GENESIS, MORPHOLOGY AND CLASSIFICATION OF SOILS IN AN OXISOL-ULTISOL TOPOSEQUENCE IN S. PAULO STATE, BRAZIL

by

IGO FERNANDO LEPSCH

A thesis submitted to the Graduate Faculty of
North Carolina State University at Raleigh
in partial fulfillment of the
requirements for the Degree of
Master of Science

DEPARTMENT OF SOIL SCIENCE

RALEIGH

1 9 7 3

APPROVED BY:

_____
Chairman of Advisory Committee

ABSTRACT

LEPSCH, IGO FERNANDO. Genesis, Morphology and Classification of Soils in An Oxisol-Ultisol Toposequence in S. Paulo State, Brazil. (Under the direction of STANELY W. BUOL).

Four soil profiles were sampled along a 550-m transverse. The soils were characterized with physical, chemical, mineralogical and micromorphological analyses to establish the nature of difference among them, properly classify and develop hypothesis about their genesis.

The two soils on the upper part of the toposequence have an ochric epipedon over an oxic horizon and are classified as very fine clayey, oxidic, isothermic Tropeptic Haplorthox. The soil below these two has an argillic horizon over an oxic horizon and is classified as very fine clayey, oxidic, isothermic Orthoxic Palehumult. The soil in the lower part of the catena has an argillic horizon over decomposed sedimentary clayey rock; it is classified as fine clayey, kaolinitic, isothermic Typic Paleudult.

The main characteristics distinguishing the profiles from the upper to the lower part of the catena were the increase in depth and eventual loss of the oxic horizon, increase in base saturation, decrease in gibbsite content, increase in 2:1 clay minerals, relative decrease of fine clay, increase in illuviated clay, relative decrease of fine clay and increase in bulk density values.

The genesis of these soils appears to be controlled mostly by the age of the geomorphic surfaces and by the nature of the parent material.

BIOGRAPHY

The author was born at Petrópolis, Rio de Janeiro, Brazil on October 23, 1937. He received his elementary and secondary education in Petrópolis.

He attended the Escola Nacional de Agronomia, Universidade Rural do Brasil, Itaguai, Rio de Janeiro, Brazil, from 1958 to 1961 and received the Engenheiro Agrônomo degree in December 1961.

From 1962 to 1966 he worked as a soil conservationist for the D.E.M.A., São Paulo State Government. In 1966 he was transferred to the Instituto Agronômico at Campinas, São Paulo State where he worked as a soil survey staff member.

In 1970 he was awarded a scholarship from the Fundação de Amparo a Pesquisa do Estado de São Paulo, Brazil, which enabled him to enter, in January 1971, the Graduate School of North Carolina State University at Raleigh to pursue the Master of Science degree in Soil Science.

ACKNOWLEDGMENTS

The author expresses his sincere appreciation to his major advisor, Dr. S. W. Buol, for his guidance and assistance during the course of this work. Appreciation is also extended to Dr. M. G. Cook and Dr. W. H. Spence, the other members of his Advisory Committee, for their constructive criticism and assistance.

Special acknowledgment is made to the Instituto Agronômico do Estado de São Paulo for granting a leave of absence, and to the Fundação de Amparo a Pesquisa do Estado de São Paulo whose scholarship enabled the author to pursue graduate studies at North Carolina State University.

The author also expresses his sincere gratitude to Dr. J. L. I. Demattê, Dr. F. Grohmann, Mr. J. B. deOliveira, Mr. C. L. Rotta and Mr. C. Ivancko for their suggestions and help in the selection and collection of soil samples.

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, Mrs. Bertha Crabtree, Mrs. Patricia Patrick and Mrs. Betty Ayers for their assistance in some laboratory work.

TABLE OF CONTENTS

Page

LIST OF TABLES vi

LIST OF FIGURES vii

INTRODUCTION 1

LITERATURE REVIEW 3

SOILS AND SITE DESCRIPTION 8

CLIMATE 11

GEOMORPHOLOGY 14

GEOLOGY 16

VEGETATION AND LAND USE 17

EXPERIMENTAL METHODS OF ANALYSIS 18

Physical Methods 18

Air-Dry Moisture Content 18
Particle Size Distribution 18
Water-Dispersible Clay 20
Clay Content by the 15-Bar Method 20
Water Retention at 1 and 1/3 Atmosphere 20
Particle Size Density 21
Porosity 21

Chemical Methods 21

Soil Reaction 21
Organic Carbon 21
Exchangeable Acidity 22
Extractable Hydrogen 22
Extractable Bases and Base Saturation 22
Cation Exchange Capacity 22
Free Iron Oxides 23

Mineralogical Studies 23

Clay and Fine Silt Mineral Identification 23
Petrography of Sand and Coarse Silt Fractions 23
Quantitative Determination of Gibbsite, Kaolinite and Amorphous Material 24

Thin Section Preparation and Analysis 24

TABLE OF CONTENTS (Continued)

Page

RESULTS AND DISCUSSION 26

Physical Properties 26

Particle Size Distribution 26
Water-Dispersible Clay 30
Bulk Density, Particle Density and Porosity 32
Water Retention and Maximum Available Water 32

Chemical Properties 35

Soil Reaction 35
Organic Carbon 35
Cation Exchange Capacity and Base Saturation 38

Mineralogy 40

Sand Mineralogy 40
Clay and Fine Silt Mineralogy 45

SOIL CLASSIFICATION 61

Diagnostic Horizons and Soil Orders 61

Profile Number 1 61
Profile Number 2 61
Profile Number 3 61
Profile Number 4 62

Soil Moisture Regimes 62
Classification at the Subgroup Level 62
Classification at the Family Level 64

Particle Size Classes 64
Mineralogy Classes 64
Soil Temperature Classes 64

SUMMARY AND CONCLUSIONS 65

LIST OF REFERENCES 68

APPENDICES 73

Appendix A. Soil Profile Description and Classification According to the Comissão de Solos (1960) 74
Appendix B. Micromorphological Descriptions 83

LIST OF TABLES

Page

1. Climatic data from near the site 12
2. Particle size, silt/clay ratio and water-dispersible clay data 27
3. Particle size as determined by the centrifugation method, with organic matter and free iron removed 29
4. Bulk density, particle density and water retention data . . . 33
5. Chemical properties 36
6. Petrographic identification of sand and coarse silt grains . . 41
7. Clay mineralogy estimations by X-ray analysis 46
8. Quantitative estimations of clay mineralogy 53

LIST OF FIGURES

Page

1. Topographic map of soil profile locations 9
2. Semi-schematic cross-section diagram showing the position of the soil profiles in relation to the landscape, slope and substrata 10
3. Rainfall-evapotranspiration balance at Cordeirópolis County, S. P.; balance calculated according to Thornthwaite. 13
4. Summation of fine clay recovery with successive centrifugations 19
5. Relative distribution of clay with depth 31
6. Total pore space with depth 34
7. X-ray diffraction patterns of the fine clay of samples from the B horizon of profile numbers 1 and 2 47
8. X-ray diffraction patterns of the fine clay of samples from the B horizon of profile numbers 3 and 4 48
9. X-ray diffraction patterns of the coarse clay of samples from the B horizons of profile numbers 1 and 2 49
10. X-ray diffraction patterns of the coarse clay of samples from the B horizons of profile numbers 3 and 4 50
11. X-ray diffraction patterns of the coarse clay fraction from the weathered bedrock under profile numbers 2 and 4 51
12. Differential thermograms of the fine clay and coarse clay fractions from the B horizons of the four studied soil profiles 54
13. Photomicrograph of a thin section from the B22 horizon of profile number 1 (without crossed nicols) 58
14. Photomicrograph of a thin section from the B22 horizon of profile number 1 (with crossed nicols) 58
15. Photomicrograph of a thin section from the B22 horizon of profile number 3 (without crossed nicols) 59
16. Photomicrograph of a thin section from the B33 horizon of profile number 3 (without crossed nicols) 59

LIST OF FIGURES (Continued)

Page

17. Photomicrograph of a thin section from the B22t horizon of profile number 4 (without crossed nicols) 60

18. Photomicrograph of a thin section from the B22t horizon of profile number 4 (with crossed nicols) 60

INTRODUCTION

In the well drained lands of the humid tropics, two main soil groups are often found in close association. These soils are classified in the orders Ultisol and Oxisol according to the Soil Taxonomy (Soil Survey Staff, 1960, 1970).

Both Ultisols and Oxisols have been considered soils which are in a highly weathered stage of genetic evolution. This is interpreted as being a reflection of the great degree of chemical weathering in the humid tropics. Oxisols have been interpreted as being more weathered than Ultisols and they indeed differ from the latter in their composition and morphology.

The differences among Ultisols and Oxisols require that different management practices be used. As a matter of fact the importance of separating these soils in soil surveys of middle and high intensity is obvious.

It is not normally difficult to distinguish Oxisols from Ultisols while doing soil survey work when dealing with the modal concepts of each order. The distinction is normally made on the basis of differences in color and texture seen at different depths and by the examination of the subsoil structure. Modal Ultisols show a perceptible increase in clay content with depth and have a blocky structure in the subsoil. In contrast, Oxisols do not show a significant increase in clay content with depth and characteristically the subsoil has a structure which appears massive but is very porous.

At the boundaries between Oxisols and Ultisols, however, their distinction is somewhat difficult since there is a gradual transformation

from one to the other. In such areas laboratory analysis is often necessary before a classification can be assigned. Although all detailed laboratory analysis such as thin section observations and clay mineralogy are not essential for low intensity soil surveys, they are important in detailed soil surveys where the soil mapping units have to be defined within a narrow range of characteristics.

This present study is a characterization of four soil profiles located in S. Paulo State, Brazil. The region has a relatively highly developed agriculture and is requiring detailed soil surveys. The profiles studied were collected in a catena where, according to field observations, one soil appeared to represent the modal concept of an Ultisol, other looked like modal Oxisol and the remaining two profiles were noted to have characteristics intermediate of both orders.

The objectives of this study are to:

1. Describe and compare the four soil profiles, analyzing their composition, morphology and fabric.

2. Classify these soils according to one of the more recent systems of classification.

3. Develop an hypothesis to explain the formation of these soils.

LITERATURE REVIEW

The early descriptions of soils from the tropics referred to them as "Laterites" or Lateritic soils (Marbut, 1927; Glinka, 1931). The term lateritic soil included almost any kind of deep, red colored and highly weathered soil within the tropics.

Vageler (1930) (quoted from Robinson, 1949) distinguished two groups of tropical soils--the red loams and the red earths. The red loams were defined as the lateritic soils with clay of siliceous type and the red earths with predominantly sesquioxidic character.

Bennet (1926) identified two main classes of upland clays in Central America--the friable and the non-friable tropical soils. The friable soils were defined as being freely permeable to water, resistant to erosion and with faint profile zonation. The non-friable soils were defined as being plastic or stiff, much more impervious and with better profile zonation. He pointed out that faint zonation through the profile is a common characteristic of large areas of soil in the tropics and stated that (p.353):

> This seemingly is due, in part at least, to a weakened efficiency in the process of elutriation and eluviation resulting from the peculiar nature of the fine particles formed under tropical conditions, a considerable proportion of which has been found to be of colloidal nature. That the fine material clings together to form clusters from which the individual grains are not readily detached by water to become suspended and moved through the soil mass is evidenced by the physical properties of these soils, such as a highly permeable granular structure through which water passes rapidly and the usual rapidity which the material suspended in water by violent agitation falls out of suspension.

In 1938 the U.S.A. soil taxonomy scheme (Baldwin et al., 1938) defined five great soil groups pertaining to the zonal soils within the "lateritic soils of forested warm temperate regions." These were the

Yellow Podzolic, Red Podzolic, Yellowish Brown Lateritic, Reddish Brown Lateritic and the Laterite soils. The genesis of these soils was explained by the so-called laterization process which was defined by Byers et al. (1938) as follows (p. 973):

> Progressive hydrolysis of rock minerals and its full development results in their conversion to silicic acid, aluminum hydroxide and iron hydroxide or their more or less complete dehydration products: the laterites.

Laterization in its strict sense was considered by Byers et al. to be a process of soil parent material development on which a process of podzolization (or lessivage) could act to form Red and the Red Yellow Podzolic soils.

The Thorp and Smith (1944) revision of the 1938 U. S. soil classification modified slightly the great groups of Lateritic soils grouping, the Red Podzolic with the Yellow Podzolic soils under the great soil group Red Yellow Podzolic soils, and including the Yellowish Lateritic soils within the Reddish Brown Lateritic great soil group.

The great group definitions in both the 1938 system and in its 1949 revision were quite vague and lacked quantitative data.

Kellogg and Davol (1949) recognized in the Congo three main groups of Zonal soils, the Latosols, the Chernozemic soils and the Podzolic soils. Kellogg (1950) used the term Latosol as a suborder category and defined these soils according to some of their qualitative morphological and compositional properties.

Bennema et al. (1959) description of the latosolic B horizon, based on data from Brazilian soils, agrees with Kellogg's (1950) characterization of the Latosol suborder while adding a more complete list of characteristics, some of them quantitatively expressed. Soil surveys done in Brazil (Comissão de Solos, 1958, 1960) have been using the terms

latosolic B horizon and textural B horizon to classify the well drained soils at the most general level of classification.

The new United States soil taxonomy system (Soil Survey Staff, 1960, 1967, 1970) defined the oxic and argillic horizons which corresponds to the latosolic B horizons and textural B horizon from the Brazilian classification (Bennema, 1966) although the latter has less detailed and less quantitative definitions.

Among the well developed soils of the humid tropics, the U. S. soil taxonomy (Soil Survey Staff, 1960, 1970) identified the three orders--Alfisol, Ultisol and Oxisol. These classes were defined in detail and several subgroups were established.

Comparative studies of tropical soils with oxic and argillic horizons had been made by several authors. Lemos et al. (Comissão de Solos, 1960) arranged sequentially the soils from São Paulo State, according to their stage of development. This arrangement was done with groups of soil profiles derived from similar parent material and under the same climate. Two main units were described as being derived from argillites--the Red Yellow Podzolic soils, Piracicaba variation and the Ortho Dark Red Latosols. The Red Yellow Latosol, Piracicaba variation presented textural B horizon and were considered to be chronologically less mature than the Ortho Dark Red Latosols which presented a latosolic B horizon.

Grohmann (1960a) determined aggregate size distribution for profiles with a latosolic B horizon and a textural B horizon. A clayey latosolic B horizon presented a predominance of aggregates smaller than 1 mm and a clayey textural B horizon presented a majority of aggregates greater than 1 mm. Significant differences were found by Grohmann

(1960b) in the porosity values for these two groups of soils--a clayey latosolic B horizon presented a total porosity considerably higher than a sandy clay loam textural B horizon. The relative values of capilar porosity (pores with less than .05 mm in diameter), however, were very similar to the non-capilar porosities for the former and considerably higher for the latter. A decrease in size aggregates with depth was also noticed in a soil with latosolic B horizon (Grohmann, 1960a).

Stoops (1968) reported micromorphological comparative studies among tropical soils with oxic and argillic horizons. He concluded that the micromorphological evidence clearly proves the polycylic character of most kaolisols (Oxisols).

Bennema et al. (1970) in a micromorphological comparative study of soils in South Brazil observed that the limit between the oxic-argillic horizon coincides with an alteration in structure, including the porosity, and pointed out that this is especially true for the B2 horizon and valid in a lesser degree for the B1 and B3 horizon.

Quantitative clay mineralogical studies of soils with an oxic and argillic horizon derived from basic rocks were carried by Moniz and Jackson (1967) and by Carvalho (1970). The soils with an oxic horizon showed an increase in both gibbsite and kaolinite content and a decrease in amorphous material when compared to the ones with an argillic horizon.

Escobar et al. (1972) performed mineralogical studies of the clay fraction in four soil profiles located in a toposequence in São Paulo State, Brazil. Two of these profiles were classified as Red Yellow Podzolic soils, "Piracicaba variation," and as Ortho Dark Red Latosol. The Ortho Dark Red Latosol were shown to have kaolinite in greater amounts than the Red Yellow Podzolic soil. Significant differences

were not found between the mineralogical composition of the coarse clay (2-.2 μ) and fine clay (<.2 μ) and it was tentatively concluded that in advanced stages of weathering the composition of these two fractions shared a closed resemblance.

Recently much emphasis has been placed on the study of landscape evolution and on cyclic nature of parent material as main factors to explain the differences between constrasting soils closely associated within tropical areas. Ollier (1959) pointed out the importance of the connection between soils and geomorphology and developed what he called "the two cycle theory of tropical pedology."

Bennema et al. (1962) reported the existence of the Latosols (Oxisols) in the older surfaces of the Brazilian and Guiana shields, these commonly developed from detrital deposits which usually take the form of very strongly weathered mineral residues. It was also noted that the soils with textural B horizons occur in association with the Latosols and on younger erosion surfaces, forming the relatively lowest part of the landscape, which was found to be covered mostly by relatively small amounts of detrital waste.

Queiroz Neto (1969) studied the geomorphology and soil properties of an area at São Paulo State, Brazil where the occurrence of Oxisols and Ultisols is common. The large occurrence of detrital deposits originated from pedimentation process was noticed. It was pointed out that the present climate is not a factor relevant to the explanation of the different soil weathering indexes. None of the isolated factors studied (erosion, organisms present and mineralogy) could explain the absence of argillic horizons in the Oxisols.

SOILS AND SITE DESCRIPTION

Four soil profiles located on a toposequence in the southern part of Rio Claro County, S. Paulo State, Brazil were selected for this study. The approximate geographic coordinates in the site are 47° 35' longitude Greenwich and 22° 32' latitude south.

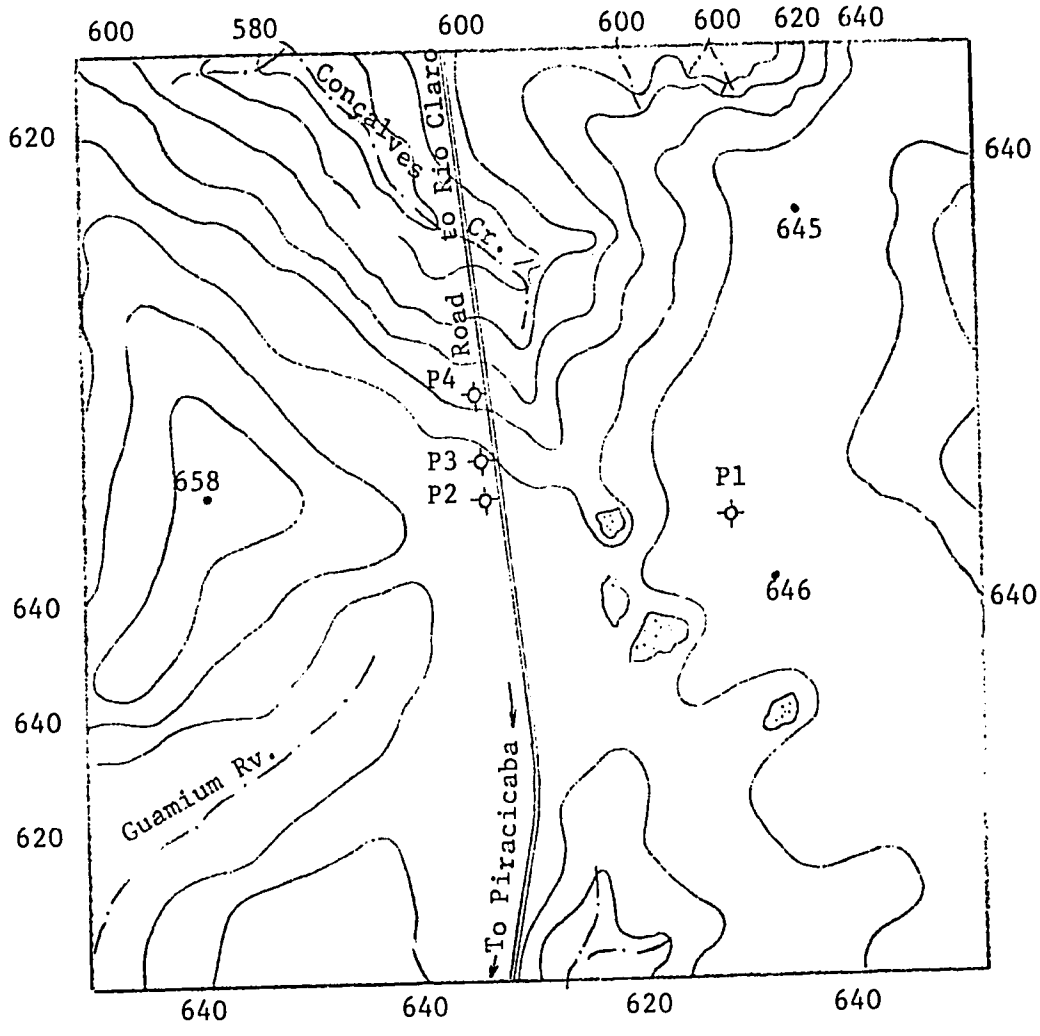
Preliminary selection of the soils was made through observations of morphological characteristics on road cuts after which fresh pits were dug. The soil descriptions were made according to the Soil Survey Manual (Soil Survey Staff, 1951) and are in Appendix A.

The profile on the top of the catena presents morphological characteristics considered to be typical for the Oxisols--light dark surface horizon over a very deep, very friable, fine granular-structured horizon. The soil at the other end of the transect presents a well developed argillic horizon with strong subangular blocky structure coated by clay skins. The two soils between apparently have argillic horizon of 30 and 60 cm thickness, respectively, over a horizon which morphologically looks like an oxic horizon.

Figure 1 shows the profiles' location on a topographic map.[1] Figure 2, schematically, diagrams the relative position of the soil profiles in the catena.

---

[1]Appreciation is expressed to Mr. P. Donzzeli from the Instituto Agronômico, Campinas, S. P., Brazil, for the completion of the topographic map.



Scale 1:25000

600 Contour line

646 Altitude in meters

Perennial stream

Intermittent lake

Soil profile location

Figure 1. Topographic map of soil profile locations

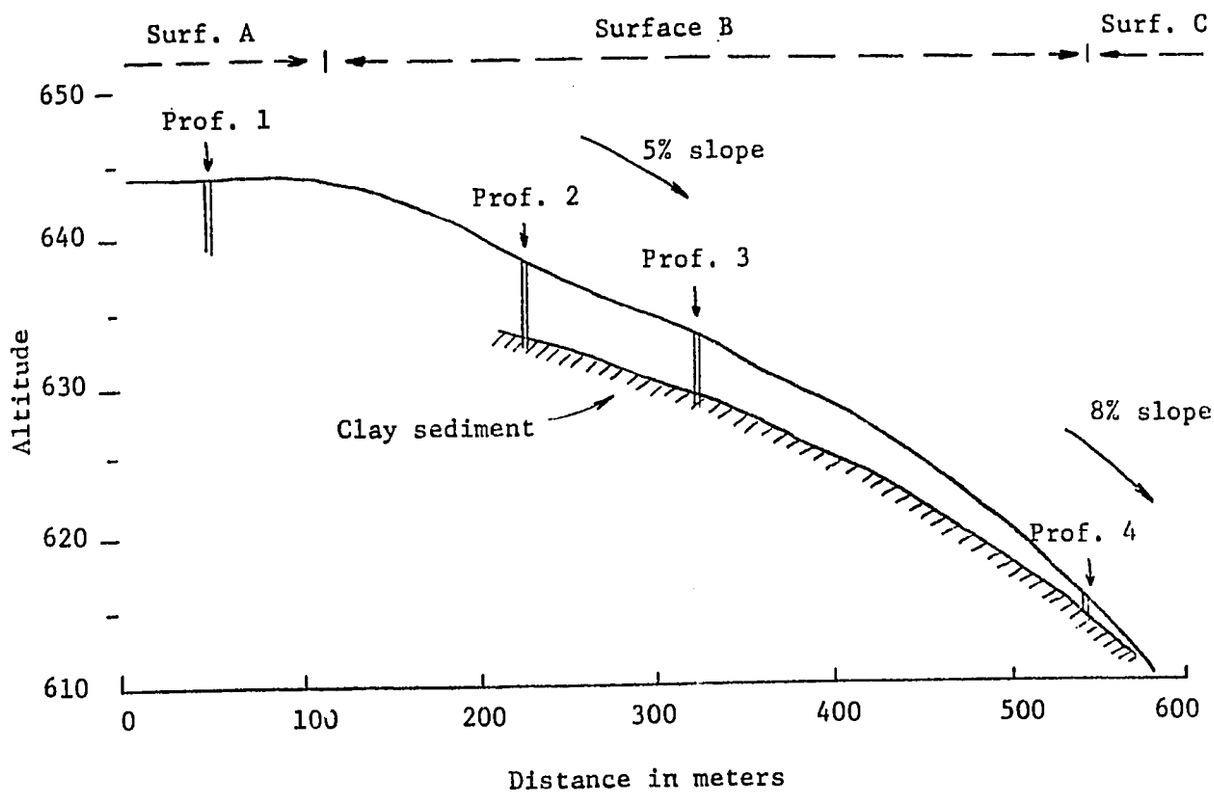


Figure 2. Semi-schematic cross-section diagram showing the position of the soil profiles in relation to the landscape, slope and substrata

CLIMATE

The present climate of the area is characterized as being subtropical, humid with a winter dry season. According to Köppen (Critchfield, 1960), the climatic classification is Cwa or subtropical of altitude. This type of climate is the one which comprises the major part of São Paulo State (Comissão de solos, 1960).

Rainfall, temperature, relative humidity and evaporation data were available from the Limeira Experimental Station at Cordeirópolis County, 20 km east of the study area. The average annual temperature is 20.1°C (68.2°F). Mean winter temperature (June, July and August) is 17.4°C and mean summer temperature (December, January and February) is 22.3°C (Table 1). Figure 3 shows the rainfall-evapotranspiration balance, according to Thornthwaite (1955) and considering a maximum soil moisture storage of 125 mm[1].

---

[1]Appreciation is expressed to Dr. A. A. Ortolani from the Instituto Agronômico, Campinas, S. P., Brazil for the organization and remittance of the climatic data.

Table 1. Climatic data from near the site (20 km)[a,b]

Month	Temperature			Relative humidity mean	Rainfall (total)	Max. rainfall in 24 hr	No. days w/rain	Evaporation
	Mean	Mean max.	Mean min.					
	C°	C°	C°	%	mm	mm		mm
January	22.6	29.4	17.8	80.0	239.6	130.0	18	67.8
February	22.5	29.2	18.0	81.3	209.4	116.7	16	58.3
March	22.0	29.1	17.1	80.0	168.3	112.0	14	64.0
April	20.1	27.7	14.4	77.0	61.6	95.0	7	63.2
May	18.1	25.5	12.2	75.3	47.8	57.5	5	58.6
June	16.9	24.6	11.0	74.3	34.7	58.9	5	62.8
July	16.7	24.9	10.3	69.9	21.4	33.5	4	78.9
August	18.6	27.4	11.7	66.9	27.6	37.5	3	108.[illegible]
September	20.1	28.5	13.2	65.1	59.4	56.0	6	109.4
October	20.8	28.4	14.8	72.4	133.0	67.0	11	89.1
November	21.4	28.8	15.5	74.0	148.6	105.0	12	85.2
December	21.9	28.9	16.7	77.5	223.5	119.5	16	71.4
Year	20.1	27.7	14.4	74.2	1374.9	130.0	117	

[a]Average of 32 years (1940-1971) from Limeira Experimental Station.

[b]Data from Instituto Agronômico do Estado de São Paulo, Campinas, S. P., Brazil.

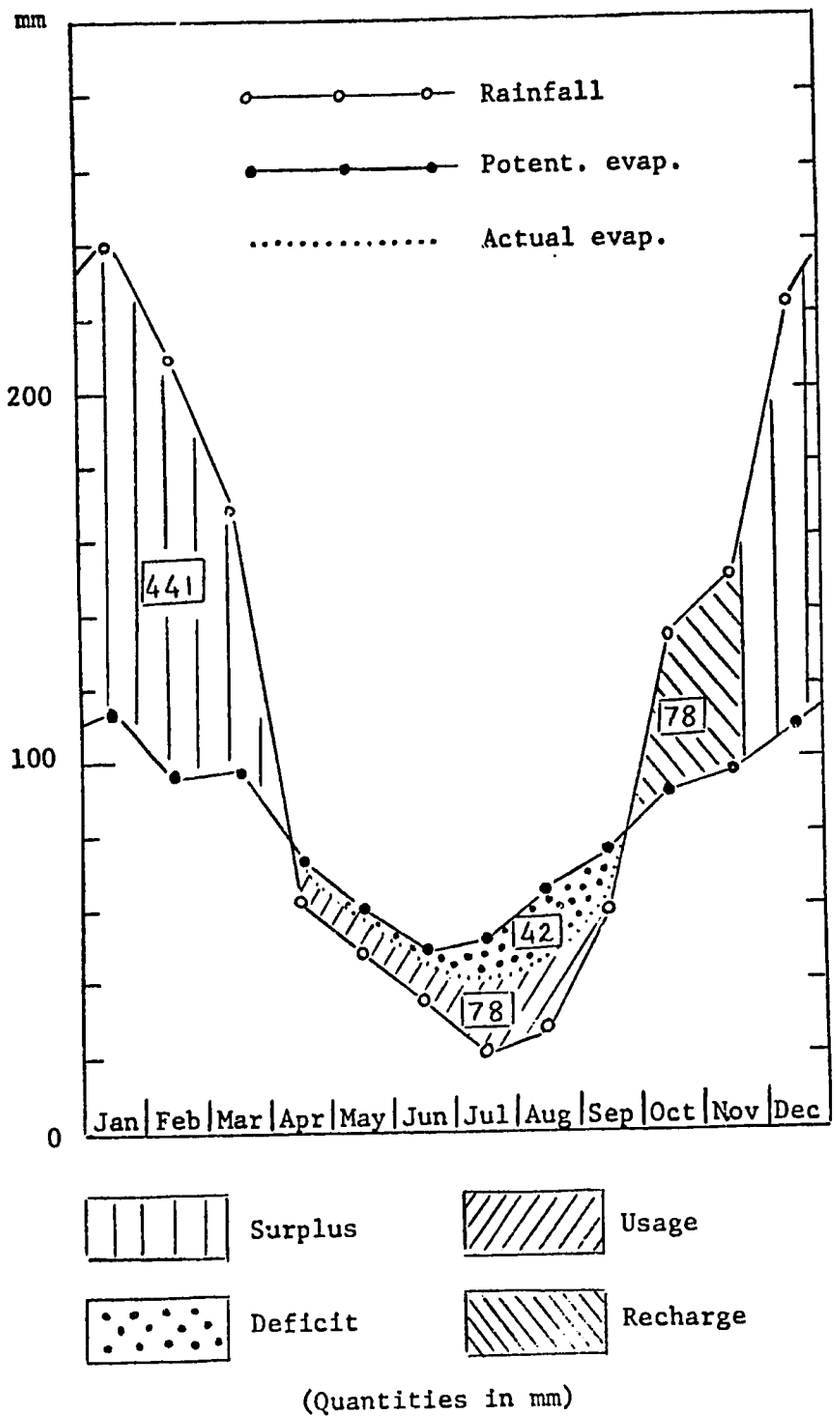


Figure 3. Rainfall-evapotranspiration balance at Cordeirópolis County, S. P.; balance calculated according to Thornthwaite (1955)

GEOMORPHOLOGY

The area is located in the so-called Rio Claro Basin of the "depressão periférica" of the S. Paulo State. The Rio Claro basin has been studied in detail by Penteado (1968, 1969) and the following considerations about this area were based on her work.

The Rio Claro Basin was formed in an inter-plateau area by the erosion of various sedimentary and basic igneous rocks, under alternation of semi-arid and humid climates. In a semi-arid period, tentatively dated between the Inferior and Middle Pleistocene time epoch, the area was extensively pediplanned in levels between 600 m and 650 m. This is the Rio Claro surface which stands mostly over Pleistocene sediments.

The Rio Claro surface was cut down by the drainage system of the Corumbatai River leaving this surface restricted to the top of the major watersheds.

Profile number 1 is located near the watershed divide line between the tributaries of the Piracicaba and Corumbatai Rivers. It is a relatively high area with smooth topography (0-2% slope), containing some intermintent natural lakes (Figure 1). This area is at an altitude of 644 m on the Rio Claro Basin. According to Penteado (1969), this particular watershed is "a pedimented surface going from the NE to the SW direction and is the southern boundary of the Rio Claro Basin."

Profile numbers 2, 3 and 4 are located on surfaces which apparently are the ones referred by Penteado (1969) as being cut on the Rio Claro surface as a result of climatic oscillations of humid to dry between Middle Pleistocene and the Holocene time epoch.

Observations on aerial photographs[1] of the area suggest that there are three geomorphic surfaces in the sites where the profiles were sampled (Figure 2). The geomorphic surface A, where profile number 1 is located would probably correspond to the Rio Claro Surface of Middle Pleistocene age. Profile numbers 2 and 3 are located on a younger geomorphic surface which may or may not have colluvial material from the sediments above surface A. Profile number 4, apparently is located on a transitional zone between the surfaces B and C and is expected to be the youngest point on the landscape.

---

[1]Appreciation is expressed to Dr. R. B. Daniels, Professor of Soil Science, North Carolina State University and USDA, Soil Conservation Service, for his assistance in this interpretation.

GEOLOGY

A clay, violateous gray material, looking like a decomposed argillite is present in profile numbers 2, 3 and 4 at a depth of 5.2 m, 4.0 m and 1.9 m, respectively (Figure 2). This same material was observed on the lower middle part of the road cut adjacent to the profiles where parallel stratification of the sediments was noticed. Although there were no efforts to identify more precisely this sediment, the work of Almeida and Barbosa (1953) and the geologic sketch of the nearby Piracicaba County made by Ranzani (1966) indicate that these sediments are probably from the Itapetininga Formation of the Tubarão series dated from Permian age.

The parent material from which profiles 2, 3 and 4 originated seems to be of colluvial origin since a sharp contact with some iron concretions was found between the red soil and the grey violateous argillite. Two hypotheses seem to be possible to explain the origin of parent material at profile number 1. It could have been developed over the sediments of the Tubarão series or over more recent sediments, brought over the Tubarão series by the pedimentation process during the formation of the Rio Claro surface. In the latter hypothesis the sediments would have received contributions from different kinds of rocks, such as eolian sandstones and basaltic lavas, situated at higher positions. The geologic sketch of the area made by Penteado (1968) supports this hypothesis but it should be considered that its small scale of 1:250,000 is not appropriate to give conclusive evidence in the small area where the profiles were located.

VEGETATION AND LAND USE

The native vegetation on the area seems to have been the tropical broadleaf forest, as indicated by some small remnant areas such as the one in which profile number 1 is located.

At site numbers 2, 3 and 4 farmers indicate that the primitive forest was cleared about 1900 A.D. After the clearing, coffee was cultivated and in 1921 the area was transformed to pastures remaining like that until around 1960 when sugar cane began to be cultivated.

Lime was used for the sugar cane cropping in amounts of 2 tons per hectare, applied once before planting. It was also reported that 200 kg per hectare of a fertilizer mixture containing nitrogen, phosphorus and potassium was applied but data concerning the frequency of the fertilizer use are not available.

EXPERIMENTAL METHODS OF ANALYSIS

Physical Methods

Air-Dry Moisture Content

The percentages of moisture at air dryness were calculated from the weight of a 10-g air-dry soil after 24 hr in a 105-110°C oven. These percentages were used to calculate all data on an oven-dry basis.

Particle Size Distribution

Particle size was determined by two methods--the pipette method (Kilmer and Alexander, 1949) and by the centrifugation method (Kittrick, 1963).

For the pipette method, 10 g of air-dry soil were treated with hydrogen peroxide, dispersed with 5 ml of 10% calgon solution (hexametaphosphate plus sodium carbonate) and stirred for 15 min with a Hamilton Beach No. 33 stirrer (10,000 rpm).

The sand fractions were separated with a 300-mesh sieve, oven dried and weighed. The clay and silt fractions were determined from aliquots pipetted at a depth of 10 cm after the appropriate settling time.

In the centrifugation method, free iron and organic matter were removed and the sample was centrifuged while suspended in a solution of NaOH at pH 9. Five portions were separated--sand (2,000 μ to 50 μ), coarse silt (50 μ to 20 μ), fine silt (20 μ to 2 μ), coarse clay (2 μ to .2 μ) and fine clay (smaller than .2 μ).

From 30 to 40 centrifugations were needed to separate the less-than-.2-μ fraction. It was observed from measurements in one sample (Figure 4) that 16 centrifugations were sufficient to remove 90% of the

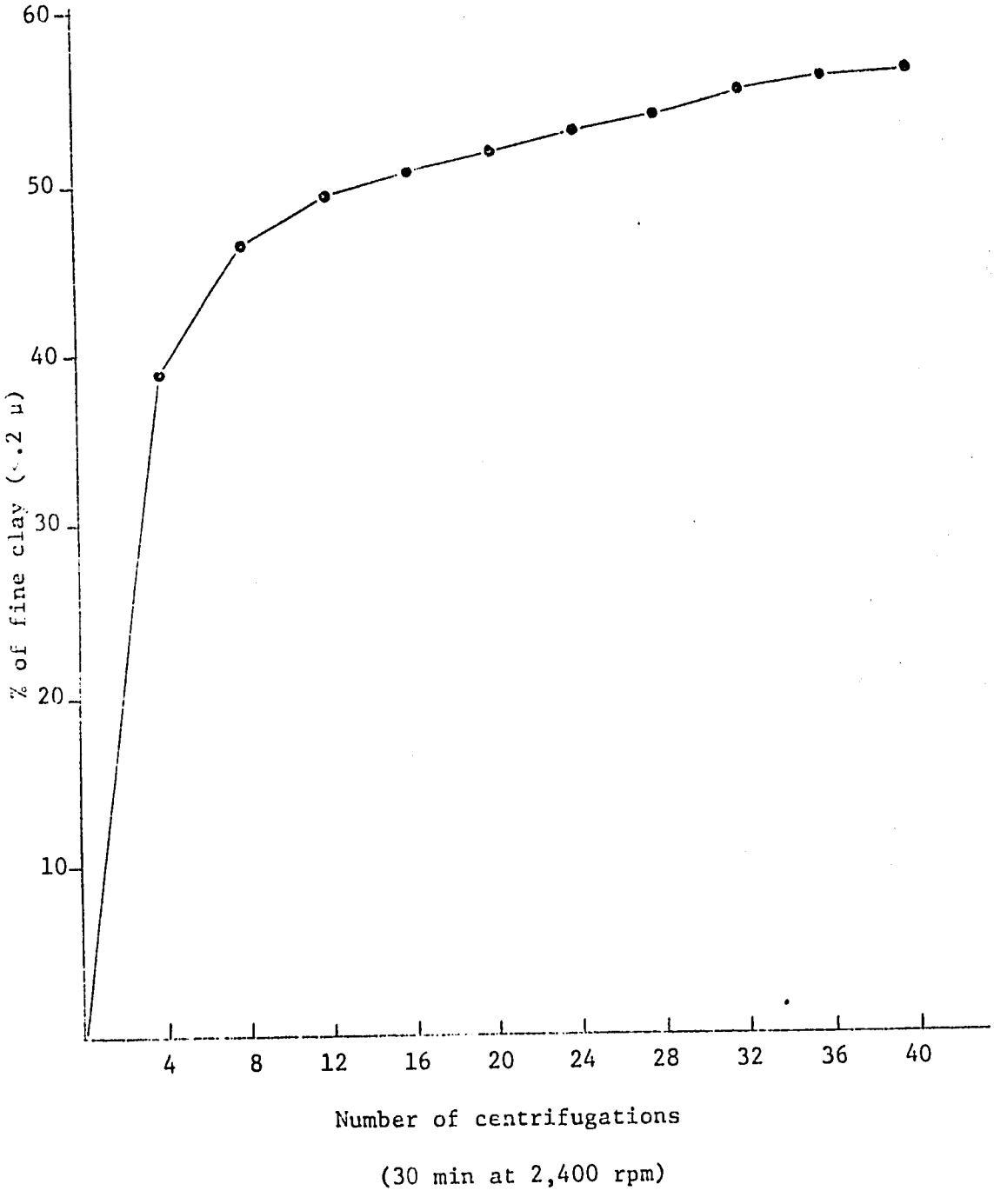


Figure 4. Summation of fine clay recovery with successive centrifugations (profile number 1, sample 1.1)

fine clay. Only this number of centrifugations was done for samples from numbers 3.5 to 4.8.

Water-Dispersible Clay

A Hamilton Beach No. 33 stirrer was used to stirr 20 g of air-dry soil in approximately 500 ml of demineralized water for 5 min (Vettori, 1969). The amount of water-dispersible clay was determined from an aliquot taken by a pipette at a depth of 5 cm after the appropriate settling time.

Clay Content by the 15-Bar Method

The water content at 15-bar pressure was determined by pressure membrane equipment (Richards, 1951). Clay percentages were calculated by multiplying the weight percentage of water retained by the factor 2.5 (Soil Survey Staff, 1967).

Water Retention at 1 and 1/3 Atmosphere[1]

The water content at 1 atmosphere and 1/3 atmosphere was done by the centrifuge method. Twenty grams of air-dry soil were placed in a metal box and allowed to saturate with water overnight. The water retention at 1 atmosphere was calculated by weighing the samples after centrifugation for 30 min at 2,440 rpm. Centrifugation for 30 min at 1,440 rpm was used to calculate the 1/3 atm values. The maximum available water was considered to be the difference between the water content at 1/3 atm and 15 atm expressed on a volume basis.

---

[1]Analysis done at the Instituto Agronômico do Estado de São Paulo, Campinas, S. P., Brazil.

Particle Density[2]

Particle density was determined by the ethyl alcohol method (Paiva Neto *et al.*, 1961). Ten grams of soil were weighed and placed in a 100-ml volumetric flask which was filled with a known amount of ethyl alcohol. The volume of the particles was calculated by subtracting the volume of alcohol filling the flask from 100 ml.

Porosity

The total soil porosity was calculated from the particle density and bulk density values through the following formula:

$$\text{Total porosity } \% = 100 - \frac{100 \times \text{bulk density}}{\text{particle density}}$$

Chemical Methods

Soil Reaction

Values for pH were obtained after allowing 20 g of soil to stand in a 1:1 soil water and 1:1 soil N KCl solution mixture for 30 min. The pH values were measured by using a glass electrode pH meter.

Organic Carbon[2]

The organic carbon was determined by oxidation with acid dicromate using external heat and titration with standard $FeSo_4$ solution (Allinson, 1965).

---

[2]Analysis done at the Instituto Agronômico do Estado de São Paulo, Campinas, S. P., Brazil.

Exchangeable Acidity[3]

Exchangeable acidity was determined by extraction with 1 N KCl and titration of leacheate with NaOH, using bromothymol blue as an indicator.

Extractable Hydrogen[3]

Extractable hydrogen was determined by leaching 10 g of air-dry soil with 1 N sodium acetate, pH 7 and titration of the displaced aluminum and hydrogen with 0.1 N sodium hydroxide using phenolphtalein as an indicator. The results were subtracted from the exchangeable acidity as determined by the KCl extraction (Paiva Neto *et al.*, 1961).

Extractable Bases and Base Saturation

The extractable bases were extracted by 1 N ammonium acetate as described by Chapman (1965). Calcium and magnesium were determined by an atomic absorption spectrophotometer; potassium and sodium were determined by flame photometry.

The base saturation percentage was calculated as percent of bases retained (Ca, Mg, K and Na), on the cation exchange capacity obtained by the sum of cations.

Cation Exchange Capacity

Cation exchange capacity (CEC_7) was determined at pH 7 by ammonium saturation method and determination of the adsorbed NH_4 by the acid-NaCl method (Chapman, 1965). Cation exchange capacity, by the sum of cations, was obtained by the sum of extractable hydrogen, extractable bases and exchangeable acidity.

---

[3]Analysis done at the Instituto Agronômico do Estado de São Paulo, Campinas, S. P., Brazil.

Free Iron Oxides

Free iron was extracted by the citrate-dithionite method as described by Kittrick and Hope (1963). Two dithionite extractions were done. Iron was determined with an atomic absorption spectrophotometer and expressed as Fe_2O_3.

Mineralogical Studies

Clay and Fine Silt Mineral Identification

The X-ray diffraction analyses of three iron-free separates (<.2 μ, .2-2 μ and 2-20 μ) were prepared as oriented specimens on glass slides. Diffractograms of these particles were obtained for the following treatments: Mg saturation and Mg saturation plus ethylene glycol solvation at room temperature; K saturation at room temperature, and heated at 350°C and 500°C (Jackson, 1956).

A nickel-filtered copper K radiation at the scanning rate of 2° (20) per minute was used. A semi-quantitative estimation of the minerals was made by visually comparing the height and width of the peaks.

Petrography of Sand and Coarse Silt Fractions

A small sample of the fine sand (100-250 μ), very fine sand (50-100 μ) and coarse silt (20-50 μ) was dropped on the surface of a glass slide, moistened with dilute solution of methyl alcohol, spread evenly and allowed to dry. A refractive index oil (n = 1.54) was spread on the grains and covered by a thin cover glass. A polarizing microscope was used to identify the grains according to their optical properties and morphology. Approximately 300 to 400 grains were identified in each

sample and their relative amounts were expressed as percentages of the total number of grains counted.

Quantitative Determination of Gibbsite, Kaolinite and Amorphous Material[4]

Kaolinite and gibbsite were estimated by differential thermal analysis using calibration curves prepared with mixtures of standard kaolinite and gibbsite. About 20 mg ($\pm$ 1 mg) of the iron-free fine clay ($<.2$ μ) and coarse clay (2-.2 μ), equilibrated with a slurry of $Mg(NO_3)_2$ was heated in a DuPont 900 differential thermal analyzer at a temperature rate of 20°C per minute in a flowing N_2 atmosphere.

The amorphous material was determined according to Hashimoto and Jackson (1960). One hundred grams of the iron-free fine clay and coarse clay fractions were boiled for 2 min with 0.5 N NaOH solution. The silica and aluminum removed less the gibbsite as estimated by DTA was recorded as amorphous materials.

Thin Section Preparation and Analysis

Small soil blocks (2-3 cm larger axis) with undisturbed structure were impregnated with polyethylene glycol (Carbowax 6000), a water-soluble resin (Mitchel, 1956). Attempts to impregnate oven-dry samples under vacuum with a polyester resin at three different dilutions with monomeric styrene were uncessful due to lack of complete impregnation in the central parts of the peds.

---

[4]Appreciation is expressed to Dr. S. B. Weed, Professor of Soil Science, North Carolina State University at Raleigh, for his orientation on these analyses.

The carbowax resin was liquefied at 100°C and poured over air-dry soil blocks in small aluminum containers. The samples were allowed to be soaked for 8 days in a 60°C oven.

The impregnated soil samples were cut into blocks with a diamond saw. A face of each block was smoothed using carburundun power (320 grit), washed, dried and cemented on a microscopic slide with epoxy resin. They were then sliced to about 2 mm thickness in a thin section cutting saw, ground to 0.3 mm in a thin section grinder and ground to a final thickness by hand on a glass plate using carburundun power (600 grit). During the process of cutting, grinding and washing, kerozene was used in order to prevent solubilization of the carbowax resin.

The thin section was examined with polarizing microscope. Descriptions were made following Brewer's terminology (1964), emphasizing the size and arrangement of primary peds; basic, referred and related distribution of the fabric; void morphology and plasma concentrations.

RESULTS AND DISCUSSION

Physical Properties

Particle Size Distribution

The clay content was over 45% throughout all profiles and the values determined by calgon-pipette method (Table 1) were higher than the ones determined by centrifugation with iron and organic matter removal (Table 2) except for the deepest layers on profile number 1 and number 2.

Clay content determined by the calgon pipette method was always higher than the amount estimated by multiplying the moisture content at 15 atm by 2.5 (Table 1).

Most of the clay, except for the decomposed argillite layer (samples number 2.13 and 4.8 in Table 3) was found to be less than 0.2 μ. The fine clay/coarse clay ratio (Table 3) decreased from the upper to the lower soil of the toposequence suggesting a decreasing weathering stage in this same direction. The fine/coarse clay ratio also decrease with depth in the soil.

The fine silt contents (20 μ to 2 μ) were very low for profiles number 1, 2 and 3. Silt/clay ratios are less than 0.09. Profile number 3 showed a small increase in the silt/clay ratio in the B horizons when compared with profiles number 1 and 2.

The lower member of the toposequence (profile number 4) contains higher silt/clay ratios, being greater than .20 in the uppermost three horizons. The narrow silt clay ratios of profiles number 1, 2 and 3 indicate extensive weathering or old age for these soils (Wanbeke, 1962).

Table 2. Particle size, silt/clay ratio and water-dispersible clay data

Sample No.	Depth	Calgon-pipette method: Sand 2 mm–50 μ	Silt 50–20 μ	Clay 20–2 μ	Clay <2 μ	Silt/clay ratio	Centrif. method Clay <2 μ	15 atm method Clay <2 μ	H_2O dispersible clay
	cm	%	%	%	%		%	%	%
1.1	0–15	20.1	2.8	6.9	70.2	.10	60	66.0	11.2
1.2	15–36	16.4	3.1	3.8	76.7	.05	--	62.8	25.4
1.3	36–65	13.7	3.5	4.2	78.6	.05	69	63.3	2.8
1.4	65–140	15.3	3.3	4.9	76.5	.06	70	64.3	1.6
1.5	140–180	14.1	3.8	6.1	76.0	.08	--	65.4	1.5
1.6	180–250	15.2	3.3	5.4	76.1	.07	--	62.6	1.7
1.7	250–300	14.4	4.4	6.4	76.8	.08	--	----	2.8
1.8	300–350	13.0	3.8	6.3	76.9	.08	--	----	2.2
1.9	350–400	13.9	4.5	7.3	74.3	.10	--	----	2.9
1.10	400–450	15.6	6.7	12.2	65.4	.20	72	----	2.7
2.1	0–12	16.9	4.5	4.4	74.1	.06	66	58.1	30.0
2.2	12–33	16.4	4.5	4.1	74.9	.05	--	60.7	20.4
2.3	33–64	14.2	4.1	3.3	76.8	.04	73	66.0	12.8
2.4	64–90	13.6	3.2	3.9	79.2	.05	71	69.3	1.2
2.5	90–140	13.4	2.9	4.7	78.9	.06	--	65.6	1.7
2.6	140–200	14.0	3.4	4.9	77.7	.06	--	67.6	1.9
2.7	200–250	14.3	3.4	5.7	76.5	.07	--	----	2.4
2.8	250–300	13.8	4.1	5.9	76.2	.08	--	----	2.3
2.9	300–350	14.0	5.3	9.5	71.2	.10	--	----	2.1
2.10	350–400	14.3	7.7	12.6	65.4	.20	--	----	2.3
2.11	400–450	13.9	6.4	14.2	65.6	.21	--	----	2.6
2.12	450–500	13.1	6.8	16.9	63.2	.27	73	----	2.2
2.13	500–550	8.4	5.9	18.6	67.1	.28	71	----	1.6

Table 2 (Continued)

Sample No.	Depth	Calgon-pipette method: Sand 2 mm-50 μ	Silt 50-20 μ	Clay 20-2 μ	Clay <2 μ	Silt/clay ratio	Centrif. method Clay <2 μ	15 atm method Clay <2 μ	H_2O dispersible clay
	cm	%	%	%	%		%	%	%
3.1	0-10	18.1	6.5	7.8	67.6	.10	62	49.2	19.8
3.2	10-25	18.4	6.6	7.4	67.6	.10	--	51.2	16.7
3.3	25-40	18.6	7.6	7.2	66.6	.11	--	51.2	25.4
3.4	40-57	13.6	4.9	6.6	74.8	.09	--	56.5	31.0
3.5	57-82	13.1	4.4	6.6	75.9	.09	69	60.7	18.3
3.6	82-100	12.1	4.0	7.1	76.8	.09	69	63.5	2.1
3.7	100-130	12.6	5.9	7.1	74.3	.09	--	----	1.6
3.8	130-165	12.8	5.9	6.4	74.9	.08	62	----	0.4
3.9	165-200	12.5	5.2	7.2	75.1	.09	--	----	0.0
3.10	200-250	12.5	5.8	6.6	75.1	.09	--	----	1.3
3.11	250-300	12.0	5.8	8.2	74.0	.11	--	----	1.6
3.12	300-350	11.9	6.4	10.4	71.2	.14	--	----	1.8
3.13	350-400	12.4	7.0	13.7	66.9	.20	--	----	1.7
3.14	400-450	10.6	7.8	20.1	61.5	.32	--	----	2.0
4.1	0-10	19.5	7.3	14.2	58.8	.24	54	45.2	30.6
4.2	10-19	19.0	6.7	13.6	60.8	.22	--	47.2	31.5
4.3	19-37	18.3	8.2	13.2	60.3	.21	54	45.7	31.0
4.4	27-64	9.2	3.3	9.5	78.0	.12	70	66.2	6.1
4.5	64-95	7.9	3.4	8.1	80.6	.10	--	69.2	4.5
4.6	95-150	8.3	2.0	7.4	82.3	.09	73	71.0	1.9
4.7	150-190	7.8	3.2	10.4	78.6	.13	--	----	1.8
4.8	190-260	2.0	4.5	22.7	70.8	.32	68	----	2.1

Table 3. Particle size as determined by the centrifugation method, with organic matter and free iron removed

Sample No.	Depth	Sand		Silt		Coarse clay	Fine clay	Fine clay/ coarse clay ratio
		2-.25 mm	.25-.05 mm	50-20 μ	20-2 μ	2-0.2 μ	<0.2 μ	
	cm	%	%	%	%	%	%	
1.1	0-15	6	13	5	3	7	53	7.6
1.3	36-65	6	8	5	3	8	61	7.6
1.4	65-140	7	9	4	4	11	59	5.3
1.10	400-450	2	13	5	3	12	60	5.1
2.1	0-12	3	17	6	5	15	51	3.4
2.3	33-64	2	14	5	6	10	63	6.3
2.4	64-90	2	13	6	6	13	58	4.5
2.12	450-500	2	12	5	7	17	56	3.3
2.13	500-550	1	7	7	12	28	43	1.5
3.1	0-10	3	16	8	7	12	50	4.2
3.5	57-82	2	12	7	5	16	53	3.3
3.6	82-100	2	14	7	5	19	45	2.4
3.8	130-165	2	13	7	9	23	39	1.7
4.1	0-10	4	15	11	12	16	38	2.4
4.3	19-27	4	6	19	13	14	40	2.9
4.4	27-64	2	4	9	8	19	51	2.7
4.6	95-150	1	5	9	6	19	54	2.8
4.8	190-260	tr.	5	3	19	30	38	1.3

The distribution of clay with depth can be best visualized in Figure 5. Profile numbers 1 and 2 have a slight increase in clay content in the B horizon. This increase is not sufficient to identify an argillic horizon on these soils (Soil Survey Staff, 1970).

In profile numbers 3 and 4 the clay content increases more than 8% within a vertical distance of less than 30 cm which is one of the requirements for an argillic horizon. The greater increase in clay content observed in profile number 4 suggests that this profile has had more clay illuviation than any of the other three profiles studied.

In profile numbers 1, 2 and 3 there is no significant clay content decrease with a depth of more than 300 cm at 190-cm depth. Profile number 4 has a clay content decrease of 11.5% from its maximum.

Water-Dispersible Clay

Water-dispersible clay content was always found to decrease from the surface horizons (A1 or Ap and A3) to the deepest layers (Table 1). Abrupt decrease in water-dispersible clay content to less than 3% was found in profile numbers 1, 2 and 3. The depth where the water-dispersible clay content was less than 3% varies among profiles, increasing from profile number 1 to profile number 4. This trend suggests that the clay fraction increases in mobility from the upper to the lower member of the toposequence. It also suggests a presence of argillic horizons in profile numbers 3 and 4 and in the horizon described as B1 (sample 2.3) in profile number 2.

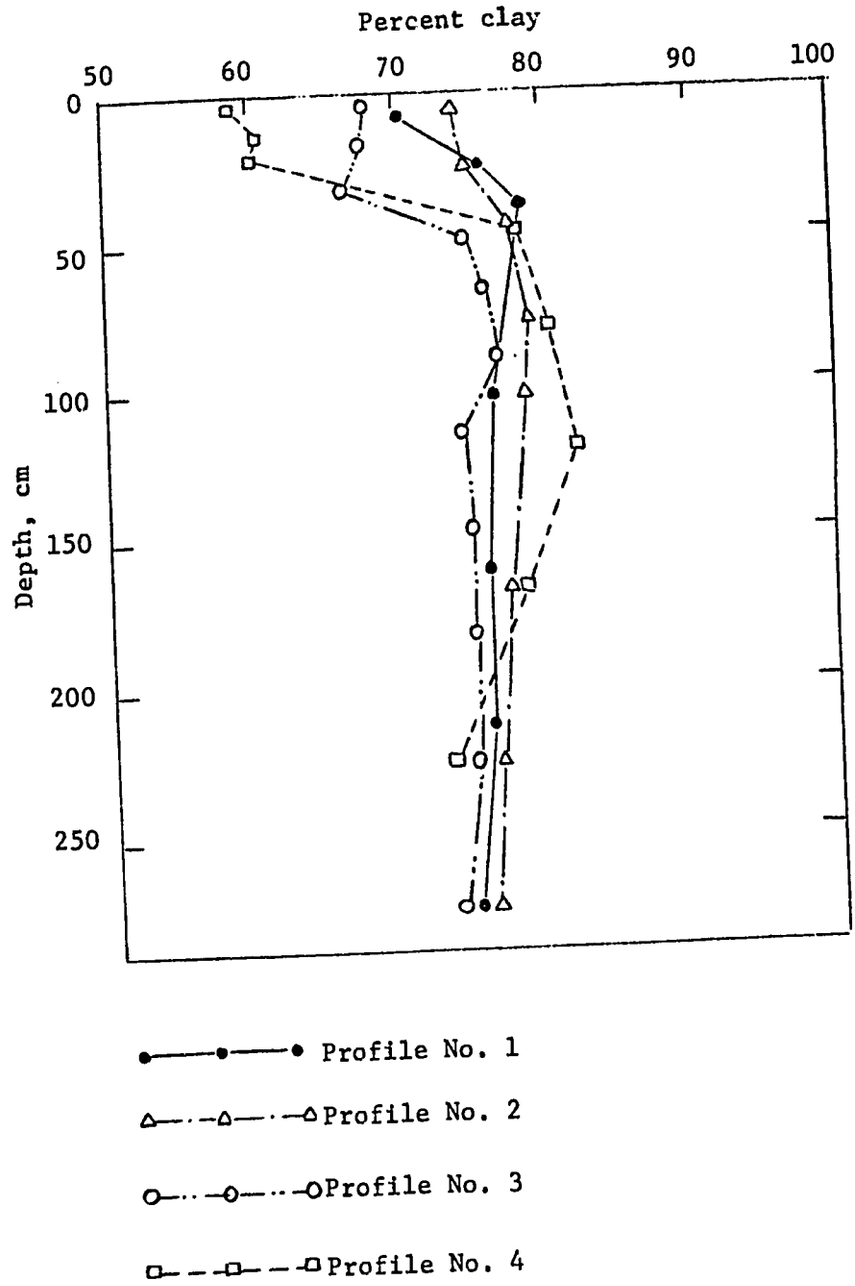


Figure 5. Relative distribution of clay (<2 μ) with depth (Calgon-pipette method)

Bulk Density, Particle Density and Porosity

Table 4 contains the results of bulk density and particle density determinations. Profile number 1 has bulk density values of approximately 0.9 g/cm^3 throughout the profile. Profile numbers 2, 3 and 4 have higher bulk density values in the second horizon, just below the plow layer. This is probably due to cultivation practices and traffic of agriculture machinery on these soils.

Profile numbers 2 and 3 also have higher bulk density values in the upper part of the B horizon. No apparent significant variation on bulk density values was noticed in the B horizon of profile number 4.

Bulk density values above 1.0 g/cc, with exception of sample number 3.6, coincides were subangular blocky structure as described in field soil descriptions (Appendix A). The values below 1.0 g/cc were found for the horizons with friable fine granular structure, characteristic of most oxic horizons (Soil Survey Staff, 1970).

The values of porosity, calculated from bulk density and particle size density are presented on Figure 6. Figure 6 shows that profile number 1 has the higher values of total porosity, all horizons having 60 to 70% of their volume occupied by pores. Porosity in profile number 4 ranged from 45 to 55%. A greater variation in porosity was found in profile numbers 2 and 3 where the upper horizons were somewhat similar to profile number 4, decreasing gradually with depth to values at about 1 m that are similar to those found in profile number 1.

Water Retention and Maximum Available Water

Water retention values for 1/3 atm, 1 atm and 15 atm are given on Table 4. No apparently significant differences were observed on the

Table 4. Bulk density, particle density and water retention data

Sample No.	Depth	Bulk density	Particle density	Water retention 1 atm	1/3 atm	15 atm	Maximum available water
	cm	g/cc	g/cc		%		g/100 cc
1.1	0-15	.90	2.53	25.7	29.5	26.4	3.4
1.2	15-36	1.01	2.63	25.7	29.5	25.1	4.4
1.3	36-65	.90	2.67	27.3	31.8	25.3	5.8
1.4	65-140	.98	2.67	28.0	32.8	25.7	6.9
1.5	140-180	.89	2.67	27.9	32.5	26.2	5.6
2.1	0-12	1.22	2.60	24.7	28.9	23.3	6.8
2.2	12-33	1.48	2.67	25.7	29.7	24.3	8.0
2.3	33-64	1.30	2.67	27.3	30.8	26.4	5.7
2.4	64-90	1.03	2.67	28.6	32.0	27.2	4.9
2.5	90-140	.90	2.53	29.5	34.6	26.6	7.0
2.6	140-200	.91	2.53	29.4	34.4	27.0	6.7
3.1	0-10	1.32[a]	2.63	24.0	27.8	19.7	10.7
3.2	10-25	1.42[a]	2.56	25.6	29.2	20.5	12.3
3.3	25-40	1.34[a]	2.60	24.7	28.1	20.5	10.2
3.4	40-57	1.19	2.56	26.0	29.1	22.6	7.7
3.5	57-82	1.07	2.67	27.3	30.8	24.3	6.9
3.6	82-100	.89	2.67	28.7	33.4	25.4	7.1
3.7	100-130	.94	2.70	--	--	--	--
3.8	130-165	.88	2.67	--	--	--	--
3.9	165-200	.92	2.63	--	--	--	--
4.1	0-10	1.23	2.63	22.0	26.5	18.1	10.3
4.2	10-19	1.41	2.60	23.2	26.8	18.9	11.1
4.3	19-27	1.34	2.67	23.4	26.8	19.0	10.4
4.4	27-64	1.31	2.67	31.7	34.8	26.5	10.9
4.5	64-95	1.32	2.67	31.9	35.1	27.7	9.8
4.6	95-150	1.25	2.67	31.9	35.6	28.4	9.0
4.7	150-190	1.24	2.70	--	--	--	--

[a]Done by the coated-clod method.

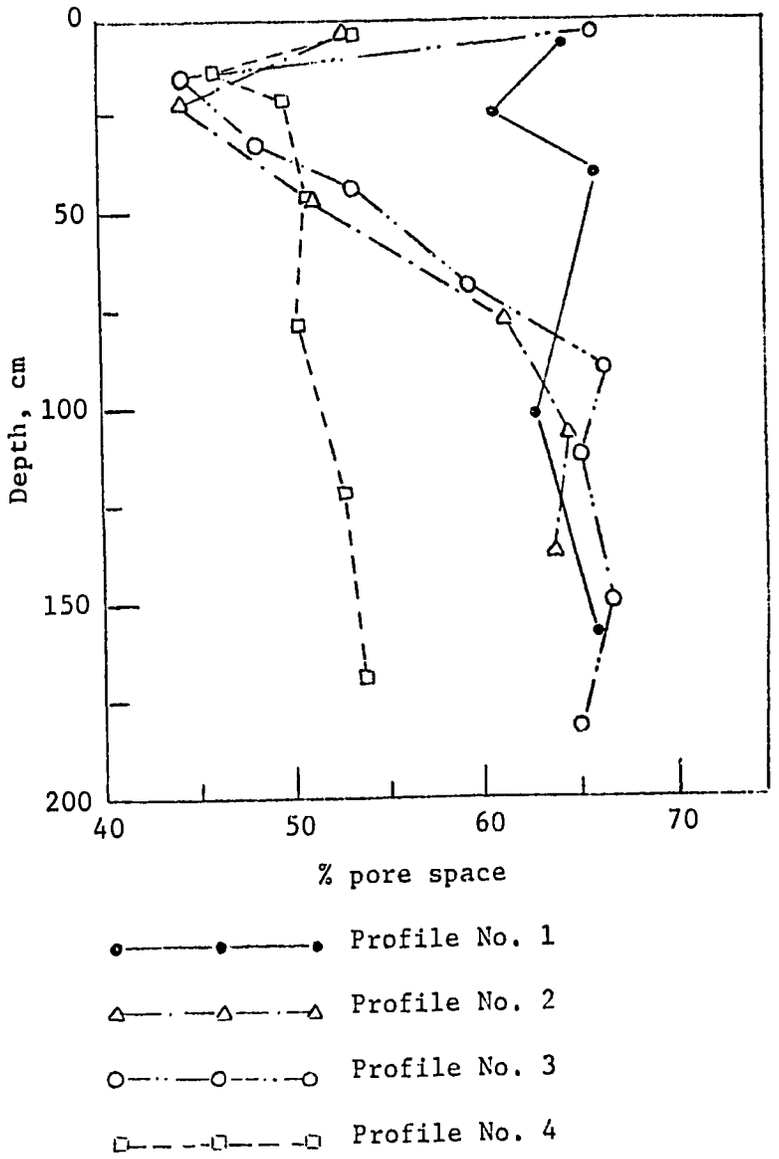


Figure 6. Total pore space with depth

moisture retention values for profile numbers 1, 2 and 3. Profile number 4 has somewhat lower values in the surface horizons (A horizons) and these differences appear related with the clay increase with depth in this profile. However, data of the maximum available water expressed in a volume basis (g H_2O/100cc of soil) increased from profile number 1 to profile number 4. The apparent increase in water availability seems to be correlated with the weathering stage and soil porosity. The data suggest that highly weathered soils with fine granular structure have lower capacity to supply water to the plants than the less weathered soils with blocky structure in the B horizon.

Chemical Properties

Soil Reaction

The results of pH determinations are listed in Table 5. No apparent significant differences in the pH values measured in water were found between profiles 1, 2 and 3. Profile number 4 showed slightly higher pH values.

The pH values determined in KCl were always lower than the ones determined in water. Some differences among profiles are apparent when we compare the calculated Δ pH (pH in KCl-pH in H_2O). According to Mekaru and Uheara (1972), when the Δ pH value is negative, the soil has a net negative electrical charge. By this calculation, the negative charge seems to increase from profile number 1 to profile number 4.

Organic Carbon

Organic carbon contents are reported in Table 5. The highest contents were found in the A1 horizon of profile number 1. The higher

Table 5. Chemical properties

Sample No.	pH H_2O	pH KCl	Δ pH KCl-H_2O	Organic carbon	CEC_7 NH_4OAc	Ca	Mg	K	Na	Exch. acid-ity	Extract H	Sum of bases	CEC sum of cations	Base saturation by sum of cations
				%		---meq/100 g soil---								%
1.1	5.0	4.2	-.8	3.01	11.36	3.08	0.71	0.43	0.17	1.45	11.35	4.00	16.8	23.8
1.2	4.8	4.0	-.8	1.72	8.72	0.21	0.19	0.19	0.16	3.00	8.55	0.75	12.3	6.1
1.3	5.0	4.2	-.8	.96	8.56	0.14	0.07	0.14	0.14	4.50	2.50	0.49	7.5	6.5
1.4	5.0	4.4	-.6	.68	7.47	0.13	0.08	0.09	0.15	1.25	5.90	0.45	7.6	5.9
1.5	5.2	4.4	-.8	.68	8.40	0.13	0.11	0.09	0.21	0.95	5.75	0.54	7.2	7.5
1.6	5.1	4.5	-.6	.65	7.62	0.09	0.07	0.06	0.12	0.95	5.60	0.34	6.9	4.9
1.7	5.4	4.9	-.5	--	7.31	0.13	0.07	0.08	0.23	tr.	5.55	0.51	6.1	8.4
1.8	5.5	5.0	-.5	--	7.94	0.13	0.05	0.06	0.22	tr.	4.70	0.46	5.2	8.9
1.9	5.5	5.0	-.5	--	4.67	0.13	0.02	0.05	0.11	tr.	4.55	0.31	4.9	6.4
1.10	5.6	5.0	-.6	--	5.45	0.11	0.02	0.04	0.10	tr.	4.20	0.27	4.5	6.0
2.1	5.3	4.4	-.9	1.45	8.56	3.58	0.42	0.22	0.15	0.70	7.35	4.37	12.4	35.2
2.2	5.3	4.4	-.9	1.55	9.03	9.25	0.48	0.15	0.14	0.80	7.05	10.02	17.9	56.1
2.3	4.9	4.1	-.8	1.38	8.56	2.13	0.10	0.13	0.09	2.10	5.85	2.54	10.5	24.2
2.4	5.0	4.3	-.7	1.35	7.78	2.16	0.13	0.13	0.13	1.60	5.95	2.55	10.1	25.2
2.5	5.2	4.6	-.6	0.75	7.63	0.62	0.06	0.12	0.12	0.75	5.25	0.92	6.9	13.3
2.6	5.4	4.7	-.7	0.58	4.83	0.11	0.08	0.12	0.10	tr.	5.30	0.41	5.7	7.2
2.7	5.7	5.0	-.7	--	6.23	0.14	0.06	0.05	0.11	tr.	4.95	0.36	5.3	6.8
2.8	5.7	4.9	-.8	--	5.29	0.13	0.04	0.10	0.11	tr.	4.90	0.38	5.3	7.2
2.9	5.5	4.8	-.7	--	5.45	0.16	0.08	0.11	0.12	tr.	4.60	0.47	5.1	9.3
2.10	5.7	4.8	-.9	--	5.29	0.11	0.03	0.06	0.09	tr.	4.70	0.29	5.0	5.8
2.11	5.4	4.6	-.8	--	5.14	0.12	0.04	0.08	0.09	tr.	4.40	0.33	4.7	7.0
2.12	5.3	4.3	-1.0	--	3.43	0.09	0.02	0.08	0.25	1.10	3.60	0.44	8.6	8.6
2.13	5.7	3.9	-1.8	--	6.38	0.13	0.05	0.09	--	3.45	2.65	0.27	6.9	4.2

Table 5 (Continued)

Sample No.	pH H_2O	pH KCl	Δ pH KCl-H_2O	Organic carbon	CEC_7 NH_4OAc	Ca	Mg	K	Na	Exch. acid-ity	Extract H	Sum of bases	CEC sum of cations	Base saturation by sum of cations
				%		---meq/100 g soil---								%
3.1	5.0	4.2	-.8	1.49	8.56	3.78	0.47	0.41	0.20	0.80	7.65	4.86	13.3	36.5
3.2	4.9	4.2	-.7	1.63	9.49	3.87	0.46	0.24	0.20	1.00	8.00	4.77	13.8	34.6
3.3	5.0	4.2	-.8	1.66	9.80	4.80	0.57	0.18	0.19	0.55	7.40	5.74	13.7	41.9
3.4	5.3	4.4	-.9	1.24	7.47	2.80	0.58	0.12	0.23	tr.	6.55	3.73	10.3	36.3
3.5	5.1	4.2	-.9	1.00	7.00	1.54	0.52	0.12	0.22	0.95	6.20	2.40	9.5	25.1
3.6	5.0	4.1	-.9	.76	5.92	0.72	0.24	0.13	0.22	1.50	5.90	1.31	8.7	15.0
3.7	5.2	4.3	-.9	--	6.07	0.33	0.15	0.13	0.27	1.00	5.65	0.88	7.5	11.7
3.8	5.5	4.3	-1.2	--	5.29	0.16	0.09	0.11	0.24	0.80	5.80	0.60	7.2	8.3
3.9	5.5	4.3	-1.2	--	4.83	0.11	0.07	0.11	0.21	0.80	5.10	0.50	6.4	7.8
3.10	5.7	4.6	-1.1	--	3.43	0.10	0.11	0.11	0.24	tr.	5.30	0.56	5.8	9.6
3.11	5.7	4.4	-1.3	--	5.14	0.13	0.09	0.11	0.10	0.70	4.40	0.43	5.5	7.8
3.12	5.5	4.2	-1.3	--	5.14	0.13	0.07	0.10	0.16	1.10	3.95	0.46	5.5	8.3
3.13	5.5	4.2	-1.3	--	--	0.10	0.14	--	--	1.30	4.35	--	--	--
3.14	5.6	3.8	-1.8	--	8.41	0.12	0.06	0.13	0.12	4.00	3.55	0.43	8.0	5.4
4.1	6.0	5.1	-.9	1.27	10.58	8.50	1.11	0.62	0.10	tr.	4.75	10.33	15.1	68.5
4.2	5.7	4.6	-1.1	1.28	9.18	7.80	0.58	0.26	0.10	tr.	3.15	8.74	11.9	73.5
4.3	5.7	4.6	-1.1	1.33	9.34	6.60	0.62	0.18	0.10	tr.	5.70	7.50	13.2	56.8
4.4	5.8	4.8	-1.0	0.77	9.65	5.30	0.79	0.10	0.10	tr.	4.80	6.38	11.2	57.1
4.5	5.8	4.9	-.9	0.64	8.56	4.55	0.82	0.23	0.13	tr.	4.65	5.73	10.4	55.2
4.6	5.5	4.6	-.9	0.43	8.56	2.40	0.75	0.32	0.13	tr.	5.70	3.60	9.3	38.7
4.7	5.3	3.9	-1.4	--	8.25	1.13	0.44	0.27	0.16	2.50	5.05	2.00	9.5	20.9
4.8	5.2	3.6	-1.6	--	11.67	0.60	0.30	0.27	0.16	6.55	4.25	1.33	12.1	11.0

organic content in the superficial horizon of profile number 1 reflects the forest cover on this site. Organic carbon content decreased with depth in profile number 1.

Profile numbers 2, 3 and 4 have an increase in the organic carbon content from the Ap1 to the Ap2 horizon. The higher amounts of organic matter in the Ap2 horizon may be due both to the influence of the grass root system and to the low porosity of these layers. It was recorded that these sites were used as pastures for 40 years. The lower porosity could prevent organic matter decomposition due to a decrease in aeration while cultivation has aerated the plow layer and enhanced organic matter decomposition.

Contents of about 1% organic carbon were determined at depths of 65, 90 and 82 cm, respectively, for profile numbers 1, 2 and 3. In profile number 4 organic carbon decrease to values of less than 1% at a depth of 27 cm.

The relatively higher amounts of organic matter at depths of 1 m in profile numbers 1, 2 and 3 suggest that faunal and floral pedoturbation (Hole, 1961) either is greater in these profiles or that they had been exposed longer at these propedoisotropic processes. Pedoturbation processes probably play a definite role in the genesis of the soils studied since high activity of ants and termites was noted in the area.

Cation Exchange Capacity and Base Saturation

The results of these determinations are listed in Table 5. Cation exchange capacity values normally decrease with depth and this seems to be correlated with a decrease in organic matter content. No apparent differences were found between profile numbers 1, 2 and 3; they have

values between 9 and 10 meq/100 g of clay in the B horizons. The B2 horizons of profile number 4 has higher CEC values, in spite of having relatively less organic carbon. The B21 horizon of this profile has 12.4 meq/100 g of clay which suggests higher activity of the clay particles in this profile when compared with the three upper members of the toposequence.

Base saturation values are extremely low in the subsurface horizons of profile number 1. This soil has a 23.8% base saturation value for the A1 horizon which decreases sharply with depth.

For profile numbers 2, 3 and 4 the base saturation percentages, with exception of the surface layers, also decrease with depth but the rate of decrease varies among profiles. Higher values were found to greater depths in the lower toposequence members than in the upper members of the toposequence.

Part of the increase in base content and base saturation among the profiles is probably due to the use of lime and artificial fertilizers in the cultivated sites (i.e., lower members). However, it seems that the use of lime and fertilizer cannot totally account for the increases at depths such as 50 cm, nor the trend in base saturation increase.

Profile number 4 shows considerably higher base saturation values in the subsoil reaching 55.2% in the B21 horizon at a depth of 95 cm.

It is possible that, in addition to liming and fertilization, other factors are involved in the observed base saturation increase among profiles. Lateral migration of subsuperficial waters enriched in bases displaced from the upper part of the landscape seems to be one possible factor. The lateral migration of enriched solutions is even

more apparent when we consider that the deepest samples analyzed in all profiles have a very low base status which excludes differences in parent material composition as an explanation for the trend in base saturation among profiles.

Mineralogy

Sand Mineralogy

Table 6 presents the results of microscopic examination of fine sand (100-250 μ), very fine sand (50-100 μ) and coarse silt (20-50 μ) particles.

Quartz was the dominant mineral in all the analyzed grain fractions. The quartz grains were mostly rounded in the fine and very fine sands (50-250 μ). The coarse silt grains were mostly angular quartz particles. Some of these angular grains can be interpreted as being fragments from larger particle sizes, broken during the repeat shaking procedures done during the clay separation procedures. The separation of the sands by sieving just after free iron removal in Kittrick's method (1963) seems to be a desirable procedure for these soils in order to avoid breakdown of sand particles.

The grains counted as "heavies plus opaques" were the second most common grains found and they were observed mostly in the 20 to 50 fractions. It was noticed that the content of these minerals tended to decrease from profile number 1 to profile number 2. It can be observed also that there is a decrease of about 50% in the "heavies plus opaque grains" from sample 2.12 to sample 2.13 and from sample 4.6 to sample 4.8. This sharp decrease suggests that there is a lithologic discontinuity between these layers. The presence of this discontinuity is

Table 6. Petrographic identification of sand and coarse silt grains

Sample No.	Depth	Grain size	Total grains	Quartz	Heavies and opaques	Opal	Rock fragments	Mica	Others
	cm	μ	No.	%	%	%	%	%	%
1.1	0-10	20-50	333	62	21	15	0	0	2
		50-100	381	92	7	1	0	0	tr.
		100-250	286	96	2	0	0	0	2
1.3	36-65	20-50	571	73	20	7	0	0	1
		50-100	359	93	5	1	0	0	1
		100-250	296	96	4	0	0	0	1
1.4	65-140	20-50	528	68	26	4	0	0	2
		50-100	416	89	6	tr.	0	0	5
		100-250	336	92	4	0	0	0	4
1.10	400-450	20-50	414	68	27	tr.	0	0	3
		50-100	384	91	7	0	0	0	2
		100-250	325	97	3	0	0	0	1
2.1	0-10	20-50	353	81	11	7	1	0	tr.
		50-100	302	93	4	2	1	0	tr.
		100-250	303	94	1	1	2	0	2
2.3	33-64	20-50	333	79	14	6	0	0	1
		50-100	336	92	3	tr.	1	0	4
		100-250	295	87	1	tr.	2	0	10
2.4	64-90	20-50	416	85	9	5	tr.	0	1
		50-100	258	96	4	0	0	0	tr.
		100-250	268	94	1	tr.	1	0	4
2.12	20-50	20-50	451	86	11	tr.	tr.	1	1
		50-100	375	97	2	0	1	0	0
		100-250	338	95	1	0	4	0	1
2.13	500-550	20-50	484	93	5	0	1	0	tr.
		50-100	351	89	1	0	10	0	1
		100-250	317	84	1	0	14	0	1

Table 6 (Continued)

Sample No.	Depth	Grain size	Total grains	Quartz	Heavies and opaques	Opal	Rock fragments	Mica	Others
	cm	μ	No.	%	%	%	%	%	%
3.1	0-10	20-50	419	84	6	9	1	0	tr.
		50-100	361	96	2	1	1	0	0
		100-250	348	92	2	0	4	0	2
3.5	57-82	20-50	588	87	8	5	0	0	tr.
		50-100	421	97	1	tr.	1	0	tr.
		100-250	233	96	1	0	2	0	tr.
3.6	82-100	20-50	525	87	10	2	0	1	tr.
		50-100	367	96	2	tr.	tr.	0	tr.
		100-250	296	92	2	0	4	0	1
3.7	130-165	20-50	565	87	10	tr.	0	2	1
		50-100	367	95	3	0	tr.	0	1
4.1	0-10	20-50	502	88	7	5	tr.	0	tr.
		50-100	423	92	3	tr.	5	0	0
		100-250	293	87	tr.	tr.	11	0	1
4.3	19-27	20-50	454	90	5	4	tr.	tr.	0
		50-100	327	93	2	1	3	0	1
		100-250	344	89	2	0	9	0	1
4.4	27-64	20-50	385	90	7	3	0	1	0
		50-100	421	92	2	tr.	5	0	0
		100-250	334	94	tr.	0	6	0	0
4.6	95-150	20-50	407	92	6	tr.	0	1	0
		50-100	373	88	3	tr.	5	0	3
		100-250	334	91	2	0	5	0	1
4.8	190-260	20-50	439	82	3	0	1	14	0
		50-100	427	91	1	0	7	0	0

reinforced by the fact that field descriptions (Appendix A) recorded stone lines and a sharp break in color between the clayey decomposed rock and the overlying earthy material.

Some elongated angular rock fragments were found in the 100-250 μ fraction in profile numbers 2, 3 and 4. Thin section observation showed that these grains are composed predominantly of quartz with some amount of "heavies" and some partially weathered minerals. None of these grains were found at any depth in profile number 1. The decomposed clayey sedimentary rock contained greater amounts of these grains than the overlying soil. It was also noted that the amount of these rock fragments increased from profile number 2 to profile number 4.

The upper to the lower member of the toposequence decreases in content of "heavy plus opaque" grains and increased in content of rock fragments. Also, the clayey sedimentary rock has less "heavies plus opaques" and more "rock fragments" than the overlying soil material, suggesting that profile numbers 2, 3 and 4 have developed in a colluvial parent material. When sediments under geomorphic surface B (Figure 2) were deposited, this colluvial material apparently received contributions both from the sediments underlying geomorphic surface A and from the clayey sedimentary rock, the trend in rock fragments and "heavy plus opaques" also suggests that the parent material of profile numbers 2, 3 and 4 received different amounts of the clayey sedimentary rock and that these amounts increase from profile number 2 to profile number 4.

Opaline silica grains were another kind of mineral identified in most samples, predominantly in the coarse silt fraction. Opaline

silica was identified by their isotropic character and also their index of refraction at 1.4, much lower than that of quartz grains. The configuration of these grains often resembles plant remains. Similar grains were described in soils by Smithson (1958, 1959) which referred them as been opal phytoliths.

The presence of opal phytoliths at any appreciable depth in a soil profile was suggested by Oberholster (1968) as evidence of pedoturbation. In the profiles studied, plant opal grain contents in the 20-50 μ fraction were 4% at 64-140 cm for profile number 1; 5% for profile numbers 2 and 3 at 64-90 cm and 57-82 cm, respectively, and 3% at 27-64 cm in profile number 4. These data suggest that some form of pedoturbation has been more active and to a greater depth in the three upper members of the toposequence since the B3 horizon of profile number 4 (95-150 cm depth) showed only traces of opal grains.

Most of the grains counted as "others" were rounded light yellow aggregates. An X-ray analysis of these grains showed appreciable amounts of gibbsite, some quartz and kaolinite and several peaks between 17 and 9.8 Angstroms with a maximum intensity at 12.4 Angstroms were also observed.

Observations of the coarse sand fractions under bionocular microscope showed the presence of rounded sesquioxide concretions which were present in all samples. These sesquioxide concretions according to Stoops (1968) may be interpreted as pedorelicts and point to a polycyclic character of formation of the soils studied.

Clay and Fine Silt Mineralogy

Table 7 summarizes the results obtained from the interpretation of X-ray diffractograms of clays and silt fractions from some selected samples. Figures 6, 7, 8 and 9 are diffractograms for the fine coarse clay particles for the B horizons and Figure 10 contains diffractograms for the coarse clay fraction of the clayey sedimentary rock.

Clay mineralogy estimations from the X-ray diffractograms indicate that kaolinite is the dominant clay mineral in all fractions from all analyzed samples. Other clay minerals estimated to be present in amounts between 10 and 50% were the chlorite-vermiculite intergradient minerals as defined by Jackson (1964), gibbsite and vermiculite. Quartz was detected to be present only as traces (less than 10%) in the coarse clay fraction.

Chlorite-vermiculite intergrade minerals were found mainly in the coarse clay fractions of profile numbers 1 and 2 (Figure 8). They were estimated to be present in amounts ranging from 25 to 50%. The chlorite-vermiculite intergrade contents in the total clay fraction of the B2 horizons were estimated to be from 10 to 25% for profile numbers 1 and 2, 5 to 10% for profile number 3 and 3 to 6% for profile number 4. The formation of intergradient 2:1-2:2 layer silicates in highly weathered acid soils might be explained by the precipitation of hydroxy Al and sesquioxides in the interlayer space of vermiculite (Jackson, 1964). The presence of these minerals in considerable amounts in the more intensively weathered profiles confirms the observations that even under moist tropical conditions vermiculite withstands severe weathering conditions when considerable Al and Fe interlayering is present (Soil Survey

Table 7. Clay mineralogy estimations by X-ray analysis

Sample No.	Depth	Particle size[a] <.2 μ	2-.2 μ	2-20 μ
	cm			
1.1	0-10	$K^3I^tG^t$	$K^2I^2G^1Q^t$	
1.3	36-65	$K^3I^tG^t$	$K^2I^2G^1Q^t$	
1.4	65-140	$K^3I^tG^t$	$K^2I^2G^1Q^t$	$Q^3K^tI^tM^tG^tA^t$
1.10	400-450	$K^3I^tG^t$	$K^2I^2G^1Q^t$	
2.1	0-10	$K^3I^tG^tV^t$	$K^2I^2G^1M^tQ^t$	
2.3	33-64	$K^3I^1G^t$	$K^2I^2G^1M^tQ^t$	
2.4	64-90	$K^3I^1G^tV^t$	$K^2I^2G^1M^tQ^t$	$Q^3K^1I^tV^tG^tM^tA^t$
2.12	450-500	$K^3I^tG^tM^t$	$K^2I^tG^tM^tV^tQ^t$	
2.13	500-550	$K^3M^1G^tV^t$	$K^3M^1V^tG^t$	$K^2Q^2M^1$
3.1	0-10	$K^3I^tG^tV^t$	$K^2I^1M^tG^tQ^tV^t$	
3.5	57-82	$K^3I^tG^tM^t$	$K^2I^1M^tG^tQ^tV^t$	
3.6	82-100	$K^3I^tG^tM^t$	$K^3I^1M^tG^tQ^tV^t$	$Q^3K^1M^1V^tA^t$
3.8	130-165	$K^3I^tG^tM^t$	$K^3I^1M^tG^tQ^tV^t$	
4.1	0-10	$K^3V^1M^t$	$K^2V^1M^1G^t$	
4.3	19-27	$K^3I^tM^tV^t$	$K^2V^1M^1Q^t$	
4.4	27-64	$K^3I^tM^tV^t$	$K^2V^1M^1Q^t$	$Q^3M^1K^1A^t$
4.6	95-150	$K^3I^tM^tV^t$	$K^2V^1M^1Q^t$	
4.8	190-260	$K^3M^2V^t$	$K^2M^2V^t$	

[a]Key: K = kaolinite
I = intergradient 2:1-2:2
M = mica
Q = quartz
V = vermiculite
A = anatase

Semi-quantitative estimation:

3 = abundant (>50%)
2 = medium (25-50%)
1 = small (10-25%)
t = trace (<10%)

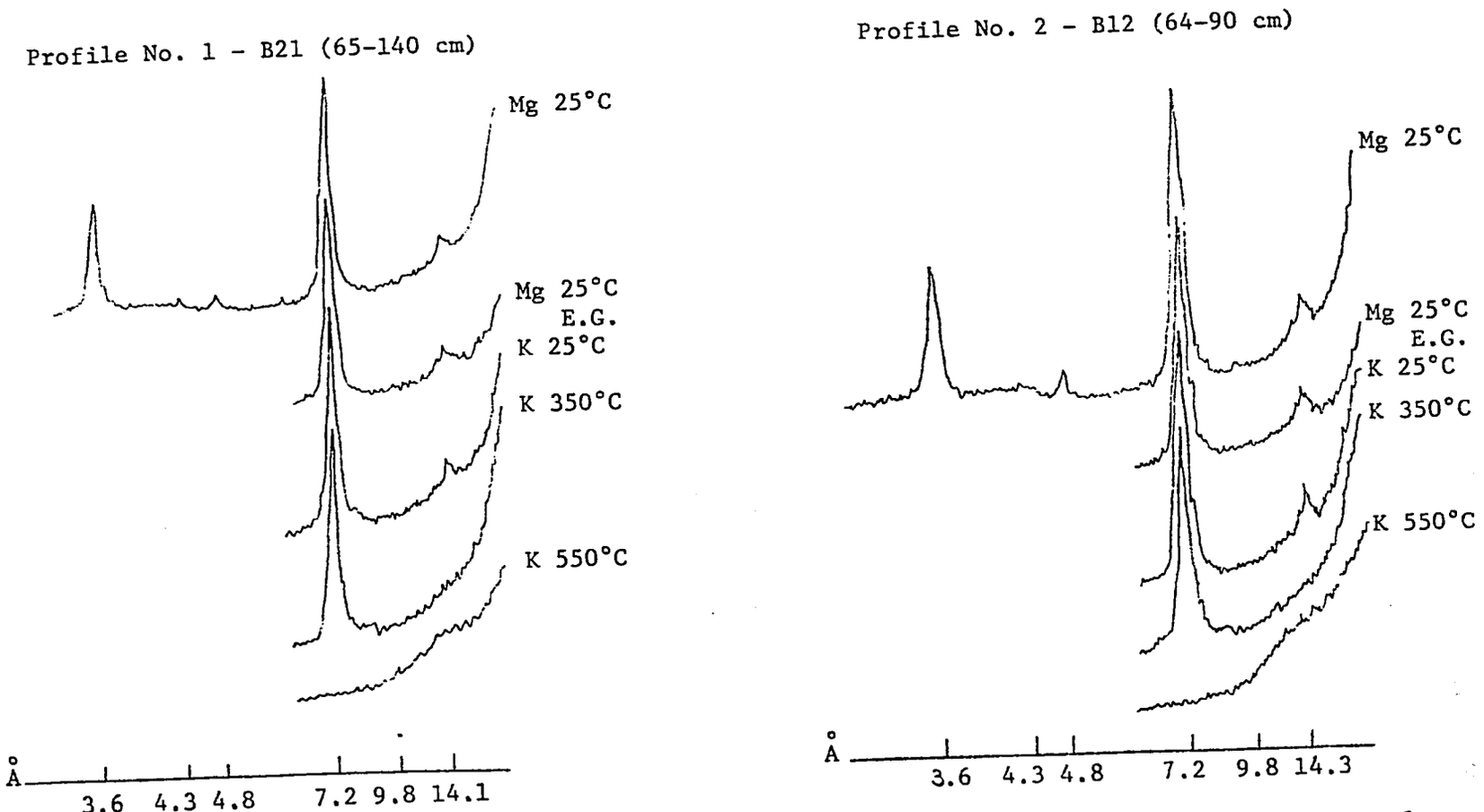


Figure 7. X-ray diffraction patterns of the fine clay (<0.2 μ) of samples from the B horizon of profile numbers 1 and 2

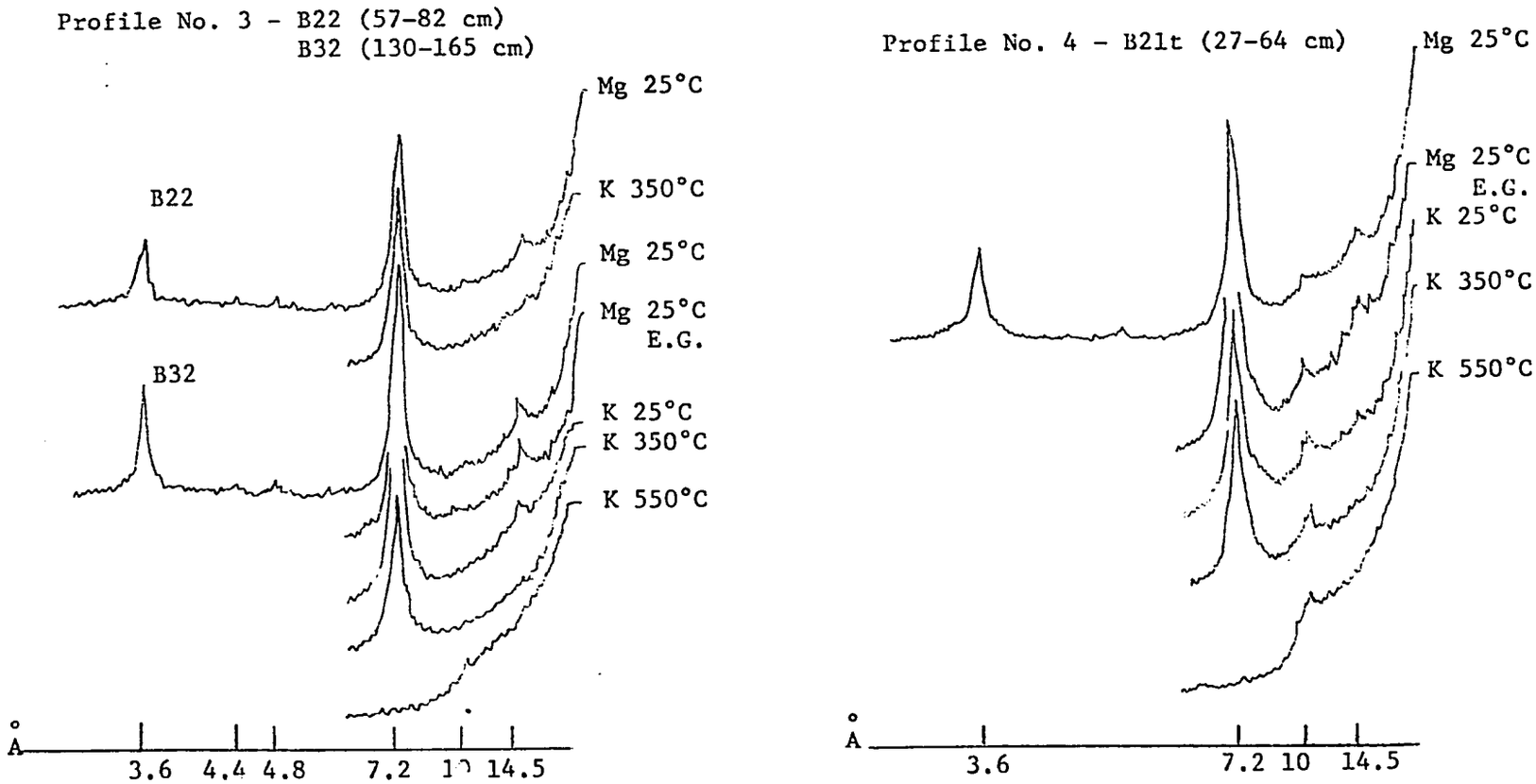


Figure 8. X-ray diffraction patterns of the fine clay (<0.2 μ) of samples from the B horizon of profile numbers 3 and 4

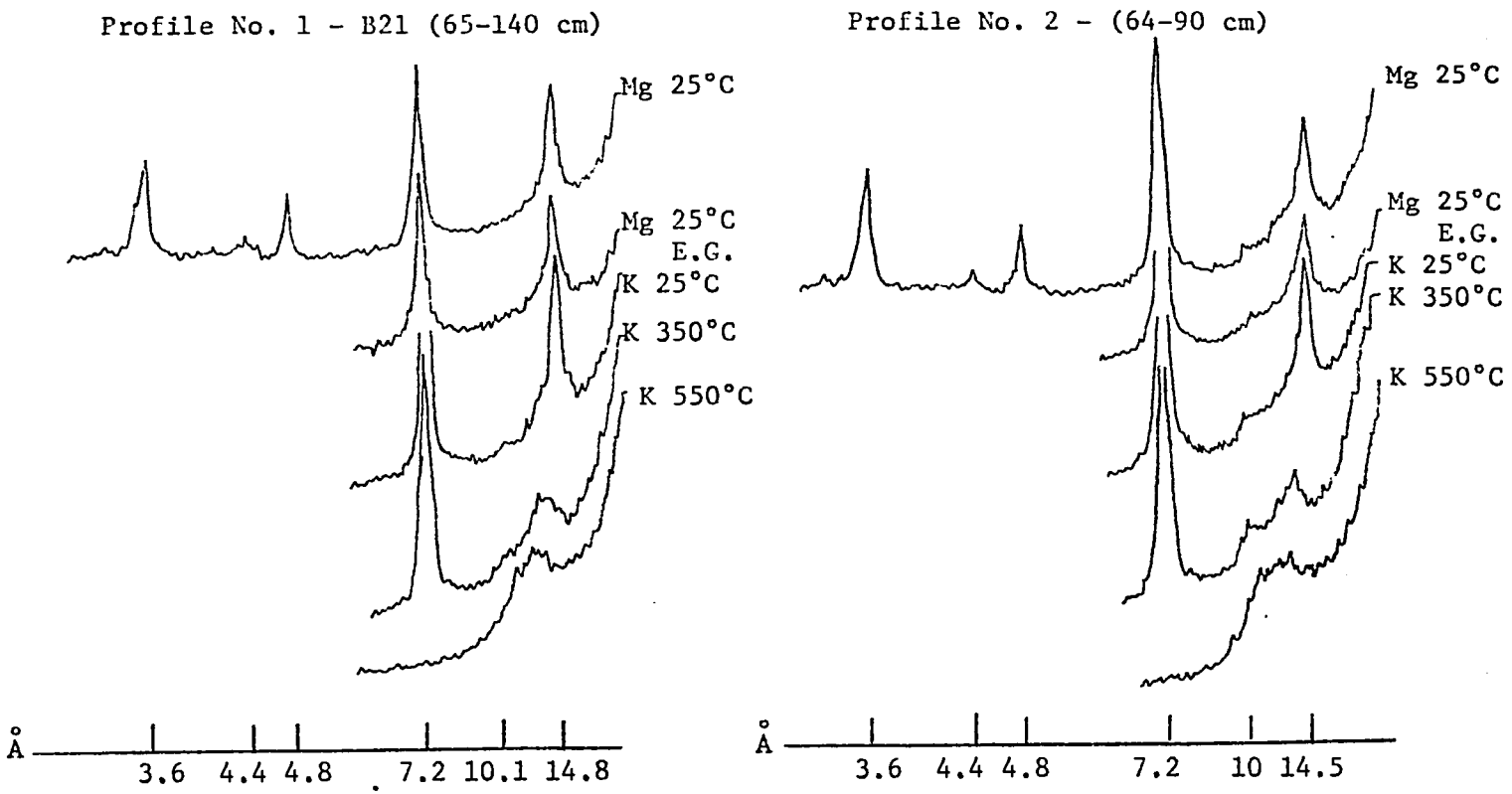


Figure 9. X-ray diffraction patterns of the coarse clay (<2-.2 μ) of samples from the B horizons of profile numbers 1 and 2

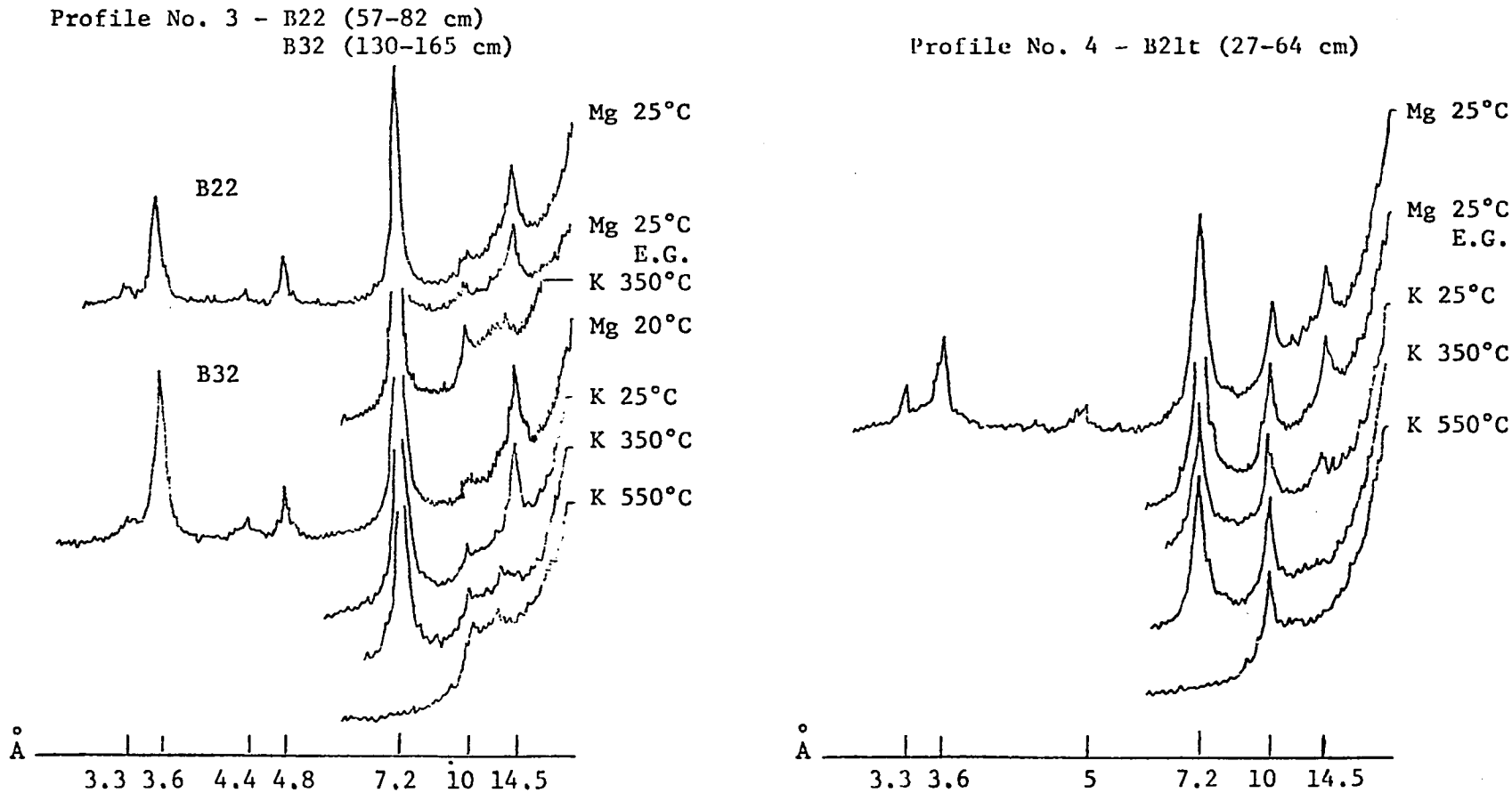


Figure 10. X-ray diffraction patterns of the coarse clay (<2-.2 μ) of samples from the B horizons of profile numbers 3 and 4

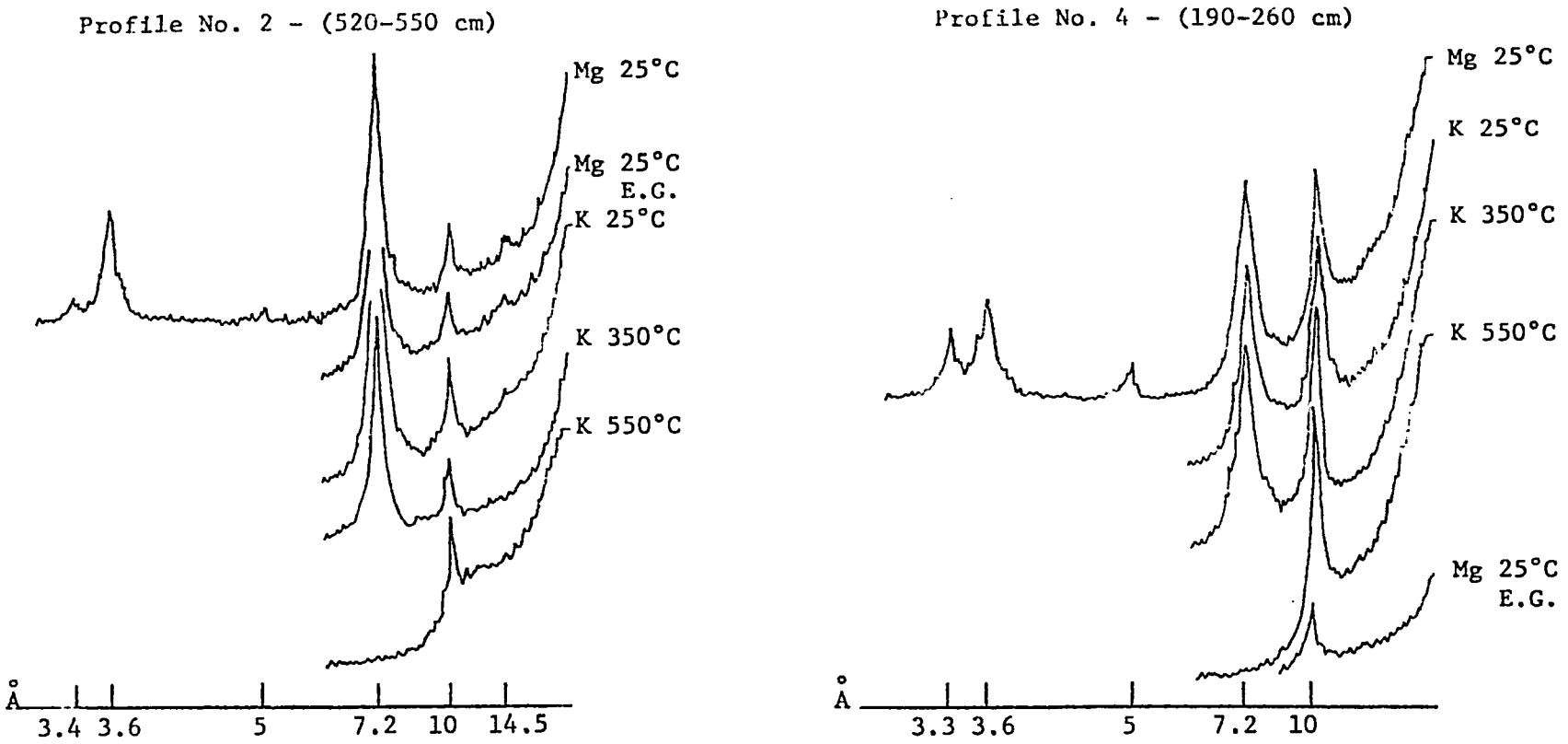


Figure 11. X-ray diffraction patterns of the coarse clay fraction (<2-.2 μ) from the weathered bedrock under profile numbers 2 and 4

Staff, 1970). Contents of 2:1-2:2 intergradient minerals were reported for highly weathered soils of the southeastern coastal plains of the United States (Fiskell and Perkins, 1970), Colombian Llanos Orientales (Guerrero, 1971), Minas Gerais State, Brazil (Moura Filho and Buol, 1972) and Panama (Reneau, 1972).

Mica and vermiculite appeared as traces in profile numbers 2 and 3 and in amounts estimated to be between 10 and 25% in the coarse clay of profile number 4.

Data for quantitative estimation of gibbsite, kaolinite and amorphous aluminous-silicates are given in Table 8. Figure 12 shows thermograms for the fine and coarse clay fractions of one B2 horizon from each profile.

The D.T.A. data estimates that kaolinite constitutes about 80% of the fine clay fraction. Profile number 4 presents smaller values. In the coarse clay fraction kaolinite was always present in smaller amounts, except for sample 4.6, usually about 50%. Profile number 4, again, showed the lowest values for kaolinite. Kaolinite content varied among horizons of same profiles but the quantitative limitations of this determination make any observation on this subject uncertain. It appears that the only apparent difference in kaolinite content among profiles is a decrease in profile number 4. The decrease in kaolinite in this profile must be followed by an increase in mica and vermiculite as evidenced by the X-ray diffractograms.

Data for gibbsite content are the best comparisons among profiles since this mineral can be detected by differential thermal analysis with good accuracy (MacKenzie, 1957).

Table 8. Quantitative estimations of clay mineralogy

Sample No.	Fine clay (<.2 μ)			Coarse clay (2-.2 μ)			Total clay (<2 μ)			Free Fe_2O_3 (<2 mm)
	Gibbsite	Kaolinite	Amorphous	Gibbsite	Kaolinite	Amorphous	Gibbsite	Kaolinite	Amorphous	
	---- % ----			---- % ----			---- % ----			%
1.1	7	86	14	20	50	5	8	82	13	9.3
1.3	7	76	14	--	--	--	--	--	--	9.5
1.4	7	76	19	20	65	5	9	74	17	9.5
1.10	8	86	15	28	50	--	11	80	--	9.7
2.1	10	83	9	12	51	8	10	76	9	10.0
2.3	9	86	10	15	53	4	10	81	9	9.3
2.4	8	76	8	14	47	8	9	71	8	10.6
2.12	7	88	9	--	--	--	--	--	--	10.9
2.13	3	86	7	3	74	5	3	81	6	10.5
3.1	5	86	14	14	61	4	7	81	12	9.2
3.5	5	85	10	14	63	4	7	80	9	9.6
3.8	5	77	11	10	64	7	7	72	9	10.0
4.1	tr.	73	10	4	46	5	1	65	8	8.0
4.4	1	76	12	3	40	--	1	67	--	8.9
4.6	tr.	64	11	tr.	76	11	tr.	69	11	9.0
4.8	0	60	7	tr.	49	4	tr.	55	6	8.3

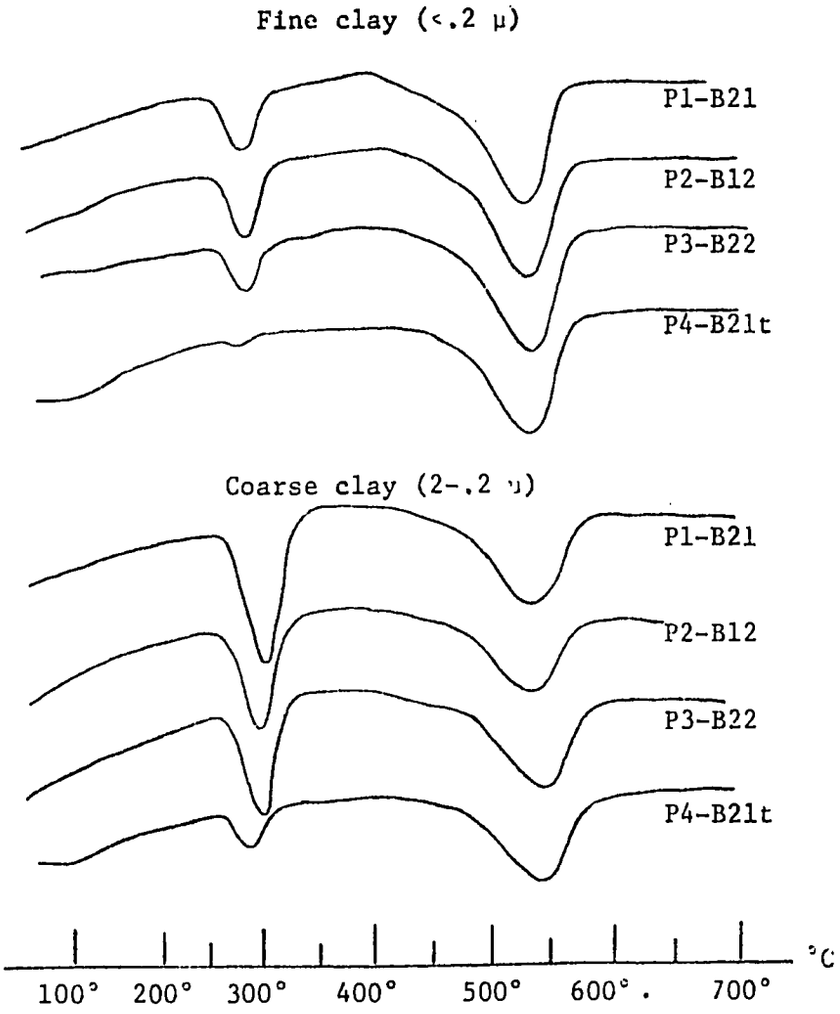


Figure 12. Differential thermograms of the fine clay and coarse clay fractions from the B horizons of the four studied soil profiles

The data show that gibbsite content is always higher for the coarse clay fraction than for the fine clay fractions. Sample 2.13, a clayey sedimentary rock was an exception, presenting equal values. A comparison of the gibbsite content as calculated for the total clay (Table 8) shows no apparent differences between profile numbers 1 and 2; profile number 3 shows a decrease of 30% and profile number 4 shows only traces of gibbsite. The trend in gibbsite content suggests a decrease in the weathering intensity of the clay minerals from the upper members to the lower members of the catena.

The amorphous aluminum-silicates showed somewhat similar values among profiles except for profile number 1 which presented higher values. The higher contents of amorphous aluminum-silicates in the highly weathered soils contradicts data obtained by Moniz and Jackson (1967) and Carvalho (1971) for soils developed from basic rocks but agrees with the data of Escobar _et al_. (1972) for soils developed from parent material apparently similar to that of the soils in this study.

The free iron oxide contents ranged between 10.9 and 8.0%. No apparent significant differences were found among profiles.

The clay mineralogy data suggest that profile numbers 1 and 2 are in the same weathering stage once they show similar amounts of clay minerals for the total clay fraction. Profile number 4 is considerably less weathered, containing very small amounts of gibbsite and considerable amounts of vermiculite and mica. Profile number 3 seems to be in an intermediate stage of weathering, as evidenced by smaller amounts of gibbsite than profile numbers 1 and 2 and by the presence of some mica and vermiculite. The data also point to a high degree of weathering to considerable depths in the upper members of the

toposequence since samples 1.10 and 2.12 at 450 and 500 cm, respectively, did not show considerable difference in the clay mineralogy when compared to the overlying soil. The uniformity in the clay mineralogy among profile horizons and the high degree of weathering at depths such as 500 cm suggests that the profiles developed from a parent material which was brought in place already fairly weathered and that little variation in the clay mineralogy occurred except for the possible formation of chlorite-vermiculite intergradient minerals in the three uppermost members and vermiculite in profile number 4. This hypothesis is reinforced by the increases in mica content between the red soil material and the immediately overlying clayey sedimentary rock which suggests lithological discontinuities.

According to the sand mineralogy data, profile numbers 2, 3 and 4 have probably received contributions from the micaceous clayey sedimentary rock. This contribution is apparently greater in profile number 4 and this could be the explanation for the presence of vermiculite and mica in this profile. The preservation of mica and vermiculite is also suggested by the increase in base saturation, probably due to lateral migration of subsurface waters, and by its lower porosity. These conditions suggest longer contact of percolating water with the soil and higher silica concentrations which would enhance the stability of mica and vermiculite.

None of the analytical data seems to be sufficient to verify whether or not profile number 1 was developed over the Tubarão series sediments or over a younger detrital deposit which, according to Penteado (1969) normally underlies the Rio Claro surface. However,

the uniformity in the clay and sand mineralogy data to a depth of 450 cm, as well as the presence of sparse rounded polished sesquioxidic nodules, interpreted as pedorelicts, seems to indicate that profile number 1 is developed over a detrital deposit.

Figure 13. Photomicrograph of a thin section from the B22 horizon of profile number 1 (without crossed nicols) (110X magnification)

Figure 14. Photomicrograph of a thin section from the B22 horizon of profile number 1 (with crossed nicols) (110X magnification)

Figure 15. Photomicrograph of a thin section from the B22 horizon of profile number 3 (without crossed nicols) (43X magnification)

Figure 16. Photomicrograph of a thin section from the B33 horizon of profile number 3 (without crossed nicols) (43X magnification)

Figure 17. Photomicrograph of a thin section from the B22t horizon of profile number 4 (without crossed nicols) (110X magnification)

Figure 18. Photomicrograph of a thin section from the B22t horizon of profile number 4 (with crossed nicols) (110X magnification)

SOIL CLASSIFICATION

The classification of the soils according to the U. S. soil taxonomy system (Soil Survey Staff, 1970) is as follows.

Diagnostic Horizons and Soil Orders

Profile Number 1

This profile presents an ochric epipedon over an oxic horizon. It is thus classified in the Oxisol order. The ochric epipedon is 36 cm thick and includes both A1 and A3 horizons. The lower epipedon boundary at 36 cm was determined according to the water-dispersible clay data (Table 1) which show amounts lower than 5% in the B1 horizon.

Profile Number 2

This profile also presents an ochric epipedon over an oxic horizon and is classified as Oxisol. The lower boundary of the ochric epipedon was set at 64 cm depth, as determined by the water-dispersible clay data which are lower than 5% in the B12 horizon.

Profile Number 3

This profile presents an ochric epipedon over an argillic horizon and base saturation is lower than 35% at 1.8 m from the soil surface. It is thus classified as an Ultisol. The ochric epipedon embraces the Ap1, Ap2 and B1 horizons which did not show any evidence of clay illuviation. The lower boundary of the argillic horizon was set at the 100 cm depth on the basis of clay illuviation evidences from thin section analysis. Below the argillic horizon there is an oxic horizon with composition and morphology very similar to the oxic horizons of profile numbers 1 and 2.

Profile Number 4

This profile presents an ochric epipedon 27 cm thick over an argillic horizon which is less than 35% base saturated at 1.8 m below the surface. It is thus classified in the Ultisol order.

Soil Moisture Regimes

The hydrologic balance (Figure 3) shows that there is a dry season with a total water deficit of 42 mm and comprising mainly the months of June, July, August and September.

The definition for the ustic moisture regime says that the soil has to have the moisture control section dry in some or all parts for more than 90 cumulative days in most years (Soil Survey Staff, 1970). According to the Soil Survey Staff (1970) (p. 3-47):

> One may assume that a soil at field capacity, with 200 m in storage, will have some part of its control section dry after 75 mm of evapotranspiration if there is no additional precipitation.

Under the above considerations the moisture regime is udic since the hydric balance shows that the actual evapotranspiration during the dryer months is always higher than precipitation (which implies that there is always some stored moisture) and only in one month (September) does the difference between evapotranspiration and precipitation for the dry period exceeds 75 mm. It is also noted that perennial crops such as coffee and oranges are grown in the area without irrigation.

Classification at the Subgroup Level

Profile numbers 1 and 2 contain less than 16 kg of organic carbon per m^2 to a depth of 1 m, and have CEC values in the B horizon ranging between 9 and 10 meq/100 g of clay and classified in the great group

Haplorthox. These profiles fit all definitions for the Typic subgroup except that they have weak subangular blocky struc ure in the upper part of the oxic horizon. This characteristic sets them apart from the Typic subgroup to be classified as Tropeptic Haplorthox.

The Tropeptic Haplorthox being considered a subgroup intergrading towards the Inceptisol order does not seem to be very well suited for these soils since they have massive appearance on fresh pits, very fine granular structure in the major part of the oxic horizon, no weatherable minerals and they are very deep. Otherwise profile number 2 seems to be intergrading more towards the Ultisol order, because of a B1 horizon with very few oriented clay bodies and moderate blocky structure and because its position on the landscape close to less weathered Ultisols.

Profile number 3 has an argillic horizon containing more than 0.9% organic carbon in the upper 15 cm and the clay distribution is such that the percentage of clay does not decrease from its maximum by more than 20% of that maximum within 1.5 m of the soil surface. These characteristics classify this soil as a Palehumult. Because of the CEC less than 24 meq/100 g of clay, this soil is classified in the Orthoxic Palehumult subgroup. The Orthoxic subgroup being considered one intergrading towards the Orthox suborder seems to agree from a genetic standpoint with the composition, morphology and position in the toposequence.

Profile number 4 has less than 0.4% of organic carbon in the upper 15 cm of the argillic horizon and the clay distribution does not decrease from its maximum amount by more than 20% of that maximum within 1.5 m of the mineral surface. These characteristics classify this

soil in the Paleudult great group. It fits also in all characteristics defined for the Typic Paleudult subgroup.

Classification at the Family Level

Particle Size Classes

All profiles have more than 60% clay in the control section and thus are in the very fine clayey family.

Mineralogy Classes

The ratio of percent extractable iron oxide and gibbsite to percent of clay is 0.21 for profile numbers 1 and 2, 0.20 for profile number 3 and 0.12 for profile number 4. The ratios equal to or above 0.2 for profile numbers 1, 2 and 3 place them into the oxidic mineralogy class. Profile number 4 is classed as kaolinitic due to the dominance of kaolinite in the clay fraction.

Soil Temperature Classes

Soil temperature at 50 cm depth may be estimated by the mean annual temperature (Smith, 1964). According to the climatic data (Table 1), the mean annual temperature is 20.1°C and the difference between mean summer and mean winter temperature is 4.9°C. These data place the soils in the isothermic temperature class.

SUMMARY AND CONCLUSIONS

This study attempts to characterize four soil profiles located in São Paulo State, Brazil. The soils were sampled along a 550 transect and field observations indicated that they represent the major members of an Oxisol-Ultisol toposequence.

Profile number 1 was located on the upper part of the landscape on a slope of 0-2% and has morphological characteristics of an Oxisol. Profile number 4 was located in the lower part of the toposequence on a slope of 8% and has morphological characteristics of an Ultisol. Profile numbers 2 and 3 have morphological characteristics of both these two soil orders.

Geomorphic evidence and petrographic sand studies suggest that all soils were developed in a detrital material brought in place as pedisediment or colluviun. Lithological discontinuities were evident in profile numbers 2 and 4. The sand mineralogy also suggests that profile numbers 2, 3 and 4 have developed from parent material which had received an increased amount of micaceous clay sedimentary rock from higher topographic positions.

There is a decrease in the extent of weathering from the upper member to the lower member of the toposequence as revealed by the following evidence: increase in the silt/clay ratio, decrease in gibbsite content and increase in mica and vermiculite content.

Profile numbers 1 and 2 did not show any significant increase in clay content in the B horizons. A very few illuviated clay bodies were detected in the B1 horizon of profile number 2. Profile numbers 3 and

4 exhibited significant amounts of clay illuviation. The greatest degree of clay illuviation was found in profile number 4.

According to field descriptions and thin section analysis, a trend in structural definitions was found among the profiles. The development of blocky structure was maximal in the lower member and minimal in the upper member of the toposequence which contained predominantly very fine granular and mammilated blocks in the B horizons. These changes in structure appear to be correlated with the bulk density values which were below 1.0 g/cc for the very friable horizons with very fine granular structure.

Chlorite-vermiculite intergradient clay minerals, gibbsite, mica and vermiculite were found to be concentrated in the coarse clay fractions. The fine clay fraction is made up predominantly of kaolinite clay minerals. The chlorite-vermiculite intergradient was found mainly in the two upper members of the toposequence and mica and vermiculite in the lower member. This suggests that the chlorite-vermiculite intergradient minerals are formed and preserved under highly weathering conditions as a result of the precipitation of aluminum and iron oxides in the interlayer space of vermiculite.

Although all the soils presented similar textures, they differ in other physical properties such as probable maximum available water-holding capacity, structure and porosity.

Profile numbers 1 and 2 have an oxic horizon and are classified as very fine, clayey, oxidic, isothermic Tropeptic Haplortox. Profile number 3 has an argillic horizon which overlies an oxic horizon. It is classified as a very fine clayey, oxidic, isothermic Orthoxic Palehumult. Profile number 4 has an argillic horizon and was

classified as a very fine clayey, kaolinitic, isothermic Typic Palehudult.

Clay illuviation is more pronounced in the less weathered lower member of the toposequence than in the upper members of the toposequence which is reverse in the weathering sequence. None of the datum obtained seem to clearly explain the absence of clay illuviation in the more highly weathered profiles. The occurrence in the primary peds of the oxic horizon of an almost isotropic plasma without any apparent voids seems to indicate that the main plasma components, fine kaolinitic clay, iron oxides and aluminum oxides, are highly flocculated and compacted. This may preclude any clay dispersion and consequent illuviation.

The position of the soils on the toposequence shows that there is a gradation from the Oxisols to the Ultisols with an increase in depth and eventual loss of the oxic horizon and an increase in the expression of the argillic horizon. The oxic horizon has its greatest degree of expression where the surface is geomorphically older, where there is a thicker and more weathered soil mantle and in a position which is not likely to receive any addition of lateral groundwater. The argillic horizon is more expressed where the surface is geomorphically younger, the soil mantle shallower and less weathered, and in a position which is more likely to receive lateral migration of groundwaters.

LIST OF REFERENCES

Allison, L. E. 1965. Organic carbon, pp. 1367-1378. Methods of Soil Analysis. Agronomy Series No. 9, Soil Sci. Soc. Amer., Madison, Wisc.

Almeida, F. F. M. de and O. Barbosa. 1953. Geologia das quadrículas de Piracicaba e Rio Claro, Estado de São Paulo. Divisão de Geologia e Mineralogia do D.N.P.M. Bol. No. 143. São Paulo, Brazil.

Baldwin, M., C. E. Kellog and J. Thorp. 1938. Soil classification, pp. 979-1001. Soils and Men. U. S. Dept. of Agriculture, U. S. Govt. Print. Ofc., Washington, D. C.

Bennema, J. 1966. Classification of Brazilian soils. Report to the Government of Brazil. Food and Agriculture Organization of the United Nations, Rome, Italy. p. 83.

Bennema, J., M. N. Camargo and A. C. S. Wright. 1962. Regional contrast in South American soil formation in relation to soil classification and soil fertility. Trans. of Joint Meet. Comm., IV and V Int. Soil Conf., New Zealand 1962:493-506.

Bennema, J., A. Jongerius and R. C. Lemos. 1970. Micromorphology of oxic and argillic horizons in South Brazil in relation to weathering sequences. Geoderma 4:333-355.

Bennema, J., R. C. Lemos and L. Vettori. 1959. Latosols in Brazil. Proc. Third Inter-African Soils Conference, Dalaba 1959:273-281.

Bennet, H. H. 1926. Some comparison of the properties of humid tropical and humid temperate American soils, with especial reference to indicated relations between chemical composition and physical properties. Soil Sci. 21:349-374.

Brewer, R. 1964. Fabric and Mineral Analysis of Soils. John Wiley and Sons, Inc., New York. p. 470.

Byers, H. G., C. E. Kellogg, M. S. Anderson and J. Thorp. 1938. Formation of soil, pp. 948-978. Soils and Men. U. S. Dept. of Agriculture, U. S. Govt. Print. Ofc., Washington, D. C.

Carvalho, A. 1960. A study of a Terra Roxa Estruturada and Latosol Roxo on a topographic sequence in São Paulo State, Brazil. Unpublished M. S. thesis, Department of Agriculture, University of New Castle Upon Tyne, New Castle, England.

Chapman, H. D. 1965a. Cation exchange capacity, pp. 891-901. In C. E. Black (ed.), Methods of Soil Analysis. Agronomy Series Vol. 9. Amer. Soc. of Agron., Madison, Wisc.

Chapman, H. D. 1965b. Total exchangeable bases, pp. 902-904. In C. E. Black (ed.), Methods of Soil Analysis. Agronomy Series Vol. 9. Amer. Soc. of Agron., Madison, Wisc.

Comissão de Solos do S.N.P.A. 1958. Levantamento de reconhecimento dos solos do Rio de Janeiro e Distrito Federal. Rio de Janeiro, Ministério da Agricultura, Brazil. p. 350 (Bol. 11).

Comissão de Solos do S.N.P.A. 1960. Levantamento de reconhecimento dos solos do Estado de São Paulo. Rio de Janeiro, Ministério da Agricultura, Brazil. p. 350 (Bol. 12).

Critchfield, H. J. 1960. General Climatology. Prentice-Hall, Inc. Englewood Cliffs, N. J.

Escobar, E. H., J. L. I. Dematê and A. C. Moniz. 1972. Gênese e classificação de alguns solos da bacia do Ribeirão Tijuco Preto. Município de Rio das Pedras. S.P.I. Análise mineralógica quantitativa da fração argila. Bragantia 30:(in press).

Fiskell, G. A. and H. F. Perkins (ed.). 1970. Selected coastal plain soil properties. Southern Coop. Bull. No. 148, Univ. of Fla., Gainesville. p. 141.

Glinka, K. D. 1931. Treatise on soil science. Israel Program for Scientific Translations, Jerusalem, Israel 1963:674.

Grohmann, F. 1960a. Análise de agregados de solos. Bragantia 19: 201-213.

Grohmann, F. 1960b. Distribuição e tamanho de poros em tres tipos de solos do Estado de São Paulo. Bragantia 19:319-328.

Guerrero, R. 1971. Soils of the Colombian Llanos Orientales--Composition and classification of selected profiles. Unpublished PhD thesis, Department of Soil Science, N. C. State University at Raleigh. University Microfilms, Inc., Ann Arbor, Mich.

Hashimoto, I. and M. L. Jackson. 1960. A rapid dissolution of allophane and kaolinite. Clay and Clay Minerals. Proc. 7th Conf. 1:102-113.

Hole, F. D. 1961. A classification of peduturbation and some other processes and factors of soil formation in relation to isotropism and anisotropism. Soil Sci. 91:375-377.

Jackson, M. L. 1956. Soil Chemical Analysis--Advanced Course. Published by the author. Madison, Wisc. p. 991.

Jackson, M. L. 1964. Chemical composition of soils, pp. 71-141. In F. E. Bear (ed.), Chemistry of the Soil. 2nd Ed. Reinhold Publ. Co., New York.

Kellogg, C. E. 1950. Tropical soils. Trans. 4th. International Congr. Soil Sci. Amsterdam 1:266-276.

Kellogg, C. E. and F. D. Davol. 1949. An exploratory study of soil groups in the Belgian Congo. Publications de l'Institut Nationel pour l'Etude Agronomique du Congo Belge (I.N.E.A.C.). Serie Scientifique No. 46, Belgium. p. 73.

Kilmer, V. J. and L. T. Alexander. 1949. Methods of making mechanical analysis of soils. Soil Sci. 68:15-24.

Kittrick, J. A. and E. W. Hope. 1963. A procedure for the particle size separation for X-ray diffraction analysis. Soil Sci. 96: 318-325.

Mackensie, R. C. 1957. The Differential Thermal Investigation of Clays. Mineralogical Society, London, England. p. 456.

Marbut, C. F. 1927. A scheme for soil classification. 1st Intern. Congr. Soil Sci. Proc. 4:1-31.

Mekaru, T. and G. Uehara. 1972. Anion adsorption in ferruginous tropical soils. Soil Sci. Soc. Am. Proc. 36:296-300.

Mitchel, J. K. 1956. The fabric of natural clays and its relationship to engineering properties. Proc. Highway Res. Board 35:693.

Moniz, A. C. and M. L. Jackson. 1967. Quantitative mineralogical analysis of Brazilian soils derived from basic rocks and slate. Univ. of Wisconsin, Madison. Soil Sci. Report 212.

Moura Filho, W. and S. W. Buol. 1972. Studies of a Latosol Roxo (Eutrustox) in Brazil: Clay mineralogy. Experientiae 13:201-217.

Oberhoster, R. E. 1968. Opal phytoliths in two soil profiles on the Sprinbock flats. South Afr. J. Agr. Sci. 11:743-748.

Ollier, C. D. 1959. A two cycle theory of tropical pedology. J. Soil Sci. 10:137-148.

Paiva Neto, J. E., R. A. Catani, M. S. Queiroz and A. Küpper. 1950. Contribuição ao estudo dos metodos analíticos e de extração para caracterização dos solos do Estado de São Paulo. Anais 1a. Reunião Brasileira de Ciência do Solo. Rio de Janeiro, Brazil. pp. 79-108.

Penteado, M. M. 1968. Geomorfologia do Setor Centro Oriental da Depressão Periférica Paulista. Umpublished tese de doutoramento, Faculdade de Filosofia Ciencias e Letras de Rio Claro. Rio Claro, S. P., Brazil.

Penteado, M. M. 1969. A bacia de sedimentação de Rio Claro, Estado de São Paulo. Rev. Geogr. da Soc. Geogr. de Lisboa 17:38-61.

Queiroz Neto, J. P. 1969. Interpretação dos Solos da Serra de Santana para fins de classificação. Umpublished tese de doutoramento, Escola Superior de Agricultura Luiz de Queiroz. Piracicaba, S. P., Brazil.

Ranzani, G., O. Freire and T. Kinjo. 1966. Carta de solos do município de Piracicaba. Piracicaba, Centro de Estudo de Solos. ESALQ-USP, Brazil. p. 85.

Reneau, R. B. and J. G. Fiskell. 1972. Mineralogical properties of clays from Panama soils. Soil Sci. Soc. Am. Proc. 36:501-505.

Richards, L. A. 1951. A pressure membrane extraction apparatus for soil solutions. Soil Sci. 51:377-386.

Robinson, G. W. 1949. Soils, Their Origin, Constitution & Classification (An Introduction to Pedology). Thomas Murby and Co., London, England. p. 573.

Smith, G. D. 1964. Soil temperature regimes: Their characteristics and predictability. Soil Cons. Serv., U. S. Govt. Print. Ofc., Washington, D. C.

Smithson, F. 1958. Grass opal in British soils. J. Soil Sci. 9:148-154.

Smithson, F. 1959. Opal sponge spicules in soils. J. Soil Sci. 10:105-110.

Soil Survey Staff. 1951. Soil survey manual. Agriculture Handbook No. 18. U. S. Dept. of Agriculture, U. S. Govt. Print. Ofc., Washington, D. C. p. 503.

Soil Survey Staff. 1960. Soil classification, a comprehensive system, 7th approximation. U. S. Dept. of Agriculture, U. S. Govt. Print. Ofc., Washington, D. C. p. 207.

Soil Survey Staff. 1967. Supplement to the soil classification system (7th approximation). U. S. Dept. of Agriculture, U. S. Govt. Print. Ofc., Washington, D. C.

Soil Survey Staff. 1970. Selected chapters from the unedited text of the Soil Taxonomy of the National Cooperative Soil Survey. U. S. Dept. of Agriculture, U. S. Govt. Print. Ofc., Washington, D. C.

Stoops, G. 1968. Micromorphology of some characteristic soils of the Lower Congo (Kinshasa). Pedologie 18:110-149.

Thornthwaite, C. W. and J. R. Mather. 1955. The Water Balance. Publications in Climatology. Vol. 8, No. 1. Certenton, N. J. p. 104.

Thorp, J. and G. D. Smith. 1949. Higher categories of soil classification: Order, suborder, and great soil groups. Soil Sci. 67:117-126.

Vageler, P. 1930. Grundiss der Tropischen and Subtropischen Bodenkunde. Verlagesgesellschaft fur. Akerban. Berlin, Germany.

Vettori, L. 1969. Métodos de análise do solo. Ministério da Agricultura. Boletim técnico No. 7. Rio de Janeiro, Brazil.

Wambeke, A. R. Van. 1962. Criteria for classifying tropical soils. J. Soil Sci. 13:124-132.

APPENDICES

Appendix A. Soil Profile Description and Classification According to the Comissão de Solos (1960)

Profile No. 1

Date: 20/11/1970

Described by: I. F. Lepsch and J. B. Oliveira

Classification: Ortho Dark Red Latosol (C.N.S., 1960)

Topographic situation: Upper part of a slope, 0-2% declivity

Parent material: Probably transported sediments from argillites of Permian Age

Relief: Slightly ondulating

Elevation: 644 m

Erosion: Not visible

Internal drainage: Rapid

Runoff: Slow

Permeability: Rapid

Soil drainage class: Somewhat excessively drained

Natural vegetation: Tropical semi-deciduous broadleaf forest

Land use: Forest

A1 - 0 - 15 cm: (Sample 1.1) Dark reddish brown (5 YR 3/3, when moist and crushed moist), reddish brown (4 YR 4/4, when dry); clay; strong medium and coarse granular structure; slightly hard, friable, plastic and slightly sticky; clear and smooth boundary.

A3 - 15 - 36 cm: (Sample 1.2) Dark reddish brown (3.5 YR 3/4, when moist), reddish brown to red (2.5 YR 4/5, when dry); clay; moderate, medium, subangular blocky structure; hard, friable, plastic and sticky; wavy and clear boundary.

B1 - 36 - 65 cm: (Sample 1.3) Dark reddish brown (2.5 YR 3.5/6, when moist), reddish brown to red (2.5 YR 4/6, when dry); weak, medium, subangular structure; slightly hard to soft; very friable; plastic and sticky; smooth and gradual boundary.

B21 - 65 - 140 cm: (Sample 1.4) Red (2.5 YR 4/6, when wet and 2.5 YR 4.5/8, when dry); clay; subangular very weak structure, porous massive appearance in place breaking in very fine granular structure; soft to slightly hard, very friable; plastic and sticky; smooth and diffuse boundary.

B22 - 140 - 180 cm: Red (2.4 YR 4/6, when moist and 2.5 YR 4.5/8, when dry); clay; porous massive appearance in place, breaking very fine granular structure; soft, very friable, plastic, slightly sticky.
(Sample 1.5)

Auger samples:

Sample 1.6 - 200-250 cm: 2.5 YR 4/6, clay

Sample 1.7 - 250-300 cm: 2.5 YR 4/6, clay

Sample 1.8 - 300-350 cm: 3.5 YR 4/6, clay

Sample 1.9 - 350-400 cm: 3.5 YR 4/6, clay

Sample 1.10 - 400-450 cm: 3.5 YR 4/6, clay

Root distribution: Fine medium abundant in the A1 and A3, fine and medium commons in the B1 and few fine in the B21 and in the B22 horizons

Biologic activities: Termites in the A1 and A3 horizons, pores filled with dark material in the A1 and A3 horizons

Remarks:

1. The horizons B1, B21 and B22 presented pedologic features of rounding peds, 1-5 cm diameter, with thickened appearance and consistence harder than the surrounding material

2. Signs of ancient ant cavities

Profile No. 2

Date: 24/11/1970

Described by: I. F. Lepsch and J. B. Oliveira

Classification: Ortho Dark Red Latosol (C.N.S., 1960)

Topographic situation: Upper third of a slope with 5% declivity

Parent material: Probably transported sediments from argillites of Permian Age

Relief: Slightly ondulating

Elevation: 638 m

Erosion: Not visible

Internal drainage: Rapid

Runoff: Medium

Permeability: Rapid, exception in the Ap2 where it is moderate

Soil drainage class: Somewhat excessively drained

Natural vegetation: Tropical semi-deciduous broadleaf forest

Land use: Sugar cane plantation

Ap1 - 0 - 12 cm: (Sample 2.1)	Dark reddish brown (3.5 YR 3/4, when moist and moist crushed), red (2.5 YR 4/6, when dry), yellowish red (5 YR 4/8, when dry crushed); clay; moderate, medium fine and coarse granular structure; slightly hard, friable, plastic and slightly sticky; wavy and abrupt boundary; horizon recently revolved.
Ap2 - 12 - 33 cm: (Sample 2.2)	Dark red (2.5 YR 3/6, when moist and moist crushed), red (2.5 YR 4/6, when dry), yellowish red (5 YR 4/8, when dry crushed); clay; massive structure; very hard, firm, plastic and sticky; clear and wavy boundary; thickened horizon.
B11 - 33 - 64 cm: (Sample 2.3)	Dark red (2.5 YR 3/6, when moist and moist crushed); reddish brown (2.5 YR 4/6, when dry); clay; moderate, fine and medium subangular blocky; discontinuous thin cutans; slightly hard, friable, plastic and sticky; gradual and wave boundary.
B12 - 64 - 90 cm: (Sample 2.4)	Dark red to red (2.5 YR 3.5/6, when moist and moist crushed) red (2.5 YR 4/6, when dry); clay; weak, medium subangular blocky structure; slightly hard, friable, plastic and sticky; gradual and wave boundary.
B21 - 90 - 140 cm: (Sample 2.5)	Dark red to red (2.5 YR 3.5/6, when moist), red (2.5 YR 4/6, when dry); clay; porous massive appearance in place, breaking very fine granular structure; soft, very friable, plastic and sticky; smooth and diffuse boundary.
B22 - 140 - 200 cm: (Sample 2.6)	Dark red to red (2.5 YR 3.5/6, when moist), red (2.5 YR 5/7, when dry); clay; porous massive appearance in place, breaking very fine granular; soft, very friable, plastic and sticky.

Auger samples:

Sample 2.7 - 200-250 cm - 2.5 YR 4/6, clay

Sample 2.8 - 250-300 cm - 2.5 YR 4/6, clay

Sample 2.9 - 300-350 cm - 2.5 YR 4/6, clay

Sample 2.10 - 350-400 cm - 2.5 YR 4/6, clay

Sample 2.11 - 400-450 cm - 2.5 YR 4/6, clay

Sample 2.12 - 450-500 cm - 2.5 YR 4/6, clay

500-520 cm - Transition layer, not collected, presenting few, small iron concretions

Sample 2.13 - 520-550 cm - Argillite decomposed with gray violaceous color

Root distribution: Fine, abundant in the Ap1 horizon and common in the other horizons

Remarks:

1. The sugar cane is burned every year for the harvest
2. Fertilized soil
3. The horizons B11, B12, B21 and B22 presented pedologic features consisting of round peds, with 1 to 5 cm diameter, with thickened appearance and consistence harder than the surrounding material

Profile No. 3

Date: 11/25/1970

Described by: I. F. Lepsch, J. B. Oliveira and C. Ivancko

Classification: Ortho Red Latosol intergrade to Red Yellow Podzolic soils Piracicaba variation

Topographic situation: Middle third of a slope with 5% of declivity

Parent material: Probably transported sediments derived from argillites of Permian period

Relief: Slightly undulating

Elevation: 634 m

Erosion: Not visible

Internal drainage: Rapid

Runoff: Medium

Permeability: Rapid, exception in the Ap2 which is moderate

Soil drainage class: Somewhat excessively drained

Natural vegetation: Tropical semi-deciduous broadleaf forest

Land use: Sugar cane plantation

Ap1 - 0 - 10 cm: (Sample 3.1)	Dark reddish brown (5 YR 3.5/4, when moist and 3.5 YR 3/4, when moist crushed), yellowish red (5 YR 5/6, when wet); clay, coarse and very coarse, moderate granular structure; slightly hard, firm, sticky and plastic; abrupt and wavy boundary; horizon recently revolved.
Ap2 - 10 - 25 cm: (Sample 3.2)	Dark reddish brown (5 YR 3/4, when moist); yellowish red (5 YR 5/6, when dry); clay; massive; very hard, firm, sticky and plastic; clear and wavy boundary; thickness 12 (10-15) cm; thickened horizon.
B1 or A3 - 25 - 40 cm: (Sample 3.3)	Reddish brown (4 YR 3/4, when moist), reddish brown (4 YR 4/4, when dry); clay; fine and medium, moderate, subangular structure; continuous thin cutans, hard, friable to firm, sticky and plastic; clear and smooth boundary.
B21 - 40 - 57 cm: (Sample 3.4)	Reddish brown (2.5 YR 4/4, when moist); reddish brown to red (2.5 YR 4/5, when dry); clay; fine and medium, moderate, subangular structure; continuous thin cutans; hard, friable to firm; sticky and plastic; clear and smooth boundary.
B22 - 57 - 82 cm: (Sample 3.5)	Dark red to red (2.5 YR 3.5/6, when moist; red (2.5 YR 4/6, when dry); clay; fine and medium weak to moderate subangular blocky structure; thin, discontinuous cutans; slightly hard, friable, sticky and plastic; gradual and smooth boundary.
B23 - 82 - 100 cm: (Sample 3.6)	Red (2.5 YR 4/6, when moist and 2.5 YR 4/7, when dry); clay; weak medium subangular structure; thin, discontinuous cutans, prevailing on vertical faces of the peds; slightly hard, very friable, plastic and sticky; smooth and diffuse boundary.
B31? - 100 - 130 cm: (Sample 3.7)	Red (2.5 YR 4/6, when moist and 2.5 YR 5/6, when dry); clay; porous massive appearance in place breaking in very fine granular; soft, very friable, plastic and slightly sticky; diffuse and smooth boundary.

B32? - 130 - 165 cm: (Sample 3.8) Red (2.5 YR 4/6, when moist and 2.5 YR 5/6, when dry); clay; porous massive appearance in place, breaking in very fine granular; soft; very friable; plastic and slightly sticky; smooth and diffuse boundary.

B33? - 165 - 200+ cm: (Sample 3.9) Red (2.5 YR 4/6, when moist and 2.5 YR 5/7, when dry); clay; porous massive appearance breaking in very fine granular; soft, very friable, plastic and sticky.

Auger samples:

Sample 3.10 - 200-250 cm - 2.5 YR 4/6, clay

Sample 3.11 - 250-300 cm - 2.5 YR 4/6, clay

Sample 3.12 - 300-350 cm - 2.5 YR 4/6, clay

Sample 3.13 - 350-400 cm - 2.5 YR 4/6, clay with iron concretions (0.2 to 0.5 mm of diameter)

Sample 3.14 - 400-450 cm - Argillite decomposed with gray violateous color

Root distribution: Fine, abundant in the Ap horizon and common in the other horizons

Remarks:

1. The sugar cane is burned every year for the harvest

2. Fertilized soil

3. The horizons B21, B22, B31 and B32 presented pedologic features consisting of rounding peds, 1 to 5 cm of diameter, with thickened appearance and harder consistence than the surrounding material

Profile No. 4

Date: 11/26/1960

Described by: I. F. Lepsch and C. L. Rotta

Classification: Red Yellow Podzolic soils, Piracicaba variation

Topographic situation: Low third of a slope with 8% of declivity

Parent material: Transported sediments from argillites of Permian period

Relief: Slight ondulating

Elevation: 615 m

Erosion: Not visible

Internal drainage: Medium

Runoff: Moderate to rapid

Soil drainage class: Well drained

Permeability: Medium

Natural vegetation: Tropical semi-deciduous broadleaf forest

Land use: Sugar cane plantation

Ap1 - 0 - 10 cm: (Sample 4.1)	Dark reddish brown (5 YR 4/4, when moist and crushed moist), reddish brown (5 YR 4/4, when dry); clay; medium and fine moderate granular structure; soft, friable, sticky and plastic; abrupt and wavy boundary; thickness 10 (8-12) cm; recently revolved horizon.
Ap2 - 10 - 19 cm: (Sample 4.2)	Dark reddish brown (5 YR 3/3, when moist) with reddish brown, diffuse, common mottles (2.5 YR 4/4, when moist); reddish brown (5 YR 4/4, when dry); clay; massive; very hard, firm, plastic and sticky; clear and wavy boundary; thickened horizon.
A3 - 19 - 27 cm: (Sample 4.3)	Dark reddish brown (5 YR 3/4, when moist), reddish brown (3.5 YR 4/4, when dry); clay; moderate, medium, subangular blocky structure; very hard, friable, very plastic and very sticky; wavy and clear boundary; thickness 9 (11-8) cm.
B21t - 27 - 64 cm: (Sample 4.4)	Red to yellowish red (3.5 YR 4/6, when moist), yellowish red (5 YR 4/6, when dry); clay; strong, fine and medium subangular blocky; continuous, thick cutans; very hard, firm, very plastic and very sticky; smooth and gradual boundary.
B22t - 64 - 95 cm: (Sample 4.5)	Red to yellow red (3.5 YR 4/6, when moist), yellowish red (5 YR 4/6, when dry); clay; strong, medium subangular blocky; continuous, thick cutans, very hard, firm, very plastic and very sticky; smooth and gradual boundary.
B3 - 95 - 150 cm: (Sample 4.6)	Yellowish red (5 YR 5/6, when moist, and 5 YR 5/6, when dry); clay; moderate, medium, subangular blocky; moderately thick and thin discontinuous cutans; slightly hard, firm, plastic and sticky; gradual and smooth boundary.

C1 - 150 - 190 cm: (Sample 4.7) Variegated red (2.5 YR 4/6, when moist) and yellowish red (5 YR 4/6, when moist), red (2.5 YR 5/6, when dry); clay; moderate, medium subangular structure; discontinuous thin cutans; slightly hard, firm, sticky and plastic; clear boundary; few, hard, rounded, small mineral nodules of iron and quartz.

IIC2 - 190 - 260+ cm: (Sample 4.8) Argillite decomposed with gray violet color.

Root distribution: Fine, fasciculate, abundant in the Ap1, Ap2 and Ap3, common in the B21 and rare in the B3 and C1 horizons

Biologic activity: Ant galleries were observed in the B3 horizon

Remarks:

1. The mottles found in the Ap2 horizon were probably due to material brought from the B horizons by ants

2. The cutans in the B22 horizons are apparently thicker than the cutans of the B21 horizon

3. The IIC2 horizon was collected with an auger

4. The sugar cane is buried every year for the harvest

5. Fertilized soil

Appendix B. Micromorphological Descriptions

Profile No. 1

1.1 - A1 horizon (0-15 cm)

Primary structure. Subrounded blocky, 4 to 6 mm, partially accommodated

Fabric analysis. Porphyroskelic, random, unrelated; isotic plasma

Voids. Macro compound packing voids, irregular orthovughs, craze planes

Plasma concentrations. None

1.2 - A3 horizon (15-36 cm)

Primary structure. Subrounded blocky, 1 to 2 mm partially accommodated

Fabric analysis. Porphyroskelic, random, unrelated, isotic plasma

Voids. Macro compound packing voids, irregular and interconnected orthovughs, small skewplanes

Plasma concentrations. None

1.3 - B1 horizon (36-65 cm)

Primary structure. Rounded and subrounded blocky (1.4 to 0.6 mm), partially accommodated

Fabric analysis. Porphyroskelic, random, unrelated, isotic-undulic plasma

Voids. Macro compound packing voids, irregular and interconnected orthovughs, skewplanes

1.4 - B21 horizon (65-140 cm)

Primary structure. Predominantly rounded blocky and mammilated blocky (.4 to .6 mm), partially accommodated; few rounded blocky (.6 to 1.0 mm)

Fabric analysis. Porphyroskelic (very compact), random, unrelated; isotic-undulic plasma

Voids. Many interpedal compounds packing orthovoids, few skew planes in the larger peds

Plasma concentrations. None observed

Pedordicts. Sesquioxidic nodules with sharp boundaries

Profile No. 2

2.1 - Ap horizon (0-12 cm)

Primary structure. Subrounded blocky (3 mm) partially accommodated.

Fabric analysis. Porphyroskelic, random, unrelated; isotic plasma

Voids. Compound packing voids, irregular orthovughs, skew-planes

Plasma concentrations. None

2.3 - B11 horizon (33-64 cm)

Primary structure. Subrounded blocky (6 mm), accommodated

Fabric analysis. Porphyroskelic, random, unrelated; isotic-undulic plasma

Voids. Compound packing voids, many irregular orthovughs, skew-planes

Plasma concentrations. Very few small yellow red void argillans and grain cutans; few papules

Pedorelicts. Tuberose sesquioxidic nodules with sharp boundaries

2.4 - B12 horizon (64-90 cm)

Primary structure. Subrounded blocky (3 mm) and rounded blocky, (.4 to .6 mm), partially accommodated

Fabric analysis. Porphyroskelic, random, unrelated, isotic-undulic

Voids. Compound interpedal packing voids, interconnected orthovughs, some skewplanes

Plasma concentrations. None

2.5 - B21 horizon (90-140 cm)

Primary structure. Predominantly rounded and mammilated blocky (.4 to .6 mm) and a few subrounded blocky, partially accommodated

Fabric analysis. Porphyroskelic, random, unrelated, isotic-undulic plasma

Voids. Many interpedal compound packing voids, few skewplanes and intercorrelated orthovughs in the subrounded blocky peds

Plasma concentrations. None

Profile No. 3

3.1 - Ap1 horizon (0-10 cm)

Primary structure. Subrounded blocky (3 mm), partially accommodated

Fabric analysis. Porphyroskelic, random, unrelated, isotic-undulic plasma

Voids. Few compound packing voids, many irregular orthovughs, craze planes

Plasma concentrations. None observed

3.2 - Ap2 horizon (10-25 cm)

Primary structure. Appedal (no peds could be distinguished in a 2 x 1 cm thin section)

Fabric analysis. Porphyroskelic, random, unrelated

Voids. Irregular orthovughs, skewplanes, vesicles and chambers

Plasma concentrations. Very few irregular papules

3.3 - B1 horizon (25-40 cm)

Primary structure. Subrounded blocky (6 mm) partially accommodated

Fabric analysis. Porphyroskelic, random, unrelated

Voids. Compound interpedal packing voids, craze and skew-planes, irregular orthovughs

Plasma concentrations. Few rounded and irregular elongated papules, few voids neocutans

Pedorelicts. Sesquioxidic nodules

3.4 - B21 horizon (40-57 cm)

Primary structure. Mostly subround blocky (2.5 mm) and some rounded blocky (5-1.0 mm), partially accommodated

Fabric analysis. Porphyroskelic, random, unrelated

Voids. Compound interpedal packing voids, irregular, single and interconnected vughs, skewplanes

Plasma concentrations. Few red yellow void illuviation argillans, few irregular shaped papules, very few voids neocutans and quasicutans

Pedorelicts. Sesquioxidic nodules

3.5 - B22 horizon (57-82 cm)

Essentially the same as the B21 horizon

3.7 - B31 horizon (100-130 cm)

Primary structure. Subangular blocky (2 to 3 mm) and rounded blocky (.4 to .6 mm), partially accommodated

Fabric analysis. Porphyroskelic, random, unrelated, isotic-undulic plasma

Voids. Irregular orthovughs, skewplanes and vesicles in the subrounded blocky peds; many interpedal packing voids

Plasma concentrations. Very few rounded papules

3.9 - B33 horizon (165-200 cm)

Primary structure. Predominantly rounded blocky and mammilated blocky (.4 to .6 mm)

Fabric analysis. Phorphyroskelic, random, unrelated, isotic-undulic plasma

Voids. Many interpedal packing voids

Plasma concentrations. None observed

Profile No. 4

4.1 - Ap1 horizon (0-10 cm)

Primary structure. Subrounded blocky (3 mm) partially accommodated

Fabric analysis. Porphyroskelic, random, unrelated, isotic-plasma

Voids. Compound packing voids, irregular orthovughs

Plasma concentrations. Very few small elongated papules

4.2 - Ap2 horizon (10-19 cm)

Primary peds. Apedal (no peds could be distinguishable in a 2 x 1.5 cm thin section)

Fabric analysis. Porphyroskelic, random, unrelated, undulic plasmic fabric

Voids. Irregular orthovughs, channels and vesicles

Plasma concentrations. Very few small elongated papules

4.3 - A3 horizon (19-27 cm)

Primary peds. Apedal (no peds could be distinguished in a 1 x 1 cm thin section)

Fabric analysis. Porphyroskelic, random unrelated, undulic to asepic plasmic fabric

Plasma concentrations. None observed

4.4 - B21t (27-64 cm)

Primary peds. Subrounded blocky (4 mm or more), partially accommodated

Fabric analysis. Porphyroskelic, random, unrelated, asepic plasmic fabrics

Voids. Compound packing voids, numerous irregular orthovughs, skewplanes, channels and vesicles

Plasma concentrations. Sparse yellow red void illuviation argillans on vughs, planes and packing voids, sparse red yellow neoargillans and quasicutans

4.7 - C1 horizon (150-190 cm)

Primary structure. Subrounded blocky (greater than 20 mm)

Fabric analysis. Porphyroskelic, random, unrelated, asepic plasmic fabrics

Voids. Packing voids, channels, skewplanes and vesicles

Plasma concentrations. Common yellow void illuviation argillans, few small irregular papules, common red yellow neoargillans and quasicutans