	--	--	--	--	--	--	--	3	28	12.4	31	--
	6	185-205	28	38	34	--	--	--	--	--	--	--	3	27	12.6	32	--
	7	205-210	21	40	39	--	--	--	--	--	--	--	3	21	--	--	--
2	8	0-20	44	39	17	44	7	14	4	10	21	31	11	45	7.1	18	3.7
	9	20-34	41	40	19	52	--	14	3	10	21	31	15	41	7.8	20	4.1
	10	34-71	39	40	21	42	3	12	4	10	29	39	20	40	7.8	20	4.4
	11	71-125	40	37	23	34	--	11	4	12	39	51	4	34	9.4	24	4.8
	12	125-178	33	37	30	29	5	11	4	13	39	52	4	31	12.3	31	6.1
	13	178-208	25	36	39	19	18	9	1	18	35	53	4	21	--	--	7.1
	14	208-218	22	36	42	16	4	9	4	18	49	67	4	19	--	--	7.4
3	15	0-16	39	30	31	--	--	--	--	--	--	--	--	--	12.0	30	--
	16	16-42	35	31	34	--	--	--	--	--	--	--	--	--	12.5	31	--
	17	42-70	33	32	35	--	--	--	--	--	--	--	--	--	12.8	32	--
	18	70-92	32	30	38	--	--	--	--	--	--	--	--	--	14.3	36	--
	19	92-112	32	31	37	--	--	--	--	--	--	--	--	--	14.0	35	--
	20	145-170	35	30	35	--	--	--	--	--	--	--	--	--	13.9	35	--

Table 1 (continued)

Soil no.	Sample no.	Depth	Calgon-pipette with O.M. removed			With organic matter and free iron removal							H$_2$O dispersible		H$_2$O at 15-bars	Clay at 15-bars	Fe$_2$O$_3$
			Sand 2mm -50μ	Silt 50μ -2μ	Clay < 2μ	Sand 2mm -50μ	Coarse silt 50-20μ	Medium silt 20-5μ	Fine silt 5-2μ	Coarse clay 2-.2μ	Fine clay <.2μ	Total clay	Clay	Sand			
		cm	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
4	21	0-8	7	58	35	6	2	24	7	13	48	61	27	12	14.6	37	6.0
	22	8-22	11	51	38	6	3	16	5	12	58	70	32	11	13.8	35	7.1
	23	22-46	19	41	40	6	17	10	4	13	50	63	38	10	14.7	37	7.4
	24	46-132	10	47	43	6	22	7	1	14	50	64	3	13	14.8	37	7.4
	25	132-140	8	43	49	5	24	7	3	17	41	58	3	14	19.0	48	7.4
5	26	0-12	12	50	38	--	--	--	--	--	--	--	26	26	14.0	35	--
	27	12-32	11	48	41	5	1	16	5	16	57	73	35	11	14.1	35	9.5
	28	32-58	11	46	43	--	--	--	--	--	--	--	28	10	14.6	37	--
	29	58-88	12	43	45	--	--	--	--	--	--	--	3	11	15.0	38	--
	30	88-148	12	43	45	5	4	22	6	16	47	63	3	8	15.6	39	9.3
6	31	0-10	9	45	46	--	--	--	--	--	--	--	36	13	17.0	43	--
	32	10-19	8	48	44	5	2	20	6	17	50	67	38	15	16.7	42	10.7
	33	19-31	8	40	52	--	--	--	--	--	--	--	42	14	17.5	44	--
	34	31-105	7	38	55	--	--	--	--	--	--	--	2	7	17.5	44	--
	35	105-140	7	34	59	4	1	8	5	20	62	82	3	30	20.1	50	11.9
	36	140-150	6	33	61	--	--	--	--	--	--	--	4	22	20.9	52	--
	36A	150-170	--	--	--	--	--	--	--	--	--	--	4	28	21.9	55	--
7	37	0-10	15	50	35	--	--	--	--	--	--	--	--	--	14.3	36	--
	38	10-25	13	48	39	--	--	--	--	--	--	--	--	--	14.3	36	--
	39	25-44	12	45	43	--	--	--	--	--	--	--	--	--	15.6	39	--
	40	44-77	11	45	44	--	--	--	--	--	--	--	--	--	16.1	40	--
	41	77-137	11	46	43	--	--	--	--	--	--	--	--	--	17.1	43	--

show a rather similar particle size distribution as that presented here.

Table 1 also shows, for selected samples, that more than 70 percent of the clay particles correspond to the fraction less than 0.2 μ (in diameter), i.e., fine clay. This may be attributed either to inherited material or *in situ* clay formation related to sedimentation processes of the initial or parent material at points distant from the banks of the rivers carrying the sediments, rather than to illuviation, as will be discussed later.

For all the samples treated with calgon without iron removal, clay content increased both within the soil profile and in the traverse south of the river bank. The sand contents were higher in the upper horizons and in the profiles closer to the river. Likewise, the sand content either water dispersible, calgon-pipette and on iron-free basis show a decrease from the northern most samples 1, 2, and 3 profiles to the southern more distant from the river profiles. For the soils 1-3, the sand percentage is relatively high while for the soils 4-7, sand content is quite low. These data suggest that the parent material for soils 1-3 may have originated as wind-blown sand materials brought from the river beaches north of the Meta River during the dry season when sandy materials are exposed and strong, northeast-trade winds appear to prevail (FAO, 1965).

Goosen (Doeko Goosen, International Institute for Aerial Survey and Earth Science, Delft, The Netherlands, Personal Communication, 1971) points out that new findings suggest that the thickness of the "loess" layers for soils of that area might reach a depth of several meters at some places.

Field textures (see profile descriptions) as compared to laboratory textures by the calgon-pipette method appeared in general to agree quite closely. This is rather unexpected since for many "Latosols" it has been reported that the presence of iron-cemented clay prevents the determination of heavier textures by field techniques (Bennema _et al._, 1959; Comissao do Solos, 1960). Folster and Ladeinde (1967), studying the particle size distribution of some tropical soils of Nigeria, stated that the widespread vertical differences in texture in the tropical soils may be caused by primary differences in the stratified pedisediments as well as by clay migration and faunal activity combined with loss of clay by surface wash. According to these authors, the latter process produces coarse-textured surface horizons impoverished in clay, above a subsoil which had had a constant clay content. Clay migration appears to be a slower process than the loss of clay by surface wash. Apparently, some of these processes may be involved in the soils of the Colombian Llanos.

Water-Dispersible Clay

Water-dispersible clay content in the upper three horizons of the seven soil profiles (Table 1 and Appendix H) was quite similar to that obtained by the calgon-pipette method, especially for profiles 1, 2, and 4. However, below the third horizon the water-dispersible clay content decreased abruptly to less than 4 percent (Figure 5). This indicates a very high degree of clay stability in the lower horizons and points out their oxic nature (Soil Survey Staff, 1970). Also, it is interesting to note the sand content after water dispersion. For the first four profiles, sand percentages were essentially similar.

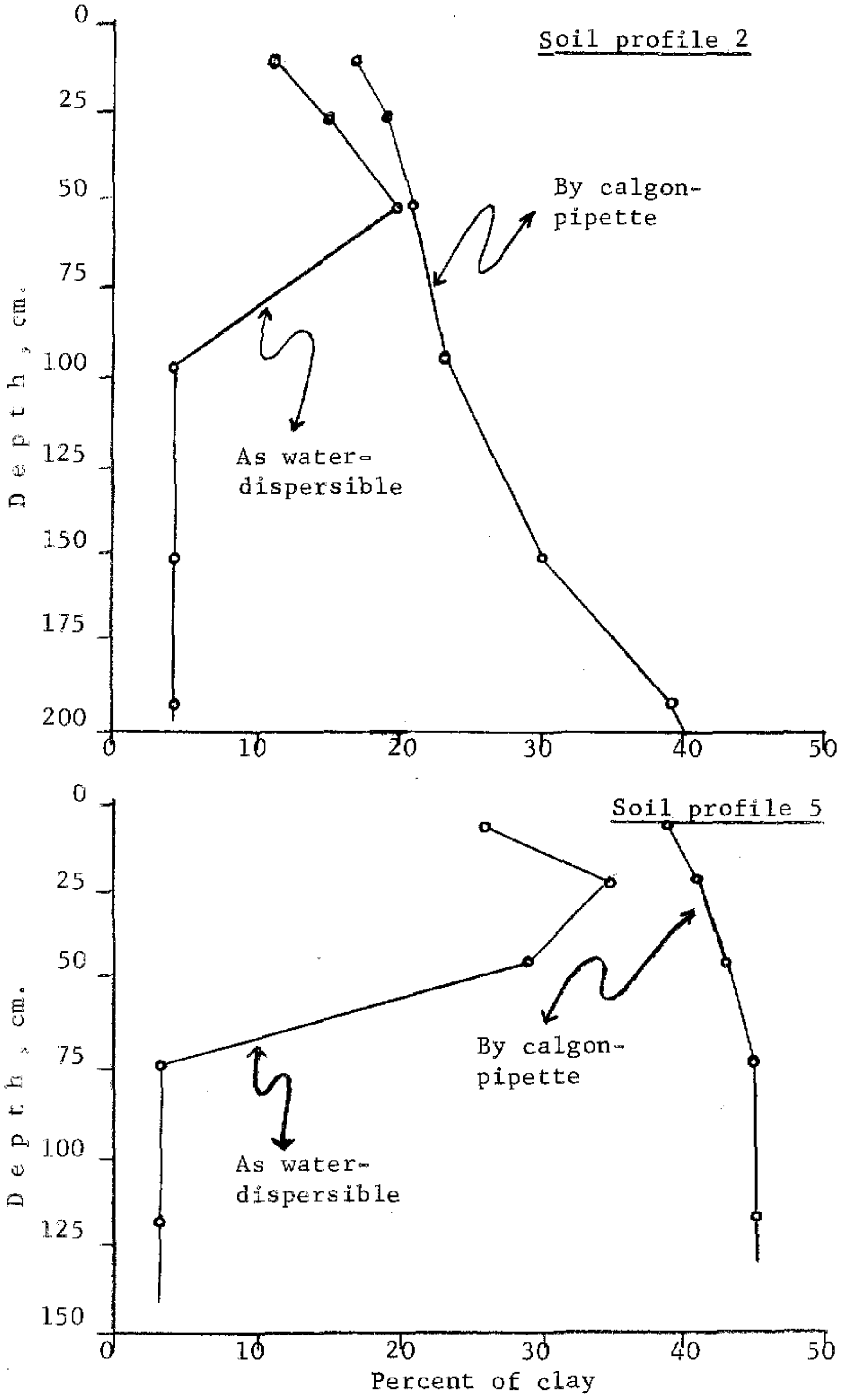

Figure 5. Comparison of water-dispersible clay vs. content of clay by calgon-pipette determination

Conversely, for profile 6, there was a sharp contrast in the sand content below the third horizon. No explanation is offered for this observation.

Clay Content by the 15-Bar Method

Clay content, obtained by multiplying the moisture percent at 15-bar extraction by 2.5, showed good agreement with the values obtained by the calgon-pipette method, especially for the first four profiles (Table 1). For the other profiles, maximum discrepancies of 11 percent were found, but the variations were commonly within a range of 4-6 percent. In general, since higher values were obtained by the calgon-pipette method, these values were used for the calculations of exchange capacity.

Free-Iron Oxides

Free-iron oxide content (Table 1) increased from the top to the bottom horizons studied and seem to be directly related to the clay content obtained after removal of iron with dithionite. Free-iron oxide content increased with distance south of the Meta River. The 5YR 4/8 and 2.5YR 4/8 colored horizons of the southernmost profiles contained more iron than the horizons with colors of 10R 4/8 to the north nearer to the river bank. The higher Fe_2O_3 content should not be related to the presence of soft pseudo plinthite concretions since these were present rather erratically both in red and red-yellow subsoils (Appendices A to G).

Soileau and McCracken (1967) working on the correlations of free iron, coloration, and other properties of soils on the Coastal Plain of North Carolina, found no consistent relationship between B-horizon coloration and Munsell hue, the general clay suite, free iron oxide content in the <2 mm soil material or its clay subfraction, or the relative thickness of absorbed iron coatings on the clay surfaces. They found a general relationship between iron content and chroma. Also, a direct relation between color hue and free iron oxide content was observed by Webster (1965) in a catena of soils of northern Rhodesia in which the soils ranged downslope from red through yellowish brown to gray. He attributed the color sequence to the proportion of free iron oxides in the soil. However, for the Llanos soils these last conclusions apparently do not hold true (Table 1 versus Appendices).

Bennema (1966) compared the total iron and aluminum content of three different Brazilian soils by extraction with H_2SO_4. In general, he found that Fe_2O_3 content was low for the red, yellow Latosol (<10 percent), medium for the dark red Latosol (10-18 percent), and high for the Latosol Roxo (20-34 percent). Moura-Filho (1968) has also reported an average value of 23 percent of free iron oxides by sodium dithionite extraction for a Brazilian Latosol Roxo classified as Typic Eutrustox whereas the Comissao do Solos (1960) found values ranging from 3 percent to 9 percent of total iron oxides for the Latosol Vermelho Escuro, sandy phase, a soil of the woody savannas. Bornemisza and Igue (1967) determining the free iron oxide content of several Latin American soils by the Kilmer technique, reported average values of 8.0 percent Fe_2O_3 for A horizons of some supposedly Latosols of western Colombia and averages of 10.1 percent, 2.0 percent, and 3.4 percent of Fe_2O_3, respectively, for a red Latosol, a yellow Latosol, and a "Terra Roxa" of the Brazilian Amazonia. Moreover, Pratt et al. (1969) investigating the iron oxide content of some A horizons of Sao Paulo, Brazil, by the sodium dithionite method of Jackson, found the following average values of Fe_2O_3: for red-yellow Podzolic soil (Hapludult), 5.2 percent; for red-yellow Latosol (Haplorthox), 3.6 percent; and, for Terra Roxa Legitima (Acrorthox), 17.1 percent. Data of this order tend to confirm great variations in free iron oxide content among different Latosols or Oxisol-like soils.

Soil Reaction

The results of pH determinations are listed in Table 2. The values obtained in water show that these are acid soils, such as expected for tropical soils of this nature and in agreement with the status of bases and exchange acidity, as presented later. In general, the values both in water and in KCl tend to increase with depth in the profile which indicates leaching of bases from the upper horizons. The pH values in KCl were approximately one unit or more lower than in the water. This was rather unexpected in dealing with oxic horizons (Soil Survey, 1970). Soil pH values did not vary greatly between sites and no geographic trend is indicated.

Organic Carbon

The content of organic carbon in selected horizons to a depth of one meter (Table 2) ranged from 3.10 percent to 0.16 percent, but most of the values are higher than 0.60 percent (more than approximately 1.0 percent organic matter). Organic carbon values were highest in the top horizons and progressively decreased with depth in the profile. However, some relatively high values were obtained for intermediate horizons that might be attributed either to the influence of the grass root system

Table 2. Chemical data

Soil no.	Sample no.	Depth	pH		Organic carbon	CEC	Ca	Mg	K	Na	Exch. Al	Exch. H	Sum of cations	Base saturation by sum of cations
			H_2O 1:1	KCl 1:1										
		cm			%	- - - - - - - -	- - -meq/100 g soil - - -						- - - - - - - -	%
1	1	0-18	4.6	3.6	1.5	6.1	.2	.2	.1	.2	1.7	.8	3.2	22
	2	18-30	4.6	3.7	0.9	4.7	.1	.1	.1	<.1	1.7	.5	2.5	14
	3	30-80	4.6	3.8	0.5	4.4	.1	.1	<.1	.1	1.4	.4	2.1	16
	4	80-160	4.8	3.9	0.2	5.4	.1	<.1	<.1	.1	0.9	.5	1.7	18
	5	160-185	4.9	3.7	--	5.8	.1	.1	<.1	.1	1.2	.7	2.2	16
	6	185-205	5.0	3.5	--	5.9	.1	.1	<.1	.2	1.8	.7	2.9	15
	7	205-210	5.0	--	--	--	.1	.2	<.1	.2	--	--	--	--
2	8	0-20	4.6	3.6	1.2	5.4	.2	.2	.1	.2	1.7	.7	3.1	23
	9	20-34	4.9	3.9	0.7	4.8	.1	.1	<.1	.1	1.5	.6	2.4	14
	10	34-71	4.6	3.8	0.4	3.3	.1	.1	<.1	.2	0.8	.7	2.0	23
	11	71-125	5.1	3.9	0.2	3.1	.1	.1	<.1	.2	0.6	.7	1.8	25
	12	125-178	4.8	3.8	--	4.4	.1	<.1	<.1	.1	1.0	.4	1.7	18
	13	178-208	5.3	3.7	--	5.8	.1	<.1	<.1	.1	1.6	.4	2.4	13
	14	208-218	5.1	4.0	--	7.3	.2	.2	.1	.1	1.8	.6	3.0	20
3	15	0-16	4.4		1.9	13.2	.2	.2	<.1	.2	2.8	.6	4.1	16
	16	16-42	4.4		1.2	11.6	.2	.2	<.1	.2	2.3	.6	3.6	18
	17	42-70	4.6		0.9	8.4	.2	.2	<.1	.2	1.5	.9	3.2	20
	18	70-92	4.8		0.6	8.0	.2	.1	<.1	.1	0.8	.7	2.0	23
	19	92-112	4.9		--	4.8	.2	.2	<.1	.3	0.8	.8	2.4	31
	20	145-170	5.1		--	6.0	.2	.2	<.1	.3	0.9	.8	2.5	30
4	21	0-8	4.8	3.6	3.1	13.0	.6	.8	.5	.5	3.1	1.0	6.5	37
	22	8-22	4.7	3.6	1.7	10.1	.2	.2	.2	.2	3.2	.6	4.6	17
	23	22-46	4.4	3.8	1.1	8.8	.2	.1	.1	.1	1.9	.5	2.9	17
	24	46-132	4.9	4.1	0.6	6.0	.1	.1	.1	.1	0.6	.4	1.4	29
	25	132-140	5.4	4.3	--	7.0	.2	.4	.1	.2	0.3	.4	1.6	56

Table 2 (continued)

Soil no.	Sample no.	Depth	pH		Organic carbon	CEC	Ca	Mg	K	Na	Exch. Al	Exch. H	Sum of cations	Base saturation by sum of cations
			H_2O 1:1	KCl 1:1										
		cm			%	- - - - - - - -	- -	meq/100 g	soil	- - - -	- - -	- - -		%
5	26	0-12	4.5	3.7	2.2	10.7	.2	.2	.4	.1	2.9	.9	4.7	19
	27	12-32	4.6	3.8	1.2	8.7	.1	.1	<.1	.1	2.3	.5	3.1	11
	28	32-58	4.8	3.9	0.9	7.1	<.1	<.1	<.1	<.1	1.7	.4	2.3	9
	29	58-88	5.2	4.2	0.4	5.4	<.1	<.1	<.1	<.1	0.4	.3	0.9	22
	30	88-148	5.1	4.3	0.3	5.9	<.1	<.1	<.1	<.1	0.3	.3	0.8	25
6	31	0-110	4.7	3.7	3.1	13.6	.3	.3	.2	.2	3.4	.7	5.1	20
	32	10-19	4.6	3.7	2.1	11.4	.2	.2	.1	.1	2.7	.6	3.9	15
	33	19-31	4.8	3.8	1.4	10.3	.1	.1	.1	.1	2.2	.6	3.2	13
	34	31-105	4.9	4.0	0.9	8.1	.1	<.1	<.1	.1	1.0	.5	1.8	17
	35	105-140	5.1	4.5	--	7.0	.1	<.1	<.1	<.1	0.1	.3	0.7	36
	36	140-150	5.5	4.4	--	7.4	.1	<.1	<.1	<.1	0.1	.3	0.7	36
	36A	150-170		4.4	--	6.8	.2	<.1	<.1	<.1	0.2	.2	0.7	57
7	37	0-10	4.7	--	2.8	12.0	.4	.4	.1	.1	2.4	1.7	5.1	20
	38	10-25	4.5	--	1.9	10.6	.3	.4	.1	.1	2.5	.8	4.2	21
	39	25-44	4.6	--	1.1	6.4	.2	.3	<.1	.1	1.7	.6	3.0	22
	40	44-77	4.8	--	0.7	7.4	.2	.2	<.1	<.1	0.8	.5	1.8	28
	41	77-137	5.4	--	0.5	7.4	.2	.1	<.1	<.1	0.1	.5	1.0	40

or to the activity of ants and other macro-organisms, or both, as noted in the soil descriptions (Appendices). Hole (1961) has reported an important role of ants and other macro-organisms in the so-called pedoturbation process. Apparently, there are some texture-organic carbon relationships, since the lighter textured river bank soils (profiles 1 and 2) contained less organic carbon than the finer textured profiles to the south. Surprisingly and with no apparent explanation, the moderately-well drained soils (profiles 3 and 7 in which water table was present at 77 and 92 cm depth, respectively) did not have high organic carbon content.

The role of organic matter in soils of the humid tropics cannot be underestimated. Greene (1961) has emphasized that after losing its original structure the organic matter serves as food for a succession of animals and microorganisms. It contains a great variety of substances carrying numbers of exchange sites, such as carboxylic or phenolic groups, able to hold cations and capable of becoming ionized in water. He cited some figures from Endredy and Montgomery, on the cation exchange capacity of organic carbon in soils of different nature, as follows:

Approximate Depth Inches	CEC, meq/100g of Carbon		
	Oxysols	Ochrosols	Basisols
0 - 3	127	213	266
3 - 9	117	185	274
9 - 22	85	79	163
22 - 47	0	0	79

Exchangeable Hydrogen and Exchangeable Aluminum

Data for exchange acidity as exchangeable hydrogen and exchangeable aluminum are reported in Table 2. It was found that aluminum is more responsible for the exchange acidity, as concluded by Coleman et al. (1959), Jackson (1963), and other workers for acid soils. The ratio

$$\frac{\text{meq. exch. Al}}{\text{meq. exh. Al + Ca + K + Mg + Na}}$$

indicates an aluminum saturation value higher than 60 percent. Under these conditions, plant growth is affected by aluminum toxicity and phosphorus applied as fertilizer becomes easily fixed and unavailable for plants, unless a wise liming program be carried out, such as pointed out by Kamprath (1967).

As a general tendency, exchangeable Al was higher in the upper horizons where the total cation exchange capacity was higher and associated with higher contents of organic matter, H-ionization from clays, selective absorption of OH, or negative charges developed from metal coordinations. For subsoil horizons, Al was significantly higher for the well-drained, bright-red profiles near the river than for the others.

Cation Exchange Capacity, Exchangeable Bases and Base Saturation

Table 2 lists the values obtained for cation exchange capacity, individual exchangeable bases, and base saturation. In general, the values obtained for cation exchange capacity were quite low, particularly for subsoil horizons. Generally these values were higher in upper horizons, associated with higher organic matter contents, decreased in intermediate horizons and increased slightly again in the bottom horizons.

However, it must be pointed out that CEC by pH 7.0 ammonium acetate includes a large number of pH-dependent charges. Therefore, differences between CEC as determined by the ammonium acetate method and that determined by the sum of the cations method must be attributed to pH-dependent charges of clays and organic matter (Coleman et al., 1959).

In general, exchangeable base contents were extremely low particularly potassium. The higher values for the upper horizons are attributed to biocycling such as it has been reported for other soils.

Base saturation percentages ranged from 9 percent to 57 percent, but most of the values are centered around 15-35 percent. There was no apparent relationship among base saturation and sites, but the top and bottom horizons tended to present the highest values.

Soil Fertility Determinations

Data for pH, organic matter, acid extractable basic cations (Ca, Mg, and K) and acid extractable phosphorus are listed in Appendix I. In general, these data revealed the soils to be more acid in the upper horizons than with depth. Organic matter content decreased with depth. Low or very low contents of Ca, Mg, K and P were found in all the soil profiles. However, samples 47 to 56 (which were taken on a river island and sand beach south and north of the Meta River) showed medium to high fertility. The higher and rather abnormal values obtained for the top layer of profile 4 (sample 21) should perhaps be attributed to artificial or disturbed conditions. The site is in a pasture near water and an animal feeding area. Thus, it is probable that it has received more manure than the other sites. Also, there exists the possibility of dusting by fertilizer material since it was near the ranch headquarters.

Micronutrient Status

The results of micronutrient determinations of surface horizons are presented in Table 3. In general, low Fe values and very low Cu, Zn, and Mn values were obtained by both methods. Higher values for these elements in sample 21 might also be attributed to animal herding as were the P, Ca, Mg, and K results. Low values obtained for samples 1 to 42 could be attributed to advanced stages of weathering. Lower contents of Cu, Zn, and B in samples 8 and 42 could be related to their higher content of sand. Higher values for the river sand samples (samples 50 and 54) could be explained by less advanced stages of weathering and some isomorphic substitution of trace elements as impurities in2:1 type clays (Kovda, 1959; Hodgson, 1963; and Mitchell, 1964).

Clay and Silt Mineralogy

Table 4 summarizes the results obtained from the interpretation of x-ray diffractograms of clays and silts from A and B horizons of profiles 2, 4, 5, and 6 and for one surface sample (0-10 cm) of the sand beach on the north side of the Meta River (sample 54). Figures 6, 7, 8, and 9 are diffractograms of the sample No. 30 (88-148 cm depth) which is characteristic of several of the other samples.

Samples of profiles 2, 4, 5, and 6 will be discussed first. With few exceptions kaolinite, intergradient 2:1 - 2:2 clays, and pyrophyllite were common to all the samples. Quartz, mica, feldspar,

Table 3. Micronutrient content of surface horizons

Soil no.	Sample no.	Kind of sample	N. C. method[a]				Hunter-Pratt method[b]				Hot water extraction method[c]
			Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn	boron
			- - - - - - - - - -			p.p.m.	- - - - - - - - - -				lbs/A
1	1	Surface layer	1.7	.3	51	2.0	6.8	4.5	3750	7.0	1.44
2	8	Surface layer	1.0	.2	65	1.5	2.5	3.0	3170	7.0	1.52
3	15	Surface layer	1.3	.4	85	2.0	3.7	4.0	4570	6.0	2.08
4	21	Surface layer	1.6	.7	155	15.0	5.6	6.5	6000	75.0	2.40
5	26	Surface layer	1.3	.3	79	3.5	3.7	5.0	4500	10.0	1.60
6	31	Surface layer	1.5	.3	65	5.0	4.3	5.0	4910	15.0	2.08
7	37	Surface layer	1.5	.8	155	2.5	3.7	5.0	4850	3.0	1.76
Dune	42	Surface layer	1.1	.4	41	3.5	1.8	4.0	1620	10.0	1.68
Island	50	Surface layer	4.2	5.0	191	69.0	8.0	25.0	5250	200.0	3.36
North Beach	54	Surface layer	4.7	5.8	204	79.0	9.3	32.0	5580	190.00	4.00

[a] North Carolina extractant solution, Soil Science Department, North Carolina State University, Raleigh.

[b] Hunter and Pratt Method, Soil Science Department, North Carolina State University, Raleigh.

[c] Soil Testing and Plant Analysis Laboratory, University of Georgia, Athens.

Table 4. Summary of clay minerals of selected horizons

Soil no.	Sample no.	Depth cm	Particle size, microns			
			<.2	.2-2	2-5	5-20
North Beach	54	0-10	K^3 M^2 $2{:}1^1$	K^3 I^T M^2 $2{:}1^1$	K^1 I^2 M^2 Q^2 F^T	K^2 M^2 Q^3 F^1
2	9	20-34	K^3 I^2 P^1	K^2 I^2 P^1	K^1 I^1 P^1 Q^3	K^T I^1 P^T Q^3
	13	178-208	K^3 I^1 P^T	K^3 I^1 P^2 M^1 V^2	K^1 I^T P^1 M^1 Q^3 F^1	K^1 I^T P^1 M^1 F^1 Q^3
4	22	8-22	K^3 I^3 P^T	K^2 I^3 P^1	K^1 I^1 P^T M^T Q^3 S^T	K^T Q^3 V^T
	25	132-140	K^3 I^2 P^T	K^2 I^2 P^1	K^1 I^1 P^T M^T Q^2 F^T	K^1 I^T P^1 M^T Q^3 F^1
5	27	12-32	K^3 I^2P^T	K^3 I^3 P^1 S^T	K^2 I^1 P^1 M^1 Q^3 V^T	K^1 I^T P^1 M^1 Q^3 F^1 S^1
	30	88-148	K^3 I^2	K^2 I^2 P^1 M^1 F^1 S^1	K^1 I^1 P^1 M^1 Q^3 F^2 S^1	K^1 P^1 M^1 Q^3 F^1 S^1 V^T
6	32	10-19	K^3 I^2 P^T	K^2 I^2 P^1	K^1 I^1 P^1 Q^3 S^1	K^1 I^1 P^T M^T Q^3 F^1
	35	105-140	K^3 I^1	K^3 I^2 P^1	K^1 I^T P^1 M^1 Q^2 S^1	K^1 I^T P^1 M^1 Q^3 F^T S^1

KEY:
K - Kaolinite
I - Intergradient 2:1 - 2:2
P - Pyrophyllite
M - Mica
Q - Quartz
F - Feldspars
V - Vermiculite
S - Vermiculite-Mica Stratification
2:1 - Smectite

Semi-Quantitative Estimation:
3 - Abundant (>50%)
2 - Medium (25-50%)
1 - Small (10-25%)
T - Trace (<10%)

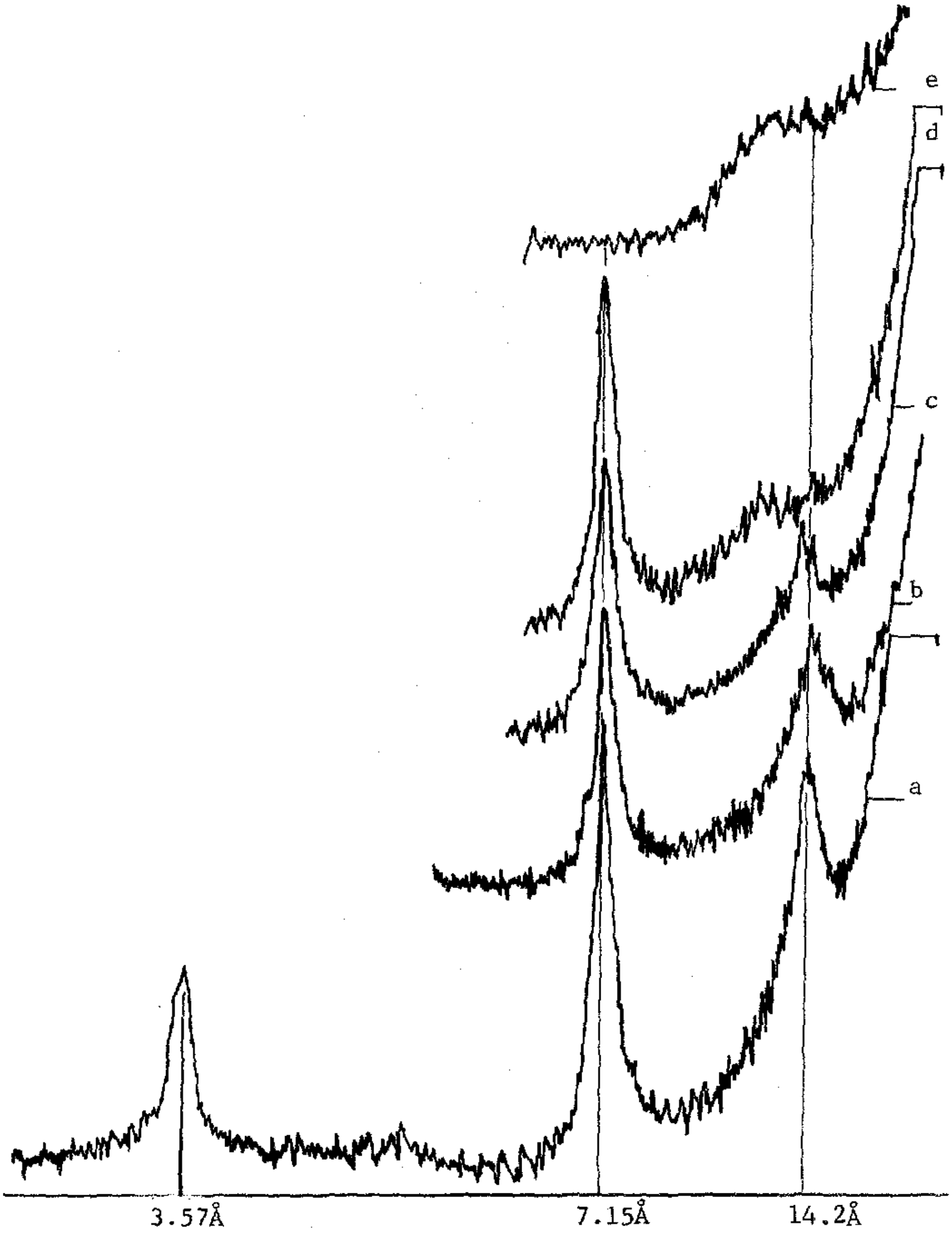

Figure 6. X-ray diffraction traces of the <.2μ clay of sample 30 (soil profile 5, 88-148 cm) (a = Mg-saturated 25°C; b = Mg-saturated 25°C ethylene glycol solvation; c = K-saturated 25°C; d = K-saturated 350°C; e = K-saturated 550°C heating)

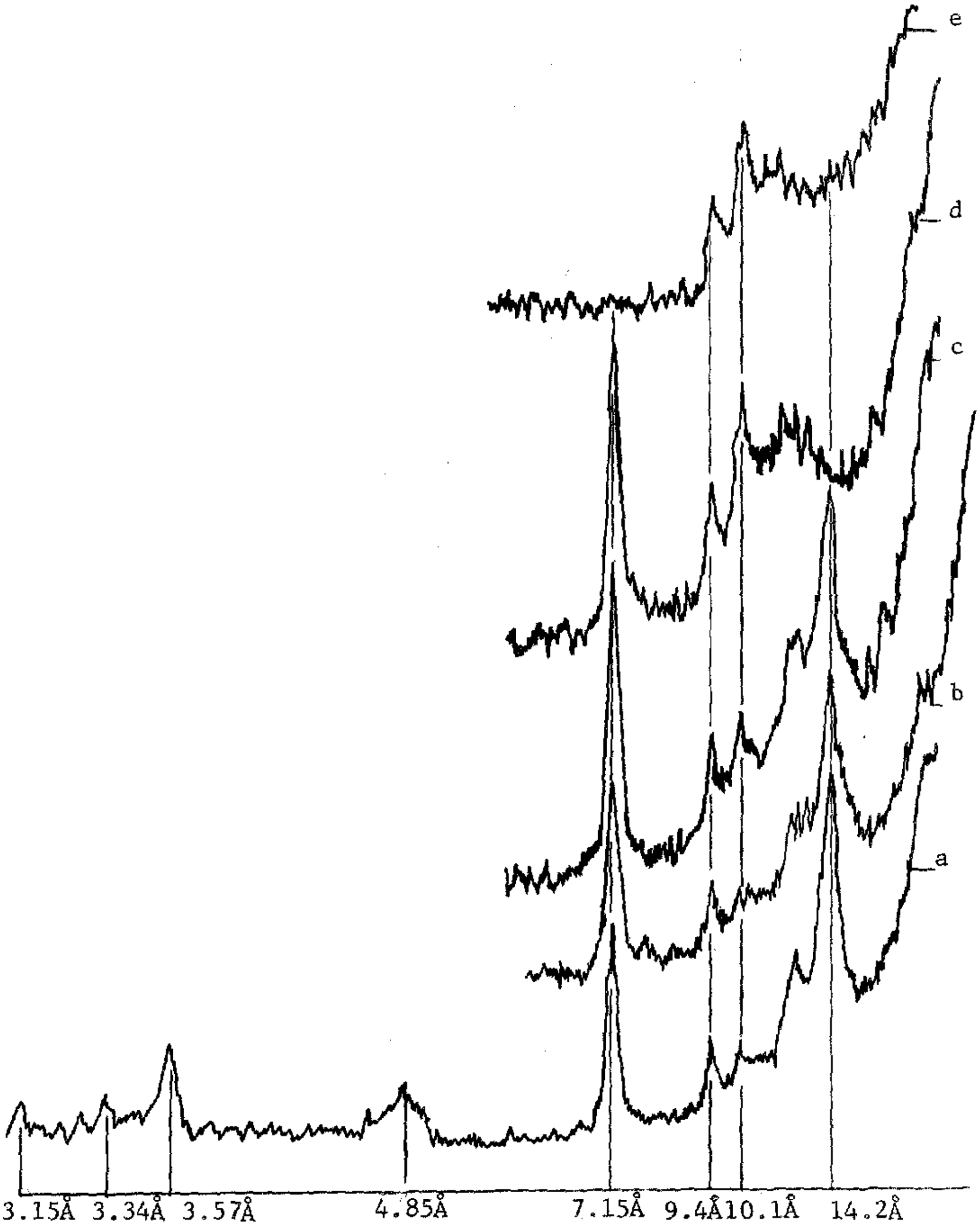

Figure 7. X-ray diffraction traces of the .2 - 2.0μ clay of sample 30 (soil profile 5, 88-148 cm) (a = Mg-saturated 25°C; b = Mg-saturated 25°C ethylene glycol solvation; c = K-saturated 25°C; d = K-saturated 350°C; e = K-saturated 550°C heating)

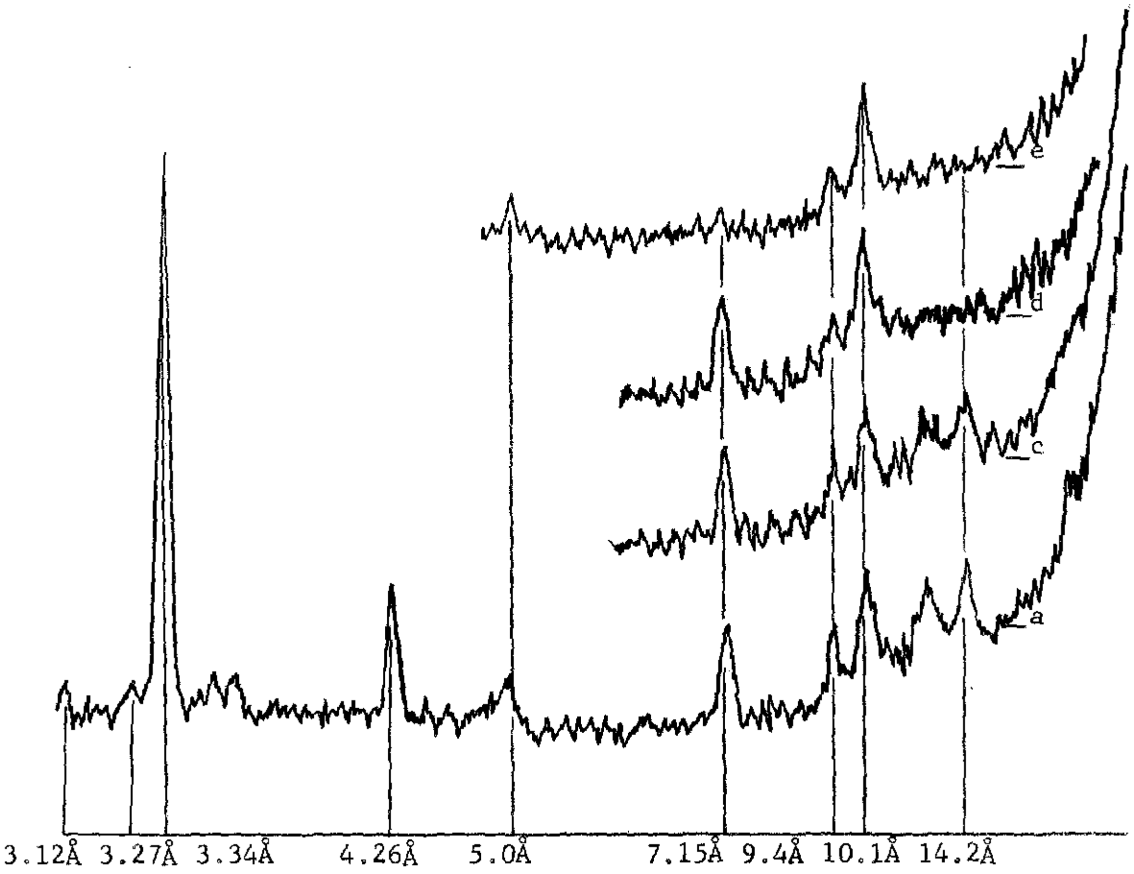

Figure 8. X-ray diffraction traces of the 2 - 5μ silt of sample 30 (soil profile 5, 88-148 cm) (a = Mg-saturated 25°C; c = K-saturated 25°C; d = K-saturated 350°C; e = K-saturated 550°C heating)

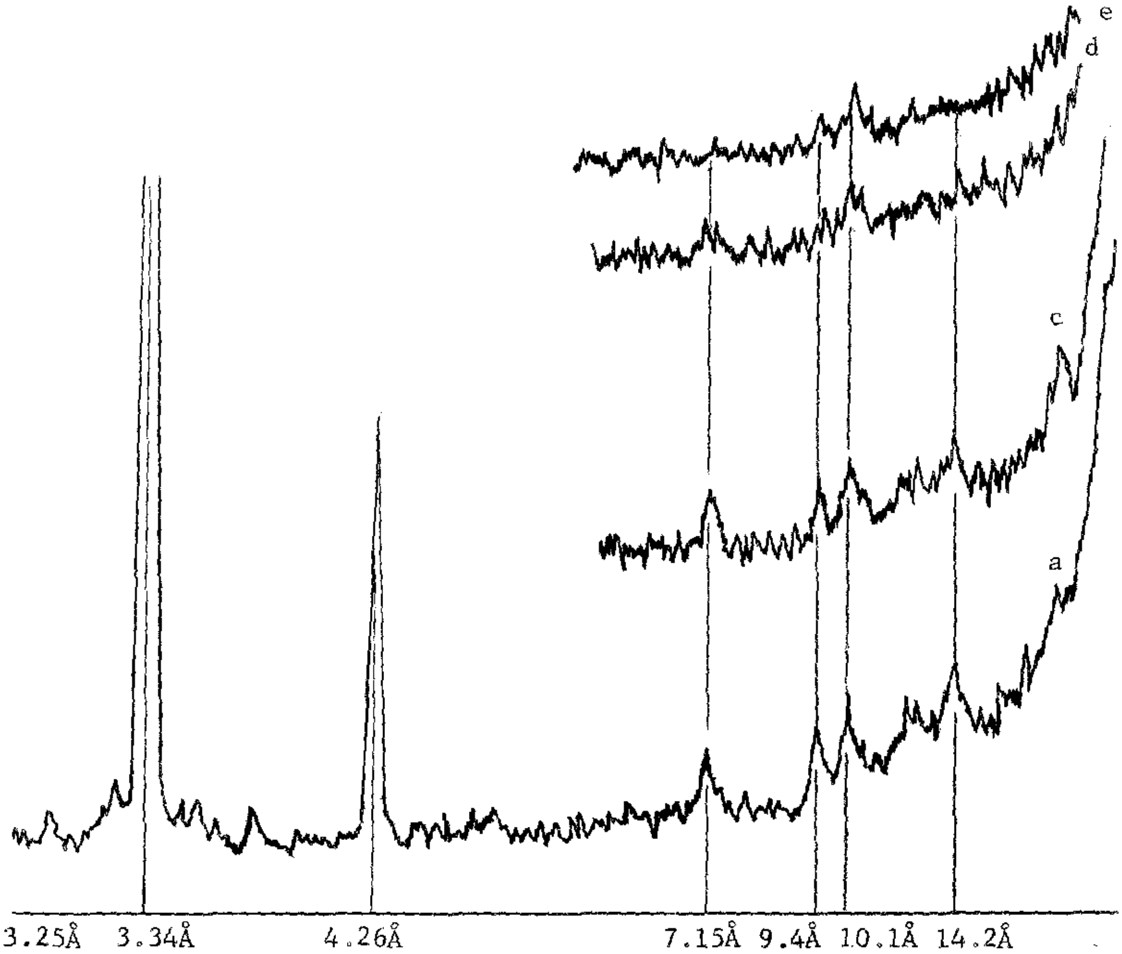

Figure 9. X-ray diffraction traces of the 5 - 20μ silt of sample 30 (soil profile 5, 88-148 cm) (a = Mg-saturated 25°C; c = K-saturated 25°C; d = K-saturated 350°C; e = K-saturated 550°C heating)

vermiculite, and a "vermiculite-mica stratification" were only present within specific particle sizes and/or at different horizons. "True" chlorite appeared to be absent or present only in trace amounts. Mica and feldspar were absent in silt from the upper horizons of profile 2 (sample No. 9) but still present in respective subsoil horizons (sample No. 13) and also in the other samples. This seems to indicate that mineral weathering has reached more advanced stages in the upper sandy loam layers of the better-drained soils near the Meta River. The absence of mica and feldspar in the fine clay (<0.2 μ) of all the horizons and also in the coarse clay (.2 - 2 μ) of the upper horizons suggested that the clay has been more weathered than the silt particles. These observations are in agreement with the sequence of clay weathering proposed by Jackson (1964b).

Semi-quantitative estimation of the diffractogram peaks showed that for the clay particles (<.2 μ and .2 - 2 μ)kaolinite was the predominant clay, followed by lesser amounts of interstratified 2:1 - 2:2 clays and pyrophyllite.

In the silt particles (2-5 μ and 5-20 μ) quartz was the predominant mineral followed by approximately equal amounts of kaolinite, 2:1-2:2, intergrades, and pyrophyllite. Mica and feldspar were sometimes present. The presence of vermiculite was rather sporadic. Intergradation or stratification of vermiculite and mica (Table 5 and Figures 7, 8, and 9) was observed for the profile 5, particularly in the subsoil horizon.

In general, these results agreed with the clay mineralogical suite expected in soils of this nature. Cady (1960) and Keller (1964, 1968),

Table 5. Sand mineralogy of selected horizons

Soil no.	Sample no.	Depth	Total grains	Quartz	Rock fragments	Feldspars	Heavies and opaques	Micas	Quartz plus heavies and opaques
		cm	No.	No.	No.	No.	No.	No.	%
1	2	18-30	327	317	5	0	5	0	98
	2	18-30	520	505	9	1	5	0	98
	5	160-185	379	357	16	0	6	0	96
2	9	20-34	304	291	9	0	4	0	97
	13	178-208	327	300	10	2	5	0	96
	13	178-208	391	371	15	0	5	0	96
4	22	8-22	311	282	14	0	13	2	95
	25	132-140	382	345	24	0	13	0	94
	25	132-140	430	410	16	0	4	0	96
5	27	12-32	358	328	16	1	12	2	95
	30	88-148	349	320	17	0	12	0	95
6	32	10-19	350	320	6	0	24	0	98
	35	105-140	370	348	25	0	7	0	96
North Beach	54	0-10	305	202	68	1	3	2	67

for instance, indicated that kaolinite would occur in soils having a high ratio of Al to Si, H-ions supplied by acid or from dissociation of water under good drainage conditions and Fe removed from solution by oxidation to the relatively insoluble Fe_2O_3 form. Under these conditions, depotassication of the clays becomes a common weathering process involving mobilization and diffusion of K^+ from the clays, H^+ from the plant-derived acids, and OH^- from the water. Combined depotassication and desilication of illite may yield kaolinite.

On the other hand, the presence of intergradient 2:1-2:2 layer silicates (Jackson, 1964a and 1964b) in acid soils, mostly as 14Å intergrades, might be explained by the precipitation of hydroxy Al and hydroxy sesquioxides, as gibbsite-like (brucite-like) structures in the interlayer spaces of montmorillonite and vermiculite whose properties are intergradient between those of the expansible minerals and those of chlorite. The common reaction with release of Al for interlayer building is as follows:

$$\text{Mica} \rightleftarrows \text{Vermiculite} \rightleftarrows \text{14A-Intergrades}$$

Accumulation of aluminum as interlayers in 2:1 minerals of soil becomes a genetic stage in the 2:2 $\longrightarrow$ 1:1 weathering sequence through which kaolinite develops in soils. Weathering proceeds by the following reactions:

$$\text{14A-Intergrade} \rightleftarrows \text{Al-Chlorite} \rightleftarrows \text{Kaolinite}$$

The occurrence of micas and feldspars in the river beach material and of minor amounts in the soil profiles may be attributed to the presence of these materials in the initial sediments. The relative decrease in feldspar and mica contents in the finer fractions indicates strong depletion of these more easily weatherable minerals in the smaller particle sizes during pedogenesis.

The presence of rather significant amounts of pyrophyllite in the soil profiles but not in the material from the river beach indicates possible development during pedogenesis or a different source of sediment. Hemley and Jones (1964) have suggested that kaolinite plus quartz yielded pyrophyllite by H-metasomatism in hydrothermal alteration according to reactions of the general order:

$$\text{Albite} + \text{H}^+ \longrightarrow \text{Paragonite} + \text{Quartz} + \text{Na}^+$$

$$\text{Paragonite} + \text{Quartz} \longrightarrow \text{Kaolinite}$$

$$\text{Kaolinite} + \text{Quartz} \longrightarrow \text{Pyrophyllite}$$

Weston-Dunn (1922), Vhay (1938), and Ehlman and Sands (1957), by phase equilibrium studies and geologic occurrences, found that pyrophyllite was formed by hydrothermal alteration or replacement of the original clay mineral suite of shales or of volcanic rocks. Likewise, Gruner (1944), working on the hydrothermal alteration of feldspars in acid solutions between 300 and 600°C, observed that with a Al/Si ratio less than 1:2 at 300°C pyrophyllite formed by reaction of microcline + K^+ if aluminum concentration was low.

Furthermore, Zen (1961, 1969), studying the conditions of pyrophyllite deposit formation in North Carolina, considered the reaction:

$$\text{Kaolinite} + \text{Quartz} = \text{Pyrophyllite} + H_2O$$

and proposed the following theory for the origin of the pyrophyllite. The original deposits were bodies of saprolite which resulted from the deep weathering of the rhyolitic or dacitic country rock or of slate and plyllite country rock. The residual material, high in silica, aluminum, and ferric oxide, with most of the other components being leached. The resulting rock would have the general chemical composition of the pyrophyllite under mutual relation with quartz and kaolinite as equilibrium coexistence; or, alternatively, the kaolinite could represent a retrograde alteration product of pyrophyllite in the presence of quartz, although kaolinite + quartz is in equilibrium with or is more stable than pyrophyllite.

Occurrence of these reactions was not verified in this study nor could they be related to hydrothermal alteration. Volcanic rocks, slate or phyllite country rocks are not suspected to occur at the sites. However, the presence of pyrophyllite in the samples suggests that perhaps such transformation is taking place during pedogenesis. Or, pyrophyllite could be inherited from the initial parent material mineral suite transported from the eastern Cordillera. No specific information was available to the author concerning mineralogical composition of materials in that Cordillera.

The absence of gibbsite might be explained by the so-called "anti-gibbsite effect" mechanism by which Al released is used for interlayer "lattice building" (Jackson, 1964a). This disposition of aluminum tends to inhibit free $Al(OH)_3$ formation in soils so long as actively weathering 2:1 layer silicates are present.

Diffractograms of the beach sand (sample No. 54) north of the Meta River indicated significant differences in clay minerals compared to the soil profile samples (Table 4). Small amounts of a 2:1 expanding clay were detected under Mg-saturated and ethylene glycol solvation both in the fine and coarse clay fractions. Likewise, significant amounts of 10 Å mica-like clay minerals which did not expand upon glycolation were observed in the clay and silt fractions. Feldspars were common in the 2-5 μ and 5-20 μ silt particles. Pyrophyllite was absent.

It seems convenient here to discuss the hypothesis of wind-blown materials from the north beaches to the high plains south of the Meta River. If active, this process should result in some mineralogical differences, particularly in the soils located at or near to the river bank. However the mineralogical data do not support this hypothesis. It is possible that the beach materials, if blown in small amounts annually rapidly become depleted of weatherable materials under the well-drained sites south of the river. Present evidence is not considered conclusive.

Sand Mineralogy

Table 5 present the results of microscopic examination of sand fractions from selected horizons. In general, quartz was the predominant mineral both in the fine (105-250 μ) and very fine sand (50-105 μ) particles. Quartz grains were usually subangular and no significant shape differences were found in the various profiles.

The total percentage of relatively stable materials (quartz plus heavies and opaques) was greater than 94 percent, followed by a low percentage of rock fragments. The content of mica and feldspars was practically negligible. This agrees with the results obtained from the diffractograms of finer fractions and with the idealized weathering pattern proposed by several authors (Jackson and Sherman, 1953; Cady, 1960). Some of the minerals listed as heavies and opaques appeared to be hematite, hornblende, tourmaline, and magnetite, but no detailed study was made of these minerals.

McKeague and Cline (1963) pointed out that for some soils quartz in crystalline form may constitute almost 100 percent of the inorganic fraction. The Oxisols, for instance, have lost a high proportion of the combined silica present in the original rock materials and contain as much as 85 percent quartz in sand and silt fractions.

Thin Section Observations

Thin section observations did not show any evidence of clay skins (argillans) on the peds, on the walls of the non-capillary pores, or on soil channels. This agrees with the field profile descriptions. At some places, there was a slight tendency for clay accumulation, but these features were interpreted as stress cutans or pressure faces (Cady, 1960; Brewer, 1964, p. 224).

The s-matrix appeared very porous. The skeletal grains consisted almost exclusively of quartz. The quartz had an intensive luster, irregular to conchoidal fracture, steel gray to whitish and yellow color, often with pronounced rounded surface and fillings or depositions of plasma in cracks or dents of the grains, such as described by Kubiena (1970) and FAO (1965).

SOIL CLASSIFICATION

Data obtained pointed out the presence of oxic horizons and, therefore, the taxonomic order of Oxisols for the soils studied (Soil Survey Staff, 1970). According to the new classification system (ibid.), the following criteria were used to establish the presence of oxic horizons.

Absence of Argillic Horizons

Particle size distribution tended to show a clay content increase, particularly for profiles 1 and 2, and a substantial increase in the content of finer clay with depth if expressed on iron-free basis, such as in profile 2 (Table 1). But, clay skins were absent in suspected argillic horizons. Further, it is necessary (ibid., 3-13) that an eight percent clay increase be observed within a vertical distance of 30 cm in order to qualify for an argillic horizon. Although the data are not explicit for this point, field observation and laboratory data indicate that the clay content increase with depth is less abrupt than required by this criteria.

Cation Exchange Capacity

Table 6 shows cation exchange capacity values, by ammonium acetate at pH 7.0 and by sum of cations for the soil particles less than 2 mm in diameter and calculated for the clay fraction. In general, values less than the 16 me/100 gram of clay specified for oxic horizons (ibid.) were obtained for most subsoil horizons, with ranges between 11.9 and 21.5 me/100 gram of clay. In fact, these values would be lower if some additional exchange capacity provided by the organic matter in the subsoil (profile descriptions) is subtracted. Benavides (1963) calculated

Table 6. Soil cation exchange capacity (CEC) and clay cation exchange capacity (clay CEC) by different methods

Soil no.	Sample no.	Depth	Clay by calgon pipette	Clay by 15-bars	CEC by ammonium acetate pH 7	CEC by sum of cations	CEC of the clay particle only: by ammonium acetate at pH 7, by pipette	CEC of the clay particle only: by ammonium acetate at pH 7, by 15-bars	CEC of the clay particle only: by sum of cations, by pipette	CEC of the clay particle only: by sum of cations, by 15-bars	Cation retention of clay[a]
		cm	%	%	meq/100 g soil	meq/100 g soil	meq/100 g of clay	meq/100 g of clay	meq/100 g of clay	meq/100 g of clay	meq/100 g of clay
1	1	0-18	19	22	6.1	3.2	32	28	17	15	11
	2	18-30	20	20	4.7	2.5	24	24	13	13	10
	3	30-80	23	23	4.4	2.1	19	19	9	9	8
	4	80-160	26	31	5.4	1.7	21	17	7	6	4
	5	160-185	27	31	5.8	2.2	22	19	8	7	5
	6	185-205	34	32	--	2.9	--	--	9	9	7
	7	205-210	40	--	--	--	--	--	--	--	--
2	8	0-20	17	18	5.4	3.1	32	30	18	17	13
	9	20-34	19	20	4.8	2.4	25	24	13	12	9
	10	34-71	21	20	3.3	2.0	16	17	10	10	6
	11	71-125	23	24	3.1	1.8	14	13	8	8	4
	12	125-178	30	31	4.4	1.7	15	14	6	6	4
	13	178-208	39	--	5.8	2.4	15	--	6	--	5
	14	208-218	41	--	7.3	3.0	18	--	7	--	6
3	15	0-16	31	30	13.2	4.1	43	44	13	14	11
	16	16-42	34	31	11.6	3.6	34	37	11	12	9
	17	42-70	35	32	8.4	3.2	24	26	9	10	6
	18	70-92	38	36	8.0	2.0	21	22	5	6	3
	19	92-112	37	35	4.8	2.4	13	14	7	7	4
	20	145-170	35	35	6.0	2.6	17	17	7	7	5

Table 6 (continued)

Soil no.	Sample no.	Depth	Clay		CEC		CEC of the clay particle only				Cation retention of clay[a]
			by calgon pipette	by 15-bars	by ammonium acetate pH 7	by sum of cations	by ammonium acetate at pH 7 by pipette	by ammonium acetate at pH 7 by 15-bars	by sum of cations by pipette	by sum of cations by 15-bars	
		cm	%	%	meq/100 g soil		meq/100 g of clay				
4	21	0-8	35	37	13.0	6.5	37	35	19	18	15.0
	22	8-22	38	35	10.1	4.6	27	29	12	13	11.0
	23	22-46	40	37	8.8	2.9	22	24	7	8	6.0
	24	46-132	43	37	6.0	1.4	14	16	3	4	2.0
	25	132-140	49	48	7.0	1.5	14	15	3	3	2.0
5	26	0-12	38	35	10.7	4.7	28	31	12	13	10.0
	27	12-32	41	35	8.7	3.1	21	25	8	9	6.0
	28	32-58	43	37	7.1	2.3	17	19	5	6	4.0
	29	58-88	45	38	5.4	0.9	12	14	2	2	1.0
	30	88-148	45	39	5.9	0.8	13	15	2	2	1.0
6	31	0-10	46	43	13.6	5.0	30	32	11	12	10.0
	32	10-19	44	42	11.4	3.9	26	27	9	9	8.0
	33	19-31	52	44	10.3	3.3	20	24	6	8	5.0
	34	31-105	55	44	8.1	1.8	15	18	3	4	2.0
	35	105-140	59	50	7.0	0.7	12	14	1	1	0.7
	36	140-150	61	52	7.4	0.7	12	14	1	1	0.7
	36A	140-150	--	55	6.8	0.7	--	--	--	--	--
7	37	0-10	35	36	12.0	5.1	34	33	15	14	9.0
	38	10-25	39	36	10.6	4.2	27	29	11	12	9.0
	39	25-44	43	39	6.4	3.0	15	16	7	8	6.0
	40	44-77	44	40	7.4	1.8	17	19	4	5	3.0
	41	77-133	42	43	7.4	1.0	18	17	2	2	1.0

[a] CEC at pH 7 by summing K^+, Mg^{++}, Ca^{++}, Na^+ and Al^{+++}; divided by percent clay by calgon-pipette method: Cation Retention = $\frac{\text{Sum of Bases + Al}}{\text{\% Clay}}$ (100)

a value of 384 me/100 gram of carbon for soils of the same area.

Cation Retention

Cation retention values for 100 grams of clay after ammonium saturation (Table 6) were in general less than 10 me/100 gram of cations for 100 grams of clay for subsoil horizons, as established for oxic horizons. Higher values for the upper horizons are attributed to negative charge sites on the organic matter.

Absence of Weatherable Minerals

Weatherable minerals (Table 5) were practically absent in the oxic horizons.

Water Dispersible Clay

The water dispersible clay content of the upper three horizons ranged from 11 to 42 percent, whereas in the subsoil (oxic) horizons, water-dispersible clay content ranged from 2 to 4 percent (Table 1 and Appendix H). This indicated the presence of high amounts of stable clay aggregates in the subsoil horizons and, consequently, suggested the boundaries for the oxic horizons (Soil Survey Staff, 1967, p. 31).

Clay Minerals and Clay Content

Low charge 1:1 type clay was predominant in the mineral suite and clay contents were above 15 percent thus satisfying these oxic horizon criteria (Soil Survey Staff, 1970, 3-32, 33) for all the subsoil horizons. In addition, field observations showed diffuse changes in color and subhorizons boundaries, solum deeper than 2 meters and lack of original rock structure in the control section.

Climatic data from the area (FAO, 1965) indicates that the subsoil is dry approximately 60 consecutive days or more in most years. Thus, soil profiles 4, 5, and 6 class as Typic Haplustox. Soil profile 3, because of the presence of low chroma colors (<3) and thus assumed water saturation in the 42-70 cm layer, would be an Umbraquox probably Typic (Soil Survey Staff, 1970), (see description in Appendices).

Soil profiles 1 and 2 would be classified as Ultisol intergrades (Ultic Haplustox) by virtue that they have cation exchange capacities greater than 13.5 me/100 gram of clay, cation retention greater than 6 me/100 gram of clay and a clay content increase approaching that diagnostic for an argillic horizon.

Profile 7 is lacking colors necessary for Aquox although a water table was present at 77 cm at the time of sampling. Further, if a comparison of depths to soft plinthite nodules is made it is noted that they occur at 44 cm in profile 7 and 70 cm in profile 3. If the theory is accepted that the soft plinthite nodules form in a zone of water table fluctuation it appears that their presence should be used as drainage class criteria in these Oxisols. It follows that profile 7, by virtue of having soft plinthite at the shallowest depth, would be considered as the most poorly drained of the profiles studied. This placement would be indicated by field observation of the landscape position and water table at the time of sampling. Further studies of color, soft plinthite nodules, and water table depth are suggested. Also, it must be noticed that the rather high content of 2:1-2:2 intergrade clay minerals present in most of the samples points to the "Ultic" nature of the soils. Since the soil sampling was not deep enough to reach the lower part of the B horizon, greater amounts of weatherable minerals and/or argillic horizons might be present deeper in the solum. Absence of argillans in the upper horizons might be explained by self-destruction under alternated dry-wet periods predominant in the area. Therefore, an argillic horizon may be present at depths greater than those sampled. This is not likely, however, since no field evidence was observed in auger borings made below the bottom of the pits.

The classification suggested here essentially agrees with previous taxonomic groups indicated by Guerrero (1963) and Wambeke (1965) for soils of the same areas. From the data available to classify these soils at the family level, soil profiles 3, 4, 5, 6, and 7 are placed in clayey, kaolinitic, isohyperthermic families, whereas profiles 1 and 2 are placed in either fine-silty or fine-loamy, kaolinitic, isohyperthermic families. In the FAO system of mapping unit names (FAO, 1970), they would be called either Xanthic or Rhodic Ferrasols.

SUMMARY AND CONCLUSIONS

Seven soil profiles within a general landscape of the eastern savannas ("Llanos Orientales") of Colombia were studied in an area immediately south of the Meta River in a traverse near Orocue. Soils of differing drainage were selected to characterize their physical, chemical, and mineralogical properties. Additional soil samples within the same area, but of recent alluvium along the Meta River, were taken to establish mineralogical and geomorphical relationships, if any. The soil profiles are believed representative of more than 1,000,000 hectareas in eastern Colombia.

The area studied consists of tropical savanna treeless plains and is located approximately 4°50' north latitude and about 250-300 meters (800-1,000 ft.) above sea level. Although little detailed information is available, some data report 1,734 mm (68 inches) of annual rainfall distributed with a long rainy season from April to November followed by a short almost rainless period from December to March. Average annual temperature is 28°C (82°F) and is practically uniform throughout the year. The strong northeast trade winds during the dry season have been observed to blow materials from the beaches of the Meta River onto areas south of the river. This is evidenced by the presence of sand dunes near the south bank of the Meta River.

The relief is essentially flat and most of the soils are well drained but since a catenary situation is present, some soils in depressions and closer to the drainage-ways ("esteros") have shallow fluctuating water tables, especially during the rainy season. The parent material consists of mixed alluvial sediments, perhaps deposited during the Pleistocene. The vegetation consists mainly of short native bunch grasses, mainly Trachypogon sp. of very low nutrient content and self-sustained to a large extent by biocycling of nutrients and annual burning.

Within the soil profiles, clay contents increase with depth, but clay skins were absent. Chemical analyses indicate that the soils are acid, they have very low cation exchange capacity, a high content of exchangeable aluminum, very low base retention, low percent of base saturation, and a relatively high content of free iron oxides. Significantly higher pH values were obtained in water than in KCl. Organic carbon content is surprisingly high both for top and subsoil horizons and decreases regularly with depth. In addition, the contents of B, Cu, Zn, and Mn are quite low. Soil test analyses reveal that the available phosphorus contents are extremely low. Mineralogical determinations in the clay and silt fractions of selected horizons for the seven profiles show that kaolinite is the predominant clay mineral in the very fine and fine clay fraction (less than .2 μ and .2-2 μ, respectively). Intergradient 2:1-2:2 clay minerals and pyrophyllite were present in most samples and minor amounts of micas and feldspars were found in some subsoil samples. A kind of "vermiculite-mica stratification" pattern is present in some horizons. Vermiculite is rather sporadic in occurrence and chlorite and gibbsite were not detected. Absence of weatherable minerals, such as mica and feldspar, in the upper horizons but their presence in trace amounts in the subsoil horizons indicates advanced weathering of the soil solums.

Mineralogy studies of the sand fraction found a predominance of quartz grains and negligible contents of micas and feldspars in all the samples.

On the other hand, the presence of some 2:1 expanding smectite-type clay, greater content of mica and rock fragments and the absence of pyrophyllite in the river alluvium sample north of the Meta River indicates a different mineral suite at a less advanced weathering stage. Consequently, it is concluded that the soils studied are developed from older alluvial material. No evidence indicates that the soils are mineralogically influenced by wind-blown material from the Meta River flood plain. Either the observed wind blown material is preweathered or deposited in such small amounts annually that it is rapidly weathered after deposition.

According to the criteria presented in the new classification system (Soil Survey Staff, 1970), the subsoil horizons of the seven profiles observed meet the requirements for oxic horizons. The clay increase with depth in the profiles is too gradual for them to be considered as argillic horizons, and clay skins were not detected in thin sections. Absence of rock structure within a depth of two meters, the presence of more than 15 percent clay, a cation exchange capacity of the clay fraction of less than 16 meq/100 gram of clay, a base retention less than 10 meq/100 gram of clay, a predominance of 1:1 kaolinite clay in the clay fraction, a low content of weatherable minerals in the sand fraction, and an abrupt water dispersible clay content decrease with depth, also support an oxic horizon classification. In addition, horizon boundaries are diffuse and free iron oxide content is high.

Accordingly, soil profiles 4, 5, and 6 could be classified as clayey kaolinitic isohyperthermic, Typic Haplustox. Soil profiles 1 and 2, because of the higher sand and silt content within the control section, clay increase in some subsoil horizons, rather high cation exchange capacity, and retention of bases class as fine loamy of fine silty Ultic Haplustox. Profiles 3 and 7, due to the presence of a shallow, fluctuating water table and presence of chromas less than 3, particularly in profile 3, class as clayey, kaolinitic, isohyperthermic, Typic Umbraquox.

Plinthite nodules were noted in the subsoil of several profiles. It appeared at the time of sampling that these were related to the occurrence of a water table but this could not be established from the limited observations. Also a high water table predictable from the position of the sites on the landscape was present at the time of sampling in profile 7, but its presence was not indicated by low chroma soil colors.

Finally, it appears that further research to characterize these soils should include such points as: (1) soil profile sampling in short vertical distances to determine more precisely vertical rate of clay content increase, (2) deeper sampling to establish the nature and amount of weatherable minerals and possible presence of argillic horizons, (3) sand fractionation to establish lithologic discontinuities, (4) relationships of the water table level to color, plinthite formation and free-iron oxide content, (5) determination of the cation exchange capacity and specific surface area of the clay fraction, and (6) revisions of the soil subgroups of classification suggested above.

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APPENDICES

Appendix A. Soil Profile No. 1 (Piñal)

Description: Pit by R. Guerrero and S. W. Buol.

Date: August 2, 1969.

Location: Approximately 1-1.5 km east of the El Piñal ranch house and about 200 meters south of the Meta cliff; southwest corner of I.C.A. 1969 experiments, between fence and air strip.

Vegetation: Treeless savanna.

Physiography: Typical river bank plain draining toward the Meta River.

Parent Material: Mixed acid alluvial sediments.

Slope: At the place, 0-1%.

Drainage: Somewhat excessively drained.

Erosion: By wind?

Depth to Water Table: Deep.

Remarks: Supposedly a site influenced by wind-blow materials, but rather local and non-representative of the whole area.

0 - 18 cm	Dark reddish brown (5YR 3/3); loam; weak, medium subangular blocky structure; firm when moist, non-sticky when wet; many medium and fine roots and earthworm activity as tonguing and channels; gradual, wavy boundary.
18 - 30 cm	Dark reddish brown (5YR 3/4); loam; weak, coarse, subangular blocky structure, at places massive; friable (brittle) when moist; less roots and worm activity than above; gradual, wavy boundary.
30 - 80 cm	Red (2.5YR 4/6); sandy clay loam; moderate, medium subangular blocky structure; friable when moist, slightly sticky when wet; common, medium roots; gradual, wavy boundary.
80 -160 cm	Red (2.5YR 4/6); sandy clay; moderate, medium to coarse subangular blocky structure; sticky when wet; common, medium roots; common, medium, soft plinthite nodules at 150 - 160 cm depth, clear, wavy boundary.

160 - 205 cm	(By auger below 185 cm). Red (10 R 4/8); clay; moderate, medium, subangular blocky structure; sticky and slightly plastic when wet; less than 5% of hard but not very hard dark red (10 R 3/6) plinthite nodules about 1 cm of diameter or less; less than 5% of dark reddish brown (5YR 3/3) of organic material as vertical and/or irregular pockets which might be root fillings or animal furrows. No reaction to H_2O_2.
205 - 210 cm	Red but lighter color than above; clay; sticky and plastic; with grayish, few, fine and distinct fibrous mottles along root channels.

Appendix B. Soil Profile No. 2 (Tabarís)

Description: Pit by R. Guerrero and S. W. Buol.

Date: August 3, 1969.

Location: Approximately 1 km west of Tabarís ranch house (Pedro Espinosa), about 250 meters west of the cross road Matapalito Piñal, about 1 - 2 km south of the cliff.

Vegetation: Treeless savanna.

Physiography: Typical river bank plain, slightly convex.

Parent Material: Mixed acid alluvial sediments.

Slope: 0-1%.

Drainage: Somewhat excessively drained.

Erosion: By wind?

Depth to Water Table: Deep.

Remarks: Supposedly a site influenced by wind-blown materials; burnt 15-25 days ago.

0 - 20 cm	Dark reddish gray (5YR 4/2); loam; moderate, medium, subangular blocky structure; friable when moist, non-sticky when wet; many, fine and medium roots; gradual, smooth boundary.
20 - 34 cm	Reddish brown (5YR 4/4); loam; weak to moderate fine to medium subangular blocky structure; friable when moist, slightly sticky when wet; many, fine roots; common, large pores; gradual, smooth boundary.
34 - 71 cm	Yellowish red (5YR 4/8); sandy clay loam; structure as above; more friable when moist, slightly sticky and plastic when wet; common, large, organic matter pockets; common, fine and medium roots; common medium pores; gradual, smooth boundary.
71 - 125 cm	Yellowish red (5YR 5/6); silty clay loam; weak, fine angular and subangular blocky structure; very friable when moist, slightly sticky and plastic when wet; common fine and medium roots and organic matter stains; common, fine pores; clear, wavy boundary. No reaction to H_2O_2.

125 - 178 cm	Red (2.5YR 5/8) matrix with common, fine to medium, distinct, large (1/4 - 1 inch) of red (10YR 4/6) plinthite nodules; heavy clay loam; moderate, medium to fine subangular blocky structure; friable when moist, sticky and slightly plastic when wet; more than 5% of plinthite as hard nodules.
178 - 208 cm	(By auger). Red (10YR 4/6); clay; sticky and slightly plastic; up to 35% - 40% of plinthite nodules.
208 - 218 cm	Red; clay; less plinthite nodules than above; few strong brown fibrist bodies.

Appendix C. Soil Profile No. 3 (Matapalito)

Description: Pit by R. Guerrero and S. W. Buol

Date: August 3, 1969.

Location: Approximately 1.5-2.0 km North-northwest of the Matapalito ranch house and about 2.5 km south of profile 2. Approximately at the boundary of the As-Aa F.A.O. areas (F.A.O., 1965).

Vegetation: Wet-treeless savanna, about 300 meters north of the "estero" (low lands with moriche palms); termite area.

Physiography: Low plain but not the lowest member of the catena; slightly concave position.

Parent Material: Mixed acid alluvial sediments.

Slope: 0-1%.

Drainage: Somewhat poorly drained to moderately well drained.

Erosion: None.

Depth to Water Table: 92 cm (3 ft. 1 in.).

Remarks: Soft plinthite nodules at intermediate horizons.

0 - 16 cm	Very dark gray brown (10YR 3/2); clay loam; moderate, fine, subangular blocky structure; friable when moist; slightly sticky and plastic when wet; many, small, medium roots; clear, wavy boundary.
16 - 42 cm	Dark gray brown (10YR 3/3); clay loam; weak, fine and medium subangular blocky structure; firm when moist, slightly sticky and plastic when wet; common, fine roots; gradual, smooth boundary.
42 - 70 cm	Gray brown (10YR 5/2) with common, medium, distinct, reddish brown (5YR 4/5) and yellowish red (5YR 4/6) mottlings; clay; moderate, medium, subangular blocky structure; sticky and slightly plastic when wet; common, medium roots; gradual, smooth boundary.
70 - 145 cm	(Below 92 cm by auger). Strong brown (7.5YR 5/6) with common, fine, faint, strong brown (5YR 5/8) mottles; clay; weak, medium, subangular blocky structure; few, medium, soft plinthite nodules; sticky and plastic when wet.
145 - 170 cm	Color becomes redder; clay; plastic and sticky when wet; soft plinthite about 20% of the soil.

Appendix D. Soil Profile No. 4 (Carimagua)

Description: Pit by R. Guerrero and S. W. Buol.

Date: August 4, 1969.

Location: Approximately 300-500 meters west of the Carimagua ranch house, near and along the fence of the experimental field.

Vegetation: Treeless savanna; herding area.

Physiography: Apparently intermediate position.

Parent Material: Mixed acid alluvial sediments.

Slope: 0-1%.

Drainage: Well drained (to somewhat poorly drained?).

Erosion: None.

Depth to Water Table: Deep.

Remarks: Possibly water table at this place is influenced by the short distance to the Carimagua lake (400 meters). An apparent catena was observed along the ditch to the lake.

0 - 8 cm	Very dusky red (2.5YR 2/2); silty clay loam; weak, coarse, massive that breaks into moderate, fine, subangular blocky structure; hard when dry, slightly sticky when wet; many medium and fine roots; clear, smooth boundary.
8 - 22 cm	Dark reddish brown (5YR 3/4); clay loam; weak, medium subangular blocky structure; friable when moist; many, fine roots; pockets and tongues of organic material transported from first horizon; gradual, smooth boundary.
22 - 46 cm	Yellowish red (5YR 4/8); clay loam; moderate fine subangular blocky structure; slightly sticky when wet; many roots but less than above, channels and tongues of organic materials from first horizons; gradual, wavy boundary.
46 - 132 cm	Yellowish red (5YR 5/8) with few, faint, fine (10YR 6/6) brownish yellow mottlings; light silty clay loam; weak, fine, subangular blocky structure; friable when moist; common, fine roots; diffuse, wavy boundary.
132 - 140 cm	Yellowish red (5YR 5/8) with common strong brown (7.5YR 5/8) and red (10 R 5/8) medium, faint mottlings; silty clay; slightly sticky; few, fine roots.

Appendix E. Soil Profile No. 5 (Carimagua)

Description: Pit by R. Guerrero and S. W. Buol.

Date: August 4, 1969.

Location: Approximately 2-2.5 km northeast of the Sta. Rita, Puerto Carreno cross road, open savanna.

Vegetation: Dense, treeless savanna.

Physiography: Open and slightly convex savanna at higher position than site No. 4.

Parent Material: Mixed acid alluvial sediments.

Slope: 0-1%.

Drainage: Well drained.

Erosion: None.

Depth to Water Table: Deep.

Remarks: No plinthite nodules in 155 cm depth. Poor horizonation. Site is representative of "open" savanna.

0 - 12 cm	Dark brown to brown (7.5YR 4/4); silty clay loam; weak, medium, subangular blocky structure; slightly sticky and slightly plastic; many roots but less than in previous profiles; gradual, smooth boundary.
12 - 32 cm	Dark reddish brown (5YR 3/4); silty clay; massive that breaks into strong, fine subangular blocky structure; sticky and slightly plastic; less roots than above and high termite activity; gradual, wavy boundary.
32 - 58 cm	Yellowish red (5YR 4/6) with few, fine and distinct, light yellowish brown (10YR 6/4) mottlings; silty clay; moderate, medium and fine subangular blocky structure; friable when moist, sticky when wet; few, small roots and pockets of dark organic material transported from above; no reaction to H_2O_2; gradual, wavy boundary.
58 - 88 cm	Yellowish red (5YR 5/8); clay; strong to moderate, fine subangular blocky structure; slightly plastic when wet; few, fine roots; few pockets of organic material; gradual, wavy boundary.
88 - 148 cm	(By auger below 130 cm). Yellowish red (5YR 4/8); clay; stickier.
148 - 155 cm	Redder; clay.

Appendix F. Soil Profile No. 6 (El Viento)

Description: Pit by R. Guerrero and S. W. Buol.

Date: August 5, 1969.

Location: Approximately 400 meters southwest of the El Viento ranch house; about 375 meters south of north end of the air strip.

Vegetation: Treeless savanna.

Physiography: Slightly convex plain at intermediate altitude.

Parent Material: Mixed acid alluvial sediments.

Slope: 0-1%.

Drainage: Well drained.

Erosion: None.

Depth to Water Table: Deep.

Remarks: Apparently the site is a lower position than Nos. 2 and 5. Poor horizonation.

0 - 10 cm	Dark brown (7.5YR 3/2); silty clay; weak to moderate coarse and medium, subangular blocky structure; friable when moist; hard when dry; many, medium, fine roots; clear, smooth boundary.
10 - 19 cm	Dark reddish brown (5YR 3/3); silty clay; moderate, fine to medium subangular blocky structure; slightly sticky and plastic when wet; many, fine roots; few pockets of organic material; gradual, smooth boundary.
19 - 31 cm	Yellowish red (5YR 4/6) with few, fine, pale brown (10YR 6/3) mottles; clay; weak, fine to medium subangular blocky structure; sticky when wet; some organic material but less than above; diffuse boundary.
31 - 105 cm	Yellowish red (5YR 4/8); clay, more clay than above; sticky and plastic; common, fine roots; diffuse boundary.
105 - 140 cm	(By auger). Red (2.5YR 4/8); clayier than above; sticky and plastic.
140 - 150 cm	Red (2.5YR 4/8); clay; soft, red plinthite nodules approximately less than 5%.

Appendix G. Soil Profile No. 7 (El Viento)

Description: Pit by R. Guerrero and S. W. Buol.

Date: August 5, 1969.

Location: Along fence of I.C.A. 1969A field experiments; approximately 200 meters south of the experiments and about 200 meters north of "estero" (swampy palms).

Vegetation: Treeless savanna with common hydrophytic species.

Physiography: Low member of the catena and wet savanna, but not the lowest. Termites are common.

Parent Material: Mixed acid alluvial sediments.

Slope: 0-1%.

Drainage: Somewhat poorly to moderately-well drained.

Erosion: None.

Depth to Water Table: 77 cm.

Remarks: Apparently worse drainage than site No. 3.

0 - 10 cm	Very dark gray brown (10YR 3/2); silt loam; weak, fine, subangular blocky structure breaking to weak, fine granular; friable when moist, slightly sticky and plastic when wet; many, fine and medium roots; clear, smooth boundary.
10 - 25 cm	Dark brown (10YR 4/3); silty clay loam; moderate medium to fine subangular blocky structure; friable when moist, slightly sticky when wet; common, fine and medium roots and pockets of organic material; gradual, smooth boundary.
25 - 44 cm	Dark yellowish brown (10YR 4/4) with brown (7.5YR 4/4) and pale brown (10YR 6/3) few, fine, distinct mottles; silty clay; weak, fine subangular blocky structure; stickier and more plastic than above when wet; common, small roots; gradual, wavy boundary.
44 - 77 cm	Strong brown matrix (7.5YR 5/6) with brown (7.5YR 5/4) common, medium, faint mottles; red plinthite nodules (10 R 3/6); silty clay; weak, fine angular and subangular blocky structure; stickier and more plastic than above in wet; few small roots; diffuse boundary.
77 - 188 cm	(By auger). Roughly the same color; clay; no plinthite nodules.

Appendix H. Particle Size Distribution by Three Methods

Soil no.	Sample no.	Depth	Water dispersible		Calgon-pipette with organic matter removed			Centrifugation (organic matter and iron removed)		
			Clay	Sand	Clay	Sand	Silt	Clay	Sand	Silt
		cm	%	%	%	%	%	%	%	%
1	1	0-18	15	40	19	32	49	--	--	--
	2	18-30	19	34	20	32	48	--	--	--
	3	30-80	21	30	23	31	46	--	--	--
	4	80-160	3	29	26	28	46	--	--	--
	5	160-185	3	28	27	28	45	--	--	--
	6	185-205	3	27	34	28	38	--	--	--
	7	205-210	3	21	40	21	39	--	--	--
2	8	0-20	11	45	17	44	39	31	44	25
	9	20-34	15	41	19	41	40	31	52	17
	10	34-71	20	40	21	39	40	39	42	19
	11	71-125	4	34	23	40	37	51	34	15
	12	125-178	4	31	30	33	37	52	29	19
	13	178-208	4	21	39	25	36	53	19	28
	14	208-218	4	19	41	22	37	67	16	17
4	21	0-8	27	12	35	7	58	61	6	33
	22	8-22	32	11	38	11	51	70	6	24
	23	22-46	38	10	40	9	41	63	6	45
	24	46-132	3	13	43	10	47	64	6	30
	25	132-140	3	14	49	7	44	58	5	37
5	26	0-12	26	15	38	12	50	--	--	--
	27	12-32	35	11	41	11	48	73	5	22
	28	32-58	28	10	43	11	46	--	--	--
	29	58-88	3	11	45	12	43	--	--	--
	30	88-148	4	8	45	12	43	63	5	32

Soil no.	Sample no.	Depth	Water dispersible		Calgon-pipette with organic matter removed			Centrifugation (organic matter and iron removed)		
			Clay	Sand	Clay	Sand	Silt	Clay	Sand	Silt
		cm	%	%	%	%	%	%	%	%
6	31	0-10	36	13	46	9	45	--	--	--
	32	10-19	38	15	44	8	48	67	5	28
	33	19-31	42	14	52	8	40	--	--	--
	34	31-105	2	7	55	7	38	--	--	--
	35	105-140	3	30	59	7	34	82	4	14
	36	140-150	4	22	61	6	33	--	--	--
	36A	140-150	4	28	--	--	--	--	--	--

Appendix I. Soil Test Data (North Carolina Method)[1]

Soil no.	Sample no.	Depth	pH in water	Organic matter	Ca	Mg	K	P
		cm		%	lbs/A			
1	1	0-18	4.4	2.5	80	14	35	2.4
	2	18-30	4.4	1.6	64	10	17	2.4
	3	30-80	4.4	0.9	96	24	29	2.4
	4	80-160	4.7	0.4	64	10	17	2.4
	5	160-185	4.7	0.3	64	12	17	0.0
	6	185-205	4.8	0.3	80	17	26	0.0
	7	205-210	4.9	0.3	80	14	23	0.0
2	8	0-20	4.5	2.0	48	12	29	2.4
	9	20-34	4.7	1.3	64	10	17	2.4
	10	34-71	4.6	0.8	64	17	29	2.4
	11	71-125	4.7	0.6	80	19	23	0.0
	12	125-178	4.9	0.3	64	12	14	0.0
	13	178-208	5.1	0.3	80	10	20	0.0
	14	208-218	4.9	0.3	96	19	29	0.0
3	15	0-16	4.4	3.7	112	19	32	2.4
	16	16-42	4.5	2.1	96	19	26	2.4
	17	42-70	4.5	1.6	80	14	26	2.4
	18	70-92	5.0	1.3	80	17	29	2.4
	19	92-112	5.0	0.8	112	22	40	2.4
	20	145-170	5.0	0.6	80	14	20	2.4
4	21	0-8	5.0	6.5	304	142	504	4.8
	22	8-22	4.6	3.0	112	22	98	2.4
	23	22-46	4.5	2.0	80	17	58	0.0
	24	46-132	4.9	1.1	80	17	55	0.0
	25	132-140	5.4	0.7	96	34	104	0.0

Soil no.	Sample no.	Depth	pH in water	Organic matter	Ca	Mg	K	P
		cm		%	---------- lbs/A ---------			
5	26	0-12	4.6	4.0	80	17	37	2.4
	27	12-32	4.6	2.0	64	14	29	2.4
	28	32-58	4.8	1.7	64	12	20	0.0
	29	58-88	5.2	0.9	64	12	20	0.0
	30	88-148	5.2	0.6	64	10	20	0.0
6	31	0-10	4.8	6.5	304	60	78	2.4
	32	10-19	4.6	4.0	64	17	37	2.4
	33	19-31	4.7	2.5	80	17	35	0.0
	34	31-105	4.8	1.6	64	10	23	0.0
	35	105-140	5.3	0.7	64	7	17	0.0
	36	140-150	5.1	0.7	64	14	14	2.4
7	37	0-10	4.6	5.2	128	38	60	2.4
	38	10-25	4.4	3.5	80	26	37	0.0
	39	25-44	4.5	2.1	80	22	23	2.4
	40	44-77	4.7	1.4	96	22	23	0.0
	41	77-137	5.0	1.1	64	14	17	0.0
Dune	42	0-20	4.6	1.3	96	26	40	2.4
Dune	43	20-40	4.7	0.7	80	22	37	2.4
Dune	44	40-60	4.6	0.6	80	19	29	2.4
Dune	45	95-115	4.6	0.5	64	12	26	2.4
South River Dune	46	Surface	4.5	0.7	64	19	29	2.4
South River Beach	47	Surface	6.0	0.7	960	106	52	67.2
South River Beach	48	Bottom Clay	5.3	1.3	1680	420	253	2.4
South River Beach	49	Bottom River	6.0	0.7	1024	110	37	60.0

Soil no.	Sample no.	Depth	pH in water	Organic matter	Ca	Mg	K	P
		cm		%	---------- lbs/A			---------
River Island Sands	50	Surface	6.0	1.3	1440	178	52	88.8
River Island Sands	51	Surface	6.2	0.4	464	53	23	33.6
River Island Sands	52	Surface	6.1	0.9	1280	156	55	81.6
North River Beach	53	Surface	5.4	0.8	736	146	63	38.4
North River Beach	54	0-10	6.0	1.4	1584	211	58	88.8
North River Beach	55	20-30	5.8	1.1	1248	175	55	86.4
North River Beach	56	80-90	5.3	2.7	2240	384	150	33.6

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[1] Appreciation is expressed to Dr. D. Eaddy, Head of North Carolina Soil Testing Laboratory, North Carolina Department of Agriculture, Raleigh, North Carolina.