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TABLELAND SOILS OF NORTH-EASTERN BRAZIL: CHARACTERIZATION, GENESIS AND CLASSIFICATION

by

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TO MY WIFE AND MY CHILDREN

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SUMMARY

The coastal low level tablelands of the State of Alagoas are located in the north-eastern region of Brazil between 8° 25' and 10° 20' south latitude, and from 35° 10' to 37° 15' west longitude of Greenwich.

These surfaces formed by Tertiary Sediments are flat or slightly undulated with slopes rarely higher than 4%.
It enjoys a tropical climate with a dry summer and a constant temperature throughout the year. The dominant vegetation is formed by the so-called "Atlantic Forest", presenting also minor areas of "Cerrado".

Nine profiles corresponding to the soil types present in, a) the well drained surfaces of the tablelands - which classify as Oxisols, Ultisols and Oxisol-Ultisol intergrades -, and b) in poorly drained depressions - classified as Spodosols -, were selected for this work.

The influence of the morphogenesis of the landscape and the topographical location on soil development is evident from the soils studied. The properties of the soils are strongly related to geomorphic processes.

The soils were characterized in terms of their morphological, physico-chamical, mineralogical and micromorphological properties. The sedimentological analysis of the sand fraction (63 - 2000μm) was also carried out.

The mineralogy of the sand fraction is similar in all profiles. The light minerals are dominant (91-98%) and almost entirely composed of quartz grains and no more than traces of feldspars. In the heavy fraction the opaques are dominant, (84-92%); among the transparent minerals zircon dominates, followed by tourmaline and rutile.

The composition of the clay fraction is also very similar throughout the region, dominated by kaolinite and minor amounts of gibbsite and oxi-hydroxides of iron and aluminium.

With the sole exception of profile 2, all the soils are developed from highly uniform parent materials. At the same time the parent materials of the different soils are also mutually very similar from sedimentological point of view.

" Selective erosion " of fine soil components as a consequence of run-off is throughout the plateaux the dominant morphogenetic process, which influences the physico-chemical properties, the classification and the distribution of the soils in the landscape.

The micromorphological analysis indicates similar features among the dominant soils of the area; and that the illuviation of clay is present in all profiles, which however is not manifested as clay skins in the field as a result of poor structure development.

The soils were classified according to Soil Taxonomy, FAO/UNESCO, the Brazilian System of Soil Classification and under the I.N.E.A.C. (Zaire) System.

SAMENVATTING

Het laag kusttafelland van de staat Alagoas is gelegen in het noordoosten van Brazilië tussen 8° 25' en 10° 20' SB en tussen 35° 10' en 37° 15' WL.

De oppervlakten gevormd door Tertiaire sedimenten zijn vlak of zacht golvend met hellingen die zelden steiler zijn dan 4%. Het gebied heeft een tropisch klimaat met een droge zomer en een konstante temperatuur doorheen het jaar. De vegetatie wordt gedomineerd door het zgn. "Atlantic Forest", in kleinere gebieden komt "Cerrado"-vegetatie voor.

Voor deze studie werden negen profielen geselecteerd uit de bodemtypes die voorkomen op a) het goed gedraineerde tafelland (Oxisols, Ultisols en Oxisol-Ultisol intergrades), en b) de slecht gedraineerde depressies (Spodosols).

Uit de studie van deze bodems blijkt dat de bodemontwikkeling vooral beïnvloed wordt door hun topografische ligging en door de morfogenetische processen die het gebied kenmerken. De kenmerken van de bodemprofielen staan in relatie tot de geomorfologische processen.

De bodems werden gekarakteriseerd op basis van hun morfologische, fysico-chemische, mineralogische en micromorfologische eigenschappen. Ook de sedimentologische kenmerken van de zandfractie (63-2000µm) werden onderzocht.

De mineralogie van de zandfractie is gelijkaardig in alle profielen. De lichte mineralen maken 91 tot 98% uit van het zand. Kwarts is het dominerende mineraal in de lichte fractie, daarnaast komen sporen van veldspaten voor. 84 tot 92% van de zware fractie bestaat uit opake mineralen. Bij de transparante mineralen is zirkoon dominant, gevolgd door toermalijn en rutiel.

De samenstelling van de kleifractie is overal zeer gelijkaardig en wordt gedomineerd door kaoliniet, met kleinere hoeveelheden gibbsiet, vrije ijzer- en aluminiumoxihydroxyden.

Alle profielen, met uitzondering van profiel 2, zijn ontwikkeld in zeer uniforme moedermaterialen. Bovendien zijn ook de moedermaterialen van de verschillende bodems, vanuit sedimentologisch oogpunt bekeken, onderling zeer gelijkend.

Selectieve erosie, als gevolg van oppervlakkige afvoer (runoff), hoofdzakelijk van fijne bodembestanddelen, is overal op de plateaus het dominerende morfogenetisch proces dat de fysico-chemische eigenschappen, de klassifikatie en de spreiding van de bodems in het landschap beïnvloedt.

De micromorfologische analyse toont gelijkaardige kenmerken aan in de dominante bodems van het gebied. Alle profielen vertonen kleiïlluviatie die zich echter in het veld als gevolg van de aanwezigheid van zwak ontwikkelde strukturen, niet als kleihuiden manifesteert.

De bodems werden geklasseerd volgens Soil Taxonomy, FAO/UNESCO, het Braziliaanse klassifikatiestysteem en volgens het I.N.E.A.C. (Zaïre) systeem.

INTRODUCTION

In Brazil the tableland soils, developed from unconsolidated sediments of Tertiary age, occupy huge areas along the country.

These areas, which provide ideal conditions for modern agriculture are in many places intensively cultivated, particularly in the last years with increasing population and pressure on land.

In spite of their geographical and economical importance, the available information about these soils is mostly restricted to numerous soil surveys and land evaluation works, principally carried out in the last 30 years by the S.N.L.C.S. (National Soil Survey and Correlation Service). With the exception of the work carried out by Acha (1976) on the tableland soils of the State of Espirito Santo, no studies exist in relation with the genesis and the classification of these soils.

Among the earliest contributions to the knowledge of the soils formed on these surfaces we can find the soil survey of the State of Rio de Janeiro (Brazil, Ministerio de Agricultura, 1958). In the region of the "littoral fluminense", soils formed on Tertiary tablelands were classified by the "Comisao de Solos" (Soils Commission) as Rego-latosols (tableland phase). The authors of these surveys pointed out the very hard consistence under dry conditions. In later years the presence of these soils on Tertiary surfaces along the "north fluminense" region was indicated by Arenas et al. (1971). Camargo et al. (1970) also reported the occurrence of similar soils in the area of Medio Jequitinhonda - Minas Gerais -, that were classified as Yellow Rego-latosols (tableland phase), and correlated with the soils of the "Unidade Colonia" (Colonia unit) of the State of Bahia.

During the soil survey of the State of Sao Paulo, Lemos et al. (1960) also emphasized the hard consistence, the high ki and kr ratios and the presence of plinthite in similar soils. In that case they were classified as Red Yellow Latosols (terrace phase). According to Acha (1976) the soils of the "Unidade Colonia" (Colonia unit), described by Olmos et al. (1969) in the State of Bahia, can be correlated with the Red Yellow Latosol (terrace phase) of the State of Sao Paulo.

Sombroek and Sampaio (1962) and Falesi et al. (1964, 1970 and 1971) classified as Yellow Latosols equivalent soils developed on Tertiary sediments in the State of Para and in areas of the Amazon Basin.

After Bennema (1979) the Yellow Latosol - as discerned in Brazil - is closely related to the soils of the Yangambi series in Zaïre, characterized by De Leenheer, D'Hoore and Sys (1952).

In 1966 Sombroek stated that in the prominent Tertiary geomorphic surfaces of the Amazon Basin the Kaolinitic Yellow Latosol constitutes the dominant soil, besides which comparable soils, that show characteristics of a textural B horizon (Brazilian sensu), are also common. In this case the names applied were either Kaolinitic Yellow Latosol, intergrade to Red Yellow Podzolic soil, or Red Yellow Podzolic soil intergrade to Kaolinitic Yellow Latosol, depending upon the degree of presence of these characteristics.

In the soil surveys of the north-east littoral States of the country Jacomine et al. (1971, 1973a, 1973b, 1975a and 1975b) stressed that the soils developed on Tertiary sediments - Group Barreiras - are highly cohesive, show variable textures that range from clayey to sandy and mainly occur on flat or slightly undulated tablelands.

The dominant soils mapped throughout this region are actually classified as Red Yellow Latosols, Red Yellow Podzolic soils and as respective intergrades between these groups of soils in function of the degree of expression of the Textural B horizon (Brazilian sensu). In 1978, during the First International Soil Classification Workshop carried out in Brazil (Camargo and Beinroth, 1978), soils of this general morphology, developed on unconsolidated sedimentary materials in the State of Alagoas, were mentioned to occur in Amazonia (Sombroek, Camargo, Rosateli), West Africa and Cameroon (Moormann) and the Congo Basin (Smith et al., 1975).

The preceeding review shows in the first place that although the Brazilian Latosols developed from Tertiary unconsolidated sediments have received different names through the country (Rego-latosol, Yellow Rego-latosol, Yellow Latosol, Kaolinitic Yellow Latosol and Red Yellow Latosol), they constitute a highly homogeneous group of soils. On the other hand, soil survey reports normally indicate the presence of these soils in association with Red Yellow Podzolic soils, which in most of the cases present ill-defined Textural B horizons. Thus, intergrades between these main groups of soils are currently described.

However, the differentiation between Latosols and Low Activity Clay (LAC) Red Yellow Podzolic soils - which broadly correspond to the Oxisols and Alfi-Ultisols of Soil Taxonomy (1975) - is not a problem only restricted to the huge sedimentary (Tertiary) surfaces of Brazil. In many other regions of Central Africa (Smith et al., 1975), Ethiopia, Uganda, Kenya, Tanzania and Zambia (Sombroek and Muchena, 1979), Angola (Benayas and Guerra, 1974), Venezuela (Comerma, 1979), Thailand (Moncharoen and Vijarnsorn, 1979), Malaysia (Jit Sai et al., 1979), Australia and New Guinea (Isbell, 1979) and Indonesia (Buurman and Sukardi, 1980), similar difficulties have been faced by tropical pedologists.

In the last years this problem, which constitutes one of the most relevant subjects of discussion in several international workshops (Camargo and Beinroth, 1978; Beinroth and Panichapong, 1979; Beinroth and Paramananthan, 1979; ACSAD, 1981; Beinroth and Eswaran, 1983), is actually thoroughly studied under the guidance of international committees working on the improvement of the classification of Oxisols (INCOMOX) and LAC soils (INCOMLAC) of Soil Taxonomy (1975).

Nine profiles that represent the different soil types present in the top flat surfaces of the plateaux were selected for the present study, considering the observed variation with respect to the presence and development of the latosolic B horizon (oxic horizon) and the textural B horizon (argillic horizon). They are located in the main well drained sections of the landscape. Soils having Podzol B horizon (spodic horizon), located in poorly drained depressions were also sampled.
Several pedological aspests were analyzed, especially those related to the uniformity of the soil parent materials, the recognition of illuvial clay, and the impact of landscape evolution processes in the actual pedogenesis resulting in the conditioning of the properties, the classification and the distribution of the soils on the landscape.

On the basis of the results obtained, a pedogenetic interpretation valid for other soils formed on similar geomorphological units could be established.

TABLE OF CONTENTS

P.

P.

P.

P.

LIST OF TABLES P.

P.

P.

LIST OF FIGURES P.

LIST OF MAPS, SCHEMES AND PHOTOS

P.

MAPS

SCHEMES

PHOTOS

CHAPTER 1 - ENVIRONMENTAL ASPECTS

1.1. Geographical location and generalities

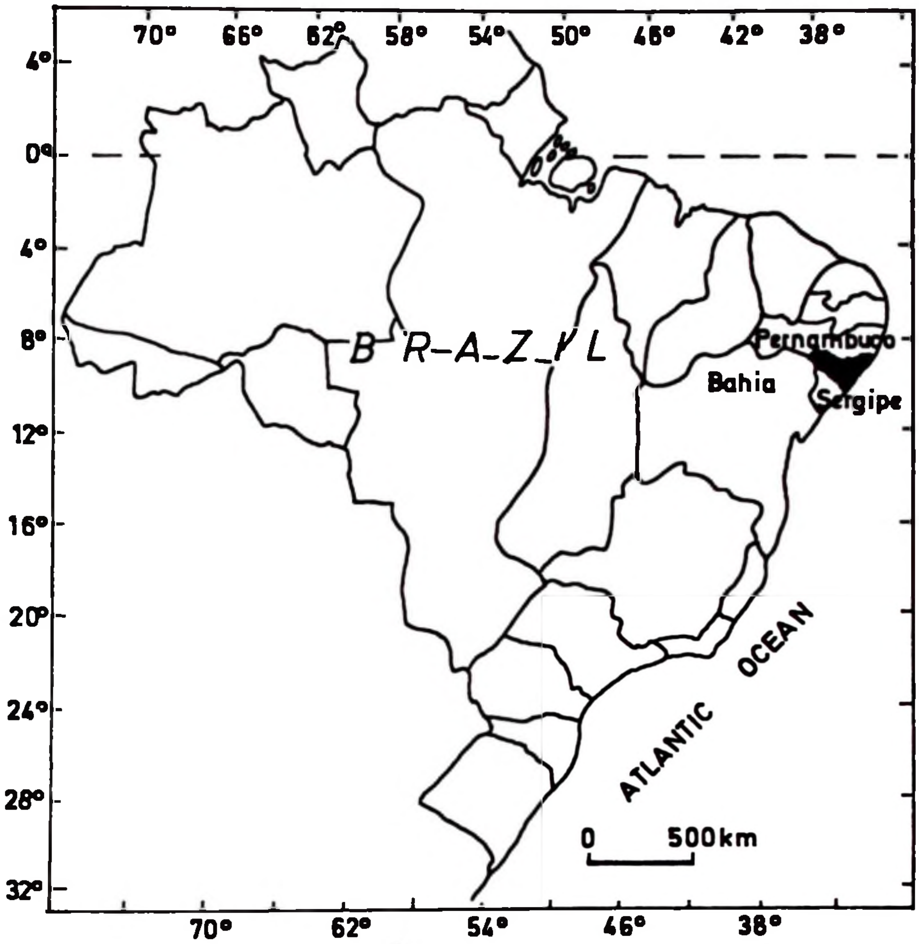
The low level tablelands of the State of Alagoas are located in the north-eastern region of Brazil and cover an approximate area of 8300 km^2. They are distributed between 8°25' and 10°20' south latitude, and from 35°10' to 37°15' west longitude of Greenwich, along the littoral area.

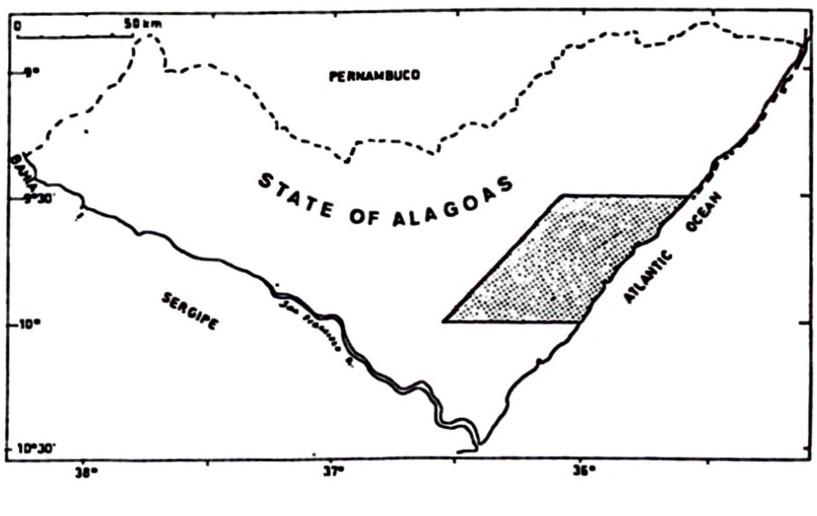
The tablelands are limited in the east by the Atlantic Ocean, in the south by a rather extensive zone of beaches, dunes and overflowed lands, and along the east and the north by the elevated Crystaline scarps of Borborema (map 1).

These surfaces are flat or slightly undulated with slopes rarely higher than 4%, mostly presenting deep and well-drained soils, except in some depressed and poorly drained zones. It enjoys a tropical climate with a dry summer and a constant temperature throughout the year. The dominant natural vegetation is formed by the so-called Atlantic Forest, showing also minor areas of "Cerrado". As a consequence of the rapid expansion of agriculture in the last years, the natural vegetation is actually restricted to small areas. Sugarcane is extensively cultivated in the whole region under a totally mechanized system.

1.2. Geology

Based on field observations, petrographical studies and bibliographical information, a geological outline of the State of Alagoas (map 2) was elaborated by Embrapa, before the Exploratory Soil Survey of the State achieved in 1975 The information provided by this work is restricted to the surface geology related to the materials having influence on soil formation.





Map 1 . Location of the studied area

The geological material of the low tablelands includes the so-called Barreiras Group and Alagoas Formation, formed by sediments of the Tertiary Period (Upper Tertiary).

The Barreiras Group has been called in the past Barreiras Series and also Barreiras Formation. Nowadays it is considered as Barreiras Group because of the diversity of the materials forming these sediments.

Barreiras Group

The Barreiras Group in the State of Alagoas is located along the humid coastal area, and separates the eastern coastal plain from the Pre-Cambrian materials (see map 2). The area is widest in the southern part of the littoral region, where it reaches 75 km. From Maceio to the north, the area progressively decreases having a width of only 8 km at the limit with the State of Pernambuco.

The Barreiras Group shows almost horizontal stratification formed by sediments of variated nature that range from sands to clays of different colors, that occasionally have stone-lines and iron concretions.

The clayey and sandy layers alternate without any special order. Occasionally present are sandier sediments and sand accumulations of greyish color, sometimes showing cross-bedding.

In the deep layers, clays dominated by purple and greyish colors very frequently outcrop in the lower thirds of the tablelands' flanks. In the upper thirds of the flanks, iron concentrations, sometimes reaching significant diameters, are also frequently noticed. In Pre-Cambrian areas, nearby the limits with the Tertiary, a thin cover, having a similar nature as the Barreiras sediments, is lying on top of the Crystaline Basement elevations. This situation is more frequently observed in the northern part, from the parallel 9°30 onwards.

The Barreiras Group in the studied area is thoroughly composed of unconsolidated materials formed by sandy to clayey layers, that occasionally present in the lower part conglomerates and lateritic concretions.

In the upper layers of the Barreiras Group, which constitute the soil parent material of the sampled soils, sediments of clayey texture are almost exclusively present.

Alagoas Formation

This geological Formation of undetermined age (Tertiary ? - Cretacic ?) outcrops discontinuously along the Atlantic Ocean coast. It is observed in the lower thirds of the tablelands' flanks, and is composed of sandstones and conglomerates. Outcrops are more frequent in the northern part of the coastal region, and normally occur at the foot of the slopes, following the humid floodplains.

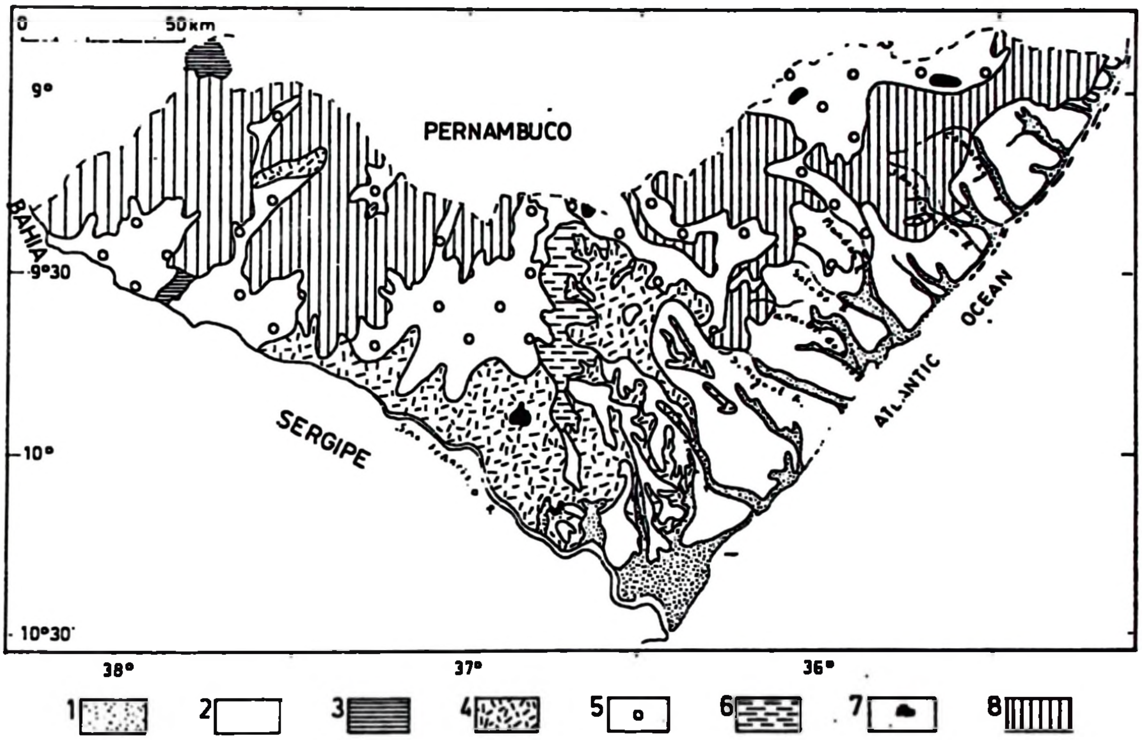
1.3. Relief

The lowland coastal tablelands of the State of Alagoas formed on sediments that belong to the Upper Tertiary (Pliocene) called Group Barreiras present variable thickness, appear directly deposited on top of the Crystalline Basement, and show some particular differences between the south and northern parts of the State, which justifies a separate description (see map 3).

The lowland tablelands (Tabuleiros) and similar surfaces

These lowland coastal plateaux form an uniform ensemble and occupy large surfaces in the southern part of the State, namely in the area comprised from Maceio to the south and from the seaside to the western limit of the Agreste region.

Map 2. Geological outline of the State of Alagoas.



1 - HOLOCENE - Beaches, dunes and alluvial plains.

2 - TERTIARY - Barreiras Group.

3 - SILURIAN and DEVONIAN - Tacaratu Formation, Inaja Formation.

4 - PRE-CAMBRIAN - Micaceous schists.

5 - PRE-CAMBRIAN - Gneisses.

6 - PRE-CAMBRIAN - With clayey and sandy mantles.

7 - PLUTONIC ACID ROCKS.

8 - PLUTONIC ACID ROCKS associated with Pre-Cambrian mantles.

They are individually very extensive where the top part has a general level configuration, dissected by deep valleys that are sometimes narrow and V-shaped, and sometimes open including very large Quaternary floodplains. In the north-western part, the sedimentary layers become thinner as far as they progress towards the continent, and in contact with the Crystaline Basement, become a thin cover of materials variable in nature and granulometry. In these cases, the surfaces have an aspect similar to the typical tablelands, but open shallow valleys replace the characteristic abrupt flanks and deep valleys of the normal plateaux.

The general relief of the top part of the coastal table-lands and similar areas correspond to a flat sub-horizontal surface having smooth slopes towards the ocean, which appear abruptly interrupted by vertical flanks along the coast line. Moreover, these generally flat surfaces are throughout characterized by a microrelief of gentle undulations.

The upper third of the tablelands' flanks show very steep slopes with very strong gradients, while in the mid- and lower thirds, undulated and smoothly undulated landscapes are respectively observed. The above mentioned lower thirds are generally located at the foot of the elevations and appear intimately associated with the floodplains when large valleys are present.

The highly dissected lowland tablelands

The highly dissected lowland tablelands are located in the northern part of the State along the humid coastal area. They show narrow and elongated top surfaces oriented towards the continent, which are laterally limited by deep and narrow V-shaped valleys. Wide valleys showing large Quaternary floodplains are also present, sometimes corresponding to the extension of the littoral depression (Holocene).

Not only the stronger dissection but also the significantly smaller area occupied, differentiates these plateaux from the ones occurring in the south, and thus not far from the coast the sedimentary layers become a very thin cover over the Crystaline Basement. In those places the hydrographic network shows a secondary dendritic pattern, and the elevations that near the sea were only longitudinally sectioned, are now also transversally dissected. In consequence, a higher number of isolated elevations is observed, having somewhat rounded slopes similar to the typical Crystaline modelling.

1.4. Climate

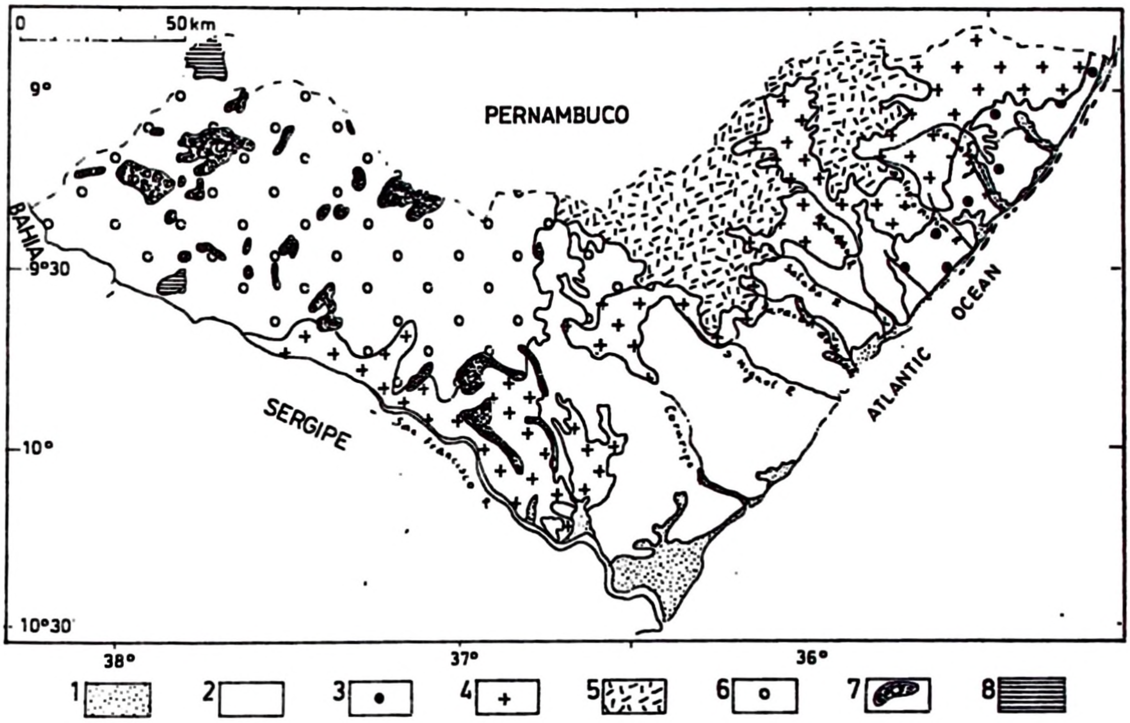
1.4.1. Generalities

The geographical location of the State of Alagoas in the southern hemisphere associated with the position of the littoral tablelands that extend from the coast to the Borborema elevations, favours the penetration of the north-east humid winds. The low latitudes on the other hand, make the variations of temperature during the day more important than the seasonal differences. Consequently, it is important to stress the influence of the geographical factors on the regional climatic conditions.

Climatic conditions

The climatic conditions of the studied area in the coastal plateaux of the State of Alagoas, were established through records of three meteorological stations located in the north (Satuba and Pilar) and southern part (Sao Miguel dos Campos) of the area.

Map 3 Geomorphological map of the State of Alagoas.



1 - Littoral depression.

2 - Low level coastal plateaux (Tabuleiros) and similar surfaces.

3 - Highly dissected low level coastal plateaux.

4 - Cristalline topography.

5 - Borborema hills.

6 - Pedimentation surfaces.

7 - Residual massifs and other elevations.

8 - Jatoba bassin and other sedimentary areas.

1.4.2. Present climatic factors

1.4.2.1. Temperature

The mean annual temperature varies from 24.2°C to 24.8°C. The mean temperature of the warmest month (February) oscillates from 25.3°C to 26.0°C. The annual amplitude of the temperature (difference between the mean temperatures of the warmest and coldest months) is directly dependent on the latitude. Therefore, an amplitude of only 3.0°C is observed. These figures show that the temperatures are extremely uniform throughout the studied area.

1.4.2.2. Rainfall and winds

The precipitations are concentrated during the winter period. They originate from the Atlantic Equatorial air masses (S.E. trade winds) that join the penetration of Polar masses in the area during the winter period. The Atlantic Polar mass incorporates high amounts of humidity along its maritime traject, and produces the precipitations along the littoral. The so-called Intertropical Front that defines the North Equatorial mass (N.E. trade winds) is responsible for the autumn summer rainfalls.

The rainfall distribution is very uniform in the whole area and the lowest records are measured in spring and summer. Precipitations are usually very abundant, and the mean annual rainfall values rather differ between the north and the south. In the north Pilar and Satuba present respective mean annual precipitations of 1678 mm and 1739.9 mm, whereas in the south Sao Miguel registers a year mean of 1388 mm.

1.4.3. Classification of the present climate

1.4.3.1. Thornthwaite's classification

This system is based on the balance between water need or potential evapotranspiration (PET) and water supply or precipitation (R). Thus apart from observations of temperature, precipitation, atmospheric humidity, pressure and wind velocity, the role of vegetation is also considered. Evapotranspiration considers the combined effect of evaporation from the soil surface and transpiration from the plants. Since this parameter is subject to biological control, the role of vegetation is therefore important in climatic quantification.

A distinction is made between actual and potential evapotranspiration (PET). The former relates to the amount of water that actually transpires and evaporates, while the latter refers to the amount that would transpire and evaporate if water was available. Essentially, the system employs two main parameters viz. rainfall (R) and temperature (T). An empirical method was idealized to obtain PET based on temperature and subsequently a moisture index was derived after having calculated the amounts of water surplus and deficiency. Since PET is an expression of temperature, it relates effectiveness of rainfall to thermal efficiency. The cumulative PET for the summer months indicate the type of summer concentration. The combination of thermal efficiency and summer concentration characterises the temperature parameter.

From mean monthly temperature and precipitation data, the mean monthly and annual values were calculated for :
1) Potential Evapotranspiration in mm (PET); 2) Actual Evapotranspiration in mm (AET); 3) Accumulated potential water loss in mm (APWL); 4) water deficit in mm (DEF); 5) Water surplus in mm (SUR); 6) Water storage in mm (STOR); 7) Water need (R - PET).

From the annual values, the following indices were calculated :

Humidity index : $Ih = \frac{SUR}{PET} \times 100$

Aridity index : $Ia = \frac{DEF}{PET} \times 100$

Moisture index : $Im = Ih - 0.6\ Ia$

Summer concentration of thermal efficiency :

$$Sc = \frac{PET\ (summer)}{PET\ (\ year\ )}$$

Based on the variations of the rainfall and evapotranspiration, water balances' diagrams (fig. 1) corresponding to the stations of Pilar and Sao Miguel dos Campos, were established for a soil water retention capacity of 125 mm.

1.4.3.2. Results obtained

Out of the results obtained, and compared with the intervals given by Thornthwaite, the determined climatic types were given in table 1.

Table 1. Climatic classification of Pilar, Sao Miguel and Satuba stations according to Thornthwaite's system

Station	PET	Ia	Ih	Im	SC	Climatic type
Satuba	1269.0	16.40	53.25	37.11	29.07	B1s1A'1a'8
Pilar	1298.7	18.74	47.95	29.21	29.95	B1s1A'2a'7
S.M.dos Campos	1345.1	22.20	25.16	2.96	29.10	C2s2A'2a'8

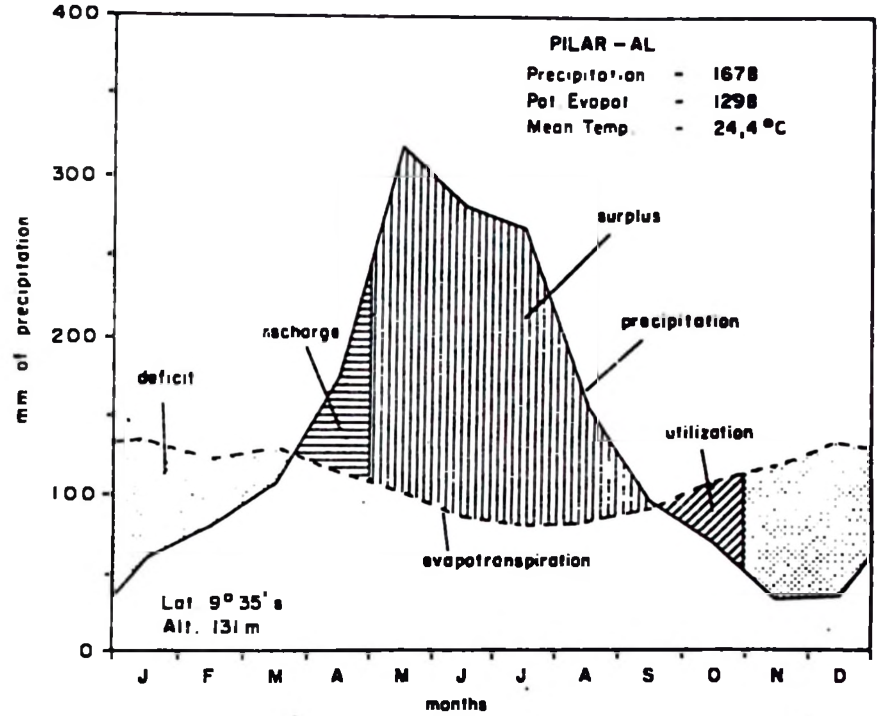
1.4.3.3. Interpretation of the results

The representative water balances for the northern (Pilar station) and southern (Sao Miguel dos Campos) zones of the studied area, given in fig. 1, indicate that in Pilar the precipitation is higher than the potential evapotranspiration during six months a year. In the case of Sao Miguel the rainfall only exceeds the potential evapotranspiration for five months. In all meteorological stations this relation is reversed during the rainy period, going from September to April. A marked water excess during Mai, June and July is thus observed in Pilar and a moderate excess in Sao Miguel, during the same period. Accordingly, the amounts of recharge and utilization water are significantly higher in the latter. The other months show a water deficit that is clearly more pronounced in Sao Miguel.

According to Thornthwaite, the climatic types of the studied stations are as follows :

Satuba	- B1s1A'1a'8 -	Humid, with large summer deficit, first megathermal, and temperature efficiency regime normal to eight megathermal.
Pilar	- B1s1A'2a'7 -	Humid, with moderate summer deficit, second megathermal, and temperature efficiency regime normal to eight megathermal.
Sao Miguel	- C2s2A'2a'8 -	Moist subhumid, with large summer water deficit, second megathermal and temperature efficiency regime normal to eight megathermal.

Therefore on the basis of Thornthwaite's system the climatic type of Pilar is humid with a moderate summer water deficit, while a moist subhumid climate with a large summer water deficit is observed in Sao Miguel. In agreement with the



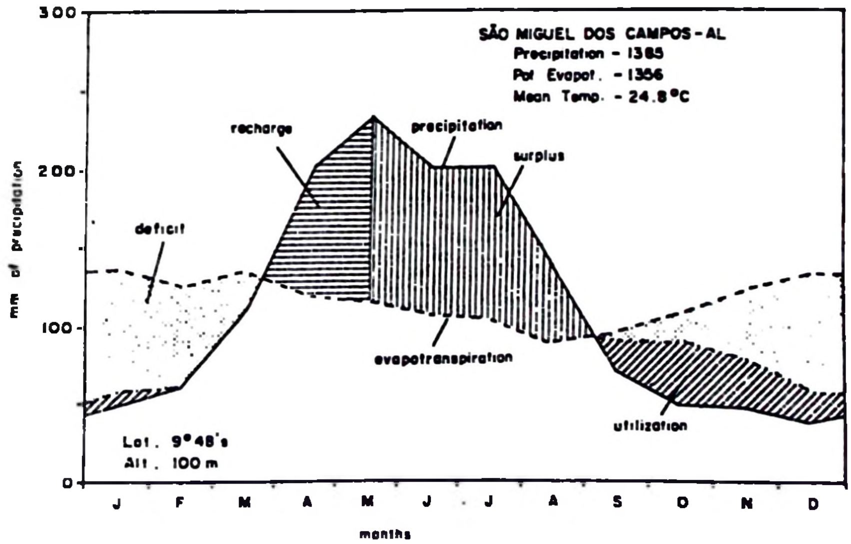


Fig. 1 - Water balance according to Thorthwaite and Mather, 1955 (125 mm.), for the stations of Pilar and Sao Miguel dos Campos.

established climatic classification, significantly higher indices of humidity and moisture were obtained in Pilar, whereas the aridity index is highest in Sao Miguel.

Finally, water balance, climatic types and indices of humidity, aridity and moisture, all confirm the climatological differences taking place between the northern (Pilar) and the southern (Sao Miguel) parts of the area under study.

1.4.4. Soil climate

The definition of taxa in Soil Taxonomy (1975) includes a number of soil climatic parameters of soil which are used at different categorical levels. According to Van Wambeke (1981) one of the reasons given for the use of soil climatic data is to make taxa meaningful for interpretative purposes and to create units, defined in such a way, that major soil limitations for plant growth are implied in the system. Also soil climates are the causes of many other properties. Furthermore, some soil characteristics are only meaningful when they are considered in a limited area restricted to a defined soil climate.

Soil moisture regimes were defined on basis of soil temperature conditions, the duration of dryness and its frequency over a period of time, existing in the control section. The regimes were calculated using a computation model developed by Franklin Newhall (1972). In the present computation, Thornthwaite's potential evapotranspiration was taken to estimate the water removal from the soil. The mean soil temperature was obtained by adding 2.5°C to the mean annual temperature, and the amplitude of temperature variation at 50 cm depth between winter and summer was reduced by 33% of the difference between air temperatures for the same seasons.

Anyhow, it is important to stress that the system here applied, serves as a rough method to estimate moisture regimes, this because climatic information of the area is limited, and the temperature and rainfall figures are only available on monthly basis.

The computed soil moisture regimes for the meteorological stations of Satuba, Pilar and Sao Miguel dos Campos are Ustic throughout as shown in table 2.

Van Wambeke (1981) has proposed a tentative scheme of sub-divisions of the soil moisture regimes included in Soil Taxonomy (1975).

According to that proposal, the soil moisture regime for the whole studied area is classified as udic tropustic. This regime is characterized by an iso-temperature regime in which the number of consecutive days that the MCS is completely or partly moist, is 270 days or more, and where the soil temperature at 50 cm depth is more than 8°C (see table 3).

1.4.5. Paleo climate

Through geomorphological, geological and phytogeographical studies it was established that in the South American continent in relatively short geological time, significant climatic and ecological changes occurred during the Pleistocene.

Among the first authors drawing the attention to the Quaternary's climatic changes in Brazil we find Maack (1947) (1948), who, based on geological evidences, suggested the existence of semi-arid conditions for that particular area. In 1957, Cailleux and Tricart perceived the magnitude of climatic fluctuations during the Holocene, in the

Table 2. Determination of soil moisture regime according to Franklin Newhall system of computation

Name of station	Mean soil temperature		Temperature regime	Cumulative days MCS in one year is			Cumulative days MCS when soil temp.5°C			Max. consecutive days that MCS is moist in some parts				Regime
	Annual	Summer		Dry	M/D	Moi	Dry	M/D	Moi	in one year	when soil temp.>8°C	Dry after summer solstice	Moist after winter solstice	
Satuba	26.7	27.4	Ischyperth.	27	108	125	27	108	225	325	325	22	120	Ustic
Pilar	26.9	27.7	Ischyperth.	37	94	229	37	94	229	294	294	20	120	Ustic
Sao Miguel	27.3	27.9	Ischyperth.	56	77	227	56	77	227	292	292	38	120	Ustic

(Correction for temperature is 2.5 seasonal amplitude modified by factor 0.66) - Computed by Fortran program VW08.

Table 3. Tentative soil moisture regime subdivisions according to Van Wambeke (1981)

Name of station	Moisture regime	Consecutive days moist/dry Temp.8°C	Temperature regime	Tentative subdivision of moisture regime	Consecutive days moist		Cumulative days moist	
					Summer	Winter	Summer	Winter
Satuba	Ustic	325	Ischyperth.	Udic Tropustic	135	180	153	180
Pilar	Ustic	294	Ischyperth.	Udic Tropustic	105	180	143	180
Sao Miguel	Ustic	282	Ischyperth.	Udic Tropustic	105	180	124	180

southern part of the country. One year later, Ab' Saber proposes the first general outline of the climatic oscillations for the whole country. Later, in 1961, Bigarella and Ab' Saber established the link between glacial conditions, low sea levels and the expansion of semi-arid climates over the continent. But it was in 1970 that Damuth and Fairbridge published a fundamental work that provides the first global explanation of the mechanisms producing the simultaneous occurrence of aridity and low sea levels, during the glacial Quaternary periods in South America as a whole. That work confirmed the hypothesis, relating the dry Pleistocene systems with the penetration in tropical latitudes of the cold Atlantic Ocean currents, and established the probable traject, followed by the cold sea currents during glacial and periglacial periods along the South American continent. Thus, two climatic schemes were defined according to the predominance of drier and cooler conditions in the glacial periods, in alternating with more humid and warmer climates during the interglacials, which are valid for a very large continental area. Moreover, it is important to mention that along these major contrasting cycles, minor climatic oscillations were taking place.

During the interglacial periods therefore, the semi-arid and desertic zones were localized in places where even in humid phases, rigorous climatic conditions occurred. In glacial times these "centers of aridity" (or semi-aridity) were remarkably expanded, transforming into deserts considerable geographic areas, currently occupied by forest during the interglacial intervals.

During the glacial periods different types of open vegetal formations dominated the dense forest actually present, and this throughout the continent. A very important core of "cerrados" associated with forest and sub-xerophytic vegetation took place in Amazonia (Ab' Saber, 1977; Tricart, 1974).

During the times of semi-aridity and extensive pedimentation the sea levels were low, while high sea levels were present along the humid and warm tropical periods.

In the warm humid epochs climatic fluctuations were frequent, and according to Bigarella (1964) these minor variations expressed by expansions and retractions of the forests from their cores of distribution, produced significant changes in the vegetative cover.

Although the climatic conditions along these minor dry phases were apparently not extremely rigorous as the semi-arid periods, they were important enough to promote the expansion of "campo" and "cerrado" in areas normally occupied by forest in the humid phases.

Therefore, a cyclic system of retraction and re-expansion of the vegetation is generally accepted by most authors (Bigarella, 1964; Ab' Saber, 1977; Tricart, 1974). Of the complex mechanisms followed by the different vegetal formations (Klein, R.M., cited by Bigarella, 1964) only fragmentary information and indirect evidences are available today.

From the beginning of the Pleistocene and due to the effect of climatic oscillations, significant changes in the existing morphogenetic processes occurred, sometimes producing radical modifications of the Upper Tertiary landscapes. That evolution of the landscapes was followed by changes in vegetation, physiography and ecological conditions.

Periods of "stability" were always succeeded by "unstable" phases, characterized by the alternation of prolonged morphoclimatic systems and fast degradation phases, with transitional periods, that in spite of their short duration were very active from a morphogenetical point of view (Ab' Saber, 1977).

The Upper Tertiary (Group Barreiras) landscapes of the low land tablelands in the Amazon Basin studied by Tricart (1974) are actually highly dissected no matter the dense forest cover. The drainage density is high, the slopes very steep and the ridges very narrow. The author therefore concludes that such a dissection cannot develop under a dense forest cover, but needs a sparse vegetation more or less of the savanna type. Furthermore, this type of sculpture must coincide with a low sea level stand that enabled the streams to cut their beds below their present floodplains.

Consequently, the Pleistocene - when compared with other periods of the earth's history - is an exceptional geological epoch from climatological point of view.

1.5. Vegetation

The semi-evergreen tropical forest and the semi-evergreen tropical cerrado are the vegetative ensembles present in the tablelands (Tabuleiros) of the State of Alagoas. The tropical forest is largely dominant along the region, and the cerrado occupies relatively reduced surfaces. The cerrado vegetation appears in some places as uniform and rather extensive ensembles (eg. Tabuleiro dos Martins), and it is also present as inclusions inside the forest or in transitional forest-cerrado areas. In recent years a very large part of both vegetal formations has been cleared to make way for agriculture. The recent agronomic success of the sugarcane has significantly accelerated the elimination of the natural vegetation.

The semi-evergreen tropical forest is a luxurious, dense and high (20-30 m) formation that includes the following trees' species :

Parkia pendula Benth. (visgueiro), *Lecythis pisonis Cambess* (sapucaia), *Bowdichia virgilioides W.B.K.* (sucupira), *Caraipa densifolia Mart.* (camaçari), *Sclerolobium densiflorum Benth.* (ingá-de-porco), *Copaifera sp.* (pau-d'oleo), *Hymenaea latifolia Hayne.* (jatoba), *Ocotea sp.* (louro), *Attalea sp.* (pindoba), *Simaruba amara Aubl.* (praiba), *Byrsonima sericia DC.* (murici-da-mata). The epiphyts species include Bromeliaceae and Orchidaceae : *Cattleya sp.*, *Oncidium sp.*, *Cryptopodium andersonii R.Br.* In the substratum the bromeliaceae are very frequent.

The semi-evergreen tropical cerrado is a vegetal formation of the savanna type, also called "tabuleiros" or "cobertos". It is characterized by the presence of sparsely distributed trees that range from 3 to 5 meters high, and by shrubs with coriaceous leaves. In the substratum the dominant species are graminae.

The most frequent species belonging to that formation are : *Byrsonima cydoniaefolia Juss.* (murici-do-tabuleiro), *Curatella americana L.* lixeira or cajueiro-brabo), *Hancornia speciosa Gomez* (mangabeira), *Ouratea sp.* (batiputa), *Miconia ferruginata DC* (apaga-fogo), *Anacardium occidentale L.* (cajueiro). The substratum is mostly formed by species of the Cyperaceae *(Bulbostylis spp.)* and Gramineae *(Echinolaena inflexa (Poir) Chase.)* families.

1.6. Hydrography

The main rivers that drain the tablelands are perennial, and flow from the Crystaline elevated zone (Borborema hills) to the Atlantic Ocean, generally a west-east direction (map 3). They are fed by minor water courses and rivulets originating in the tablelands, that transport fine sediments mostly composed of clay and silt particles (Wanderley Leite, 1974). Due to the reduced gradient between the bottom of the valleys and the rivers' mouths, the transported material is not readily evacuated in the areas near the Littoral. Therefore, only the finer sediments are carried out from the area of the tablelands. Anyhow, zones of sedimentation are not observed within the area of the tablelands, and the real zone of colmatation takes place in the so-called "Littoral Depression" where areas flooded by the rivers, lagoons, and small internal deltas occur.

From Maceio to the north, Santo Antonio Mirim, Santo Antonio Grande, Camaragibe and Manguaba, are the main rivers draining the waters from the highly dissected plateaux of the area, where the most extensive ones (Santo Antonio Mirim and Camaragibe) range from 40 to 50 km length.

Throughout the tablelands area the major rivers are to be found in the south of Maceio. The Mundau river with 200 km and the Paraiba river with 150 km length are the longest; in their lowest course, not far from the rivers' mouths, they show the largest lagoons of the State, respectively called "do Norte" and "Manguaba". Other rivers like Coruripe (120 km), Sao Miguel (50 km), Santo Antonio and Manguaba have minor extensions but remain important from an agricultural point of view, due to the presence of large associated floodplains that are intensively cultivated.

1.7. Morphogenetic processes

The general aspect of the low level plateaux observed in the State of Alagoas, suggests a long history of erosion mainly related to the age of these surfaces and to the climatic oscillations during the Quaternary.

The geomorphological study of similar surfaces carried out by Wanderley Leite (1974) in the neighbouring State of Sergipe, stresses the importance of erosion in the present landscape and characterizes the morphogenetic processes actually taking place. The author concludes that regardless of the type of vegetation cover (Tropical forest, Cerrado or Grassland), "sheet erosion" caused by run-off is the dominant morphogenetic process observed throughout. This, in agreement with Sys (1967), who stated that "run-off is always significant in the intertropical zone, whatever the nature of the plant cover". Sheet run-off, which occurs even beneath ombrophile forest, is the erosion form most frequently observed (Rougerie, 1958, cited by Sys, 1967). "Anyhow, if vegetation does little to check run-off, its effect on erosion control is far from negligible. It slows down the rate of movement of the surface water and reduces its eroding effect, no matter the vegetation type" (Sys, 1967). The vegetation cover controls the kinetic energy of raindrops and prevent them from beating against the soil, with the consequences resulting therefrom, viz. maintenance of the soil structure, better infiltration, and reduced run-off (Fournier, 1967). The vegetation also influences the content of coarse elements (quartz grains and fine gravel), which become concentrated as a result of the removal of fine material by run-off, and produces some homogeneity in these materials through the mechanical action of roots (Sys, 1977).

Therefore, the top level surfaces and the flanks of the tablelands present a diffuse surface drainage pattern, where following the way of the run-off water, material is removed and transported to the bottom of the valleys. The transported material is mainly composed of silt and clay; however, coarser fractions can also be displaced during heavy rainfalls. The coarser fractions - when removed - are commonly stopped by the grassland vegetation and thus deposited, and the finer fractions composed of silt and clay are transported further, reaching the river-beds (Wanderley Leite, 1974). A similar description of the same phenomena is given by De Leenheer, D'Hoore and Sys (1952) for the plateaux of Yangambi (Zaïre). The selective losses of silt and clay particles due to run-off in tropical areas, have been also reported by many authors. U.S.D.A. (1960), Sys (1960) and Folster (1967) indicate the surface erosion as a factor contributing to the generally sandier textures present in the upper horizons of many tropical soils. Also Roose (1970) emphasizes the preferential impoverishment in fine particles (silt and clay) due to run-off, in the surface horizons of ferralitic soils of Ivory Coast.

Besides the vegetation, slope gradients are considered to influence soil erosion throughout the world, and strong gradients have a powerful effect on the extent of erosion. In any case, in the coastal plateaux of the State of Alagoas, run-off erosion is currently observed even in the slightly undulated top surfaces where slope gradients are rarely higher than 4%. The existence of severe erosion on very slight slopes (1-1.5%) indicates that the presence of a slope is not necessary to induce erosion in tropical Africa, and thus the action of the rain is sufficient (Fournier, 1967). On plateaux of Kolwezi (Zaïre), with slopes of 1.1%, De Dapper (1979) indicates the presence of run-off, which - among other factors - plays an important role in the genesis of the local microrelief. According to De Dapper and De Moor (1978), "slope values that limit erosion processes ought not to be generalized." Other factors like precipitation surplus, soil type (structural stability and permeability), vegetation type and cover also condition the erosive power of the run-off. On the other hand, it is stressed that some of the erosion forms actually observed (rills) in these Tertiary surfaces, could be generated during a period of higher erosion intensity where the climate was characterized by lower mean annual precipitation, larger dry season and higher rainfall variability.

In places where the surface of the tablelands is covered with thick (several meters depth) sandy sediments, the typical diffuse surface drainage pattern is absent due to the rapid indiltration of rainwater. The sands are bleached in the top soil and subsurface horizons and become gradually yellow with depth.

The amount and distribution of rainfall acting on unconsolidated sandy clay sediments, produces locally, on the slopes, erosion processes expressed as "soil creep". This process involves the slow displacement of soil particles along slopes under the effect of gravity. Its intensity is favoured by strong slope gradients and by the existence of clayey layers that impede deep water percolation, and thus producing the saturation and occasional flooding of the surface material. Anyhow, it is important to mention that in the studied area processes of soil creep are not frequently observed.

During the construction of highways the flanks of the plateaux are excavated and the natural vegetation totally removed; as a result the landscape stability is locally affected. As a consequence, "land slides" are only observed along the road cuts during the rainy periods, and are entirely due to the influence of human activity.

1.8. Soils

1.8.1. General

The soils of the lowland tablelands of the State of Alagoas belong to the so-called Red Yellow Latosols, Red Yellow Podzolic soils and Podzols of the Brazilian soil classification system.

On these surfaces the Red Yellow Latosols, Red Yellow Podzolic soils and intergrades between these two classes are largely dominant. They are characteristic of the well drained uplands and respectively correspond to the Oxisols, Ultisols and Oxisol-Ultisol transitions of the USDA Soil Taxonomy (1975).

In the same landscapes, Podzols occupy minor surfaces. They occur in imperfectly to poorly drained depressions where water accumulates during the rainy periods, and are classified as Spodosols according to the USDA Soil Taxonomy (1975).

In order to achieve a better understanding of the soil profiles selected for this work, some classification concepts actually used in Brazil, in relation with the studied soils, will be commented in the following paragraphs.

1.8.2. The Brazilian system of soil classification

The soil classification system actually applied in Brazil is based on the Baldwin, Kellogg and Thorp' system of 1938, that preceed the VIIth Approximation (Soil Survey Staff, 1960).

Under that classification system, the soils are grouped in different classes according to morphological, physical, chemical and mineralogical attributes. However, it must be said that some of these classes are differentiated in relation to physical, chemical and mineralogical characteristics, which cannot necessarily be observed in the field.

At the highest level of classification the well drained soils are subdivided in two wide classes : 1) soils with a Latosolic B horizon and 2) soils with a textural B horizon.

1.8.2.1. Soils with latosolic B horizon - The modal Latosol

Based on the concept of Latosol given by Kellogg (1949, 1950), in 1959 Bennema, Lemos and Vettori presented the first extensive characterization of the Brazilian Latosols. The same elaborated concept presented by Bennema (1963) has not suffer further modifications until the present.

The modal Latosol

The most important characteristics of Latosols are related to the nature and constitution of the mineral soil mass, indicating the high degree of weathering of the soil. It consists of sesquioxides, 1:1 type silicate clays, quartz and highly resistant minerals. Primary silicate minerals are present in small amounts or absent, as are 2:1 lattice clay minerals, and those amorphous compounds of Fe and Al (allophanes) that have high cation exchange capacities. Free aluminum oxides are often present, but not always. The silt contents are generally low. Concretions of iron, manganese or aluminum oxides may be present in the soil mass.

The most remarkable properties and characteristics as proposed by Bennema (1963) are as follows :

1) Indistinct horizon differentiation with often diffuse or gradual transitions between horizons.
2) Absence or scarcity of distinct clay skins on peds or distinct linings in the channels.
3) Low cation exchange capacities of the clays.
4) Red, yellow or brown colors of the subsurface horizon, or part of the subsurface horizon.
5) Absence or near absence of electro-negative "natural clay" in parts of the subsoil horizons that have low percentages of carbon (carbon/clay ratio less than 0.015).

In addition to those characteristics and properties, typical Latosols have :

6) Absence of well developed blocky or prismatic structure. The structural elements are often very fine granules that may be more or less coherent, forming together a porous, friable, massive soil mass. A weak or moderate blocky structure, or seemingly massive structure without much visible porosity, may be found in Latosols intergrading to other soils.
7) Deep solum (A B horizons).
8) Consistency in the moist state : very friable or friable.
9) High porosity and high permeability.
10) Low base saturation in the whole profile, or at least in the subsoil.
11) Relatively high anion exchange capacity, and high phosphorous fixing power.
12) Relatively low amounts of exchangeable aluminum, due to the low effective cation exchange capacities of the clays.
13) High resistence to gully erosion. Soft or hard plinthite may be present in the lower part of the solum, or below the solum, but it is not an essential characteristic of a Latosol.

The brown, yellow or red colors, the absence of well developed blocky or prismatic structure, and the absence of distinct clay skins, the porosity, the high friability, the indistinct horizon differentiation, and frequently the great depth of the solum are the best and most easily recognizable morphological characteristics of typical Latosols.

1.8.2.2. Soils with textural B horizon - The modal Red Yellow Podzolic soil

Besides the Latosols the other main well drained soils having a textural B horizon present in the studied area are the so-called Red Yellow Podzolic soils.

According to Thorp and Smith (1949), the modal Red Yellow Podzolic soils were defined as : "Well developed, well drained acid soils, having a thin organic (Ao) and organic mineral (A1) horizons, over a light colored bleached (A2) horizon, over a red, yellowish red or yellow and more clayey (B) horizon. Parent materials are more or less siliceous. Coarse reticulate streaks or mottles of red, yellow, brown and light gray are characteristic of deep horizons of Red Yellow Podzolic soils where parent materials are thick." It is important to stress that in the preceeding definition is not mentioned the necessity of having clay skins in the B horizon.

Based on this concept, Lemos, Bennema, Santos et al.(1960) defined the Red Yellow Podzolic as soils where the clay sized minerals should consist of silicate clay mainly of 1:1 lattice structure, and iron oxides. The latter are generally present in smaller quantity than in most Latosols, and there are few if any aluminum oxides. At the same time the B horizon should have the characteristics of a "Textural B", which are listed below :

1) Normally very distinct contrast with the upper horizons. Transitions are either abrupt, clear or gradual. The separation of subhorizons is mainly based on structure, texture and the presence of clay coatings.
2) At least 15% clay size mineral particles, and more clayey than the A horizon.
3) Structure - If the structure is "clayey", "sandy clay" and "clay loam" (heavy textured), the structure is

strongly or moderately subangular or angular blocky or prismatic.
If the texture is "sandy clay loam", "loam" or "heavy sandy loam" (medium textured), the structure is weakly or moderately subangular or angular blocky. The textural ratio is above 1.6.

4) Coatings - If the structure is moderate, strong blocky or prismatic, the clay skins are well developed and often continuous.
If the structure is weakly or moderately blocky, the clay skins are rather well developed.
5) Porosity - In clayey soils a rather low porosity is present. Lighter textured soils show an homogeneous soil mass.
6) Consistence - If textures are clay or "sandy clay", the consistence is hard when dry, firm humid, and sticky, slightly plastic to plastic when wet.
If the texture is "sandy clay loam", the consistence is friable when humid.
7) The Ki value (SiO_2/Al_2O_3 molecular ratio) is normally above 1.8, less commonly between 1.8 and 1.6.
The Kr value (SiO_2/AlO_3 Fe_2O_3) is normally above 1.5.
8) The cation exchange capacity is in general larger than in the Latosolic B.
9) The base saturation has a large variation (from 10 to 90%) and is one of the criteria employed at lower categoric level for the separation of soils having a textural B.

1.8.2.3. Soils with podzol B horizon - The Podzols

It includes soils having a Podzol B horizon (Spodic horizon as defined in the 7th Approximation, 1967), very well differentiated, mostly sandy, strongly acid with very low fertility and originated from sandy quartzitic materials.

These soils are easily identified in the field due to their contrasting horizonation. They normally have a thick grayish A horizon that ranges from 50 to 100 cm. The A horizon is normally sandy, with loose consistence in dry or humid state, and presents an abrupt transition with the B horizon. The B horizon shows variable thickness. It is characterized by the presence of illuvial concentrations of organic material and/or sesquioxides; colors are dark (Bh), yellowish or reddish giving Bir or Bh.ir horizons which normally show red mottling. In some cases the B horizon is irreversivelly indurated (Bm) giving an "ortstein" where the silica and/or aluminum concentrates; occasionally it constitutes a fragipan (Brazilian sensu). The permeability in the upper layers is rapid, and slow or very slow in the subsoil. These are in general imperfectly drained soils, that occupy semi-circular small depressions in the tablelands where Red Yellow Podzolic (with fragipan) soils are dominant. Intermediary soils between Podzols and Red Yellow Podzolic soils are also present. The vegetation cover is Cerrado and Tropical Forest.

Besides the very low fertility which is characterized by serious deficiencies of macro- and micronutrients, drainage limitations are remarkable in areas where indurated B horizons occur at shallow depths, leading to periodical flooding during the rainy season.

1.8.2.4. Discussion

No matter the process involved in the formation of Latosols and Red Yellow Podzolic soils are different in nature. These soils may, in many cases, show similar mineralogical, physico-chemical and morphological properties. Moreover, in the area under study, Latosols and Red Yellow Podzolic soils occur in close proximity, and the separation in the field is normally difficult. Transitional soils between the modal types are in consequence frequently indicated in soil survey reports (e.g. Jacomine et al., 1975,a; Lasa Engenharia e Prospecçoes S.A., 1971a, 1971b, 1971c, 1971d, 1971e), in spite of the efforts done by Brazilian pedologists to establish quantitative boundaries between latosolic and podzolic character. For the heavy textured soils of the studied area, the principal differentiating characteristics between latosolic and textural B horizons are compared in table 4.

From the morphological and soil analytical data published by Jacomine (1975) and Lasa Engenharia e Prospecçoes (1971,a,b,c,d,e), it appears that in the Tertiary coastal plateaux of the State of Alagoas, the soil profiles actually classified as Latosols and Red Yellow Podzolic are similar in : a) consistence, b) "natural clay" (water dispersible clay), c) mineralogical composition of the clay fraction (SiO_2/Al_2O_3 molecular ratio), d) cation exchange capacity, e) weatherable minerals and f) silt/clay ratios. Therefore, the separation of these soil classes is finally based on the estimation of a restricted number of qualitative field properties such as : 1) contrast and type of transitions between horizons, 2) type and degree of structure development, and 3) identification of clay skins. The estimation of the contrast and transitions between soil horizons and the degree of structure development are features not always equally appreciated by different pedologists. Moreover, the identification of clay skins in the field is frequently doubtful, and here also the individual concepts and experience of the soil surveyor are determinant.

Due to the difficulties encountered in the identification of the diagnostic latosolic B and textural B horizons, the separation of Latosols and Red Yellow Podzolic soils, can be considered highly subjective.

Table 4. Principal characteristics of latosolic and textural B horizons (after Bennama, Lemos and Vettori, 1959 and Lemos, Bennema, Santos et al., 1960)

TEXTURAL-B	LATOSOLIC-B
Normally very distinct contrast with the other horizons. The transitions are either abrupt, clear and gradual.	Weak contrast with the other horizons; The transitions are normally diffuse or gradual.
When the horizon is heavy textured (clay, sandy clay, clay loam), then the structure is strongly or moderately subangular and angular blocky, or prismatic, with well or moderately well developed, often continuous clay skins, and relatively low porosity.	When the horizon is heavy textured (clay, sandy clay), then the structure is generally of fine or very fine granules, forming a porous homogeneous mass with very weak coherence. It also may have a weakly or moderately developed subangular and angular blocky structure, the blocky elements being composed of fine granules. Clay skins, when present, are non-continuous and of weak development. The porosity is generally high.
The consistence when moist is firm or friable.	The consistence when moist is friable or very friable.
The 'natural clay' content can be relatively high.	The 'natural clay' content is normally low. It is less than 1% in the B2, except when the Ki value is very low and the pH-KCl is higher than the pH-H_2O, or the carbon-clay ratio is relatively high (C/clay > 0.015).
The Ki value (SiO_2/Al_2O_3 molecular ratio) is normally above 1.8, less commonly between 1.8 and 1.6.	The Ki value (SiO_2/Al_2O_3 molecular ratio) is normally below 1.8, less commonly between 1.8 and 2.0.
The cation exchange capacity is often larger than in the latosolic-B.	The cation exchange capacity is small. It is below 12 m.e./100 g of clay (NH_4OAc method).
Easily weatherable primary minerals may be present.	Weatherable primary minerals are practically absent. They comprise less than 4% of the sand fraction.
The silt content is often higher than in the latosilic-B.	The silt content is generally low. The silt/clay ratio is normally below 0.25.

(Adapted from Sombroek, 1966).

1.8.3. Soil forming factors

1.8.3.1. Parent material

The parent materials of the soils formed on the plateaux of Alagoas correspond to sediments of the Upper Tertiary. These sediments present the same mineralogy throughout the region and are composed of highly resistant primary minerals where quartz (up to 98%) is predominant. Their heavy fraction includes mainly opaques (84-99%) and among the transparent minerals zircon is the most important, followed by tourmaline and rutile. Easily weatherable minerals are practically absent.

From granulometric viewpoint, the parent material in almost the entire surface of the region, is always clayey and shows a narrow textural variation that ranges from about 60 to 70% clay and 3 to 5% silt in the deepest B2 or B3 horizons.

On the other hand, in some sites following the edges of the plateaux, sandy layers of generally limited extension and variable thickness are observed in shallow depressions.

These textural variations of the soil parent materials are correlated with the regional distribution of some types of soils. In this way, the dominant soil types - Latosols, Red Yellow Podzolic and Latosol-Red Yellow Podzolic intergrades - are always formed in clay-rich materials, while Podzols develop in sandy parent materials.

One of the purposes of this work is to demonstrate that the studied profiles, which represent the different soil types present in the flat surfaces of the plateaux, were all developed in homogeneous and highly similar original materials.

1.8.3.2. Relief

One of the most relevant features of the studied tablelands is that in spite of the low gradients of their slopes, these landscapes present an important morphological potential. In consequence, not only the vertical migrations normally expected for a flat topography, but also the transport and lateral removal of soil components occur under these conditions.

In the case of these plateaux, the macro- and microrelief are both related to the soil drainage, and to the intensities of run-off and erosion.

So, in depressed zones where the excess of rainwater is collected by run-off during the rainy season, the watertable (temporary) is closer to the soil surface than in the adjacent and more elevated sections of the relief, and in some places remains above the soil for rather long periods. In these sectors of the landscape the infiltration is therefore reduced and the lateral displacement of soil components may be important when the external drainage is favourable. The closer the watertable gets to the surface, the stronger is the intensity of run-off.

As a result, the strongest contrast between soil horizons is normally observed in parts of the landscape where the run-off waters are accumulated, and thus produce maximum percolation through the profile and/or lateral transport of soil components.

1.8.3.3. Climate

The present climatic conditions of the area under study can be considered similar throughout, and the influence they actually have on some soil characteristics will be commented in the following paragraphs.

The difference between the mean annual temperature of the warmest month (February) and the coldest month (August) is about 3°C. This narrow difference suggests that weathering processes, biological activity and other factors affecting soil properties are not influenced by temperature variations along the year. On the other hand, the water balances indicate a marked water excess during part of the autumn and throughout the rainy season - from April to September -, and a clear water deficit for the rest of the year.

Under these conditions, it is evident that leaching processes, migration of soil components and run-off are significant during the water surplus period, while the biological activity is at the same time restricted, especially in the poorly drained soils.

1.8.3.4. Vegetation

The type of vegetation actually present in the coastal plateaux of Alagoas is not uniform throughout the region. It is mainly composed of the semi-evergreen tropical forest, and areas of semi-evergreen tropical cerrado which appears as inclusions inside the forest, or in some places forming rather extensive homogeneous zones.

The presence of cerrado vegetation in tropical areas is generally associated with drier climatic conditions or related to human activity. Anyhow, in the studied region forest and cerrado occur together - under the same climatic conditions -, and the presence of cerrado is apparently not due to man. Moreover, the northern part of the studied area, covered by cerrado, shows a remarkably higher mean annual total rainfall (Satuba - 1739 mm), than the southern part covered by forest (Sao Miguel - 1358 mm). This apparent disagreement between the type of vegetation and the total rainfall observed today could probably result from the retraction and re-expansion cycles followed by the vegetation during the Quaternary.

But regardless of the evolution followed by the vegetation in the past, the vegetation types actually present exert an important influence in the control of the run-off. Thus, the well-drained uplands today covered by cerrado are more easily eroded than the forest zones, at the same time the soils show somewhat lower organic matter contents in the topsoil and are more desaturated, and are mostly classified as Latosols, while under forest Red Yellow Podzolic soils are dominant.

1.8.3.5. Time

The parent material of the studied soils were deposited in the Upper Tertiary. In consequence the age of the dominant well-drained soils formed on these materials have at least two million and no more than twenty three million years.

From the analyses of the different soil forming factors prevailing in the study area, it can be concluded that the soil parent materials are uniform throughout, except in restricted zones that show contrasting granulometries. The water balances indicate an unequal rainfall distribution, with important water excesses for about five months a year. During this period, leaching processes, run-off and erosion controlled by the relief and the vegetation, are manifestly present.

1.8.4. Studied soils

1.8.4.1. Basic formation

A generalized map of soils intermediary between Exploratory and Reconnaissance levels, scale 1/400,000 of the State of Alagoas, was published by Embrapa in 1975.

The methodology of the survey included field observations (done by auger and in soil pits) and physico-chemical analyses. A large use of photo-interpretation was necessary in places of difficult access, by means of aerial photos in the scale 1/25,000. Geological maps published by Petrobras, scale 1/100,000 and Hydrogeological maps of Sudene, scale 1/500,000, were also employed.

The different soil mapping units were defined following the norms established by the C.P.P. (Comisão de Pesquisa Pedologica) and respective phases according to relief, vegetation, stoniness, erosion and presence of concretions were established. The resulting soil mapping units were presented as soil associations. In the studied area the taxonomic units forming these soils associations include the following soil classes of the Brazilian system of soil classification : 1) Soils with Latosolic B horizon - the Latosols -; 2) Soils with textural B horizon - the Red Yellow Podzolic - and 3) the Latosol-Red Yellow Podzolic intergrades, that approximately correspond to the Oxisols, Ultisols and Oxisol-Ultisol transitions of Soil Taxonomy (1975).

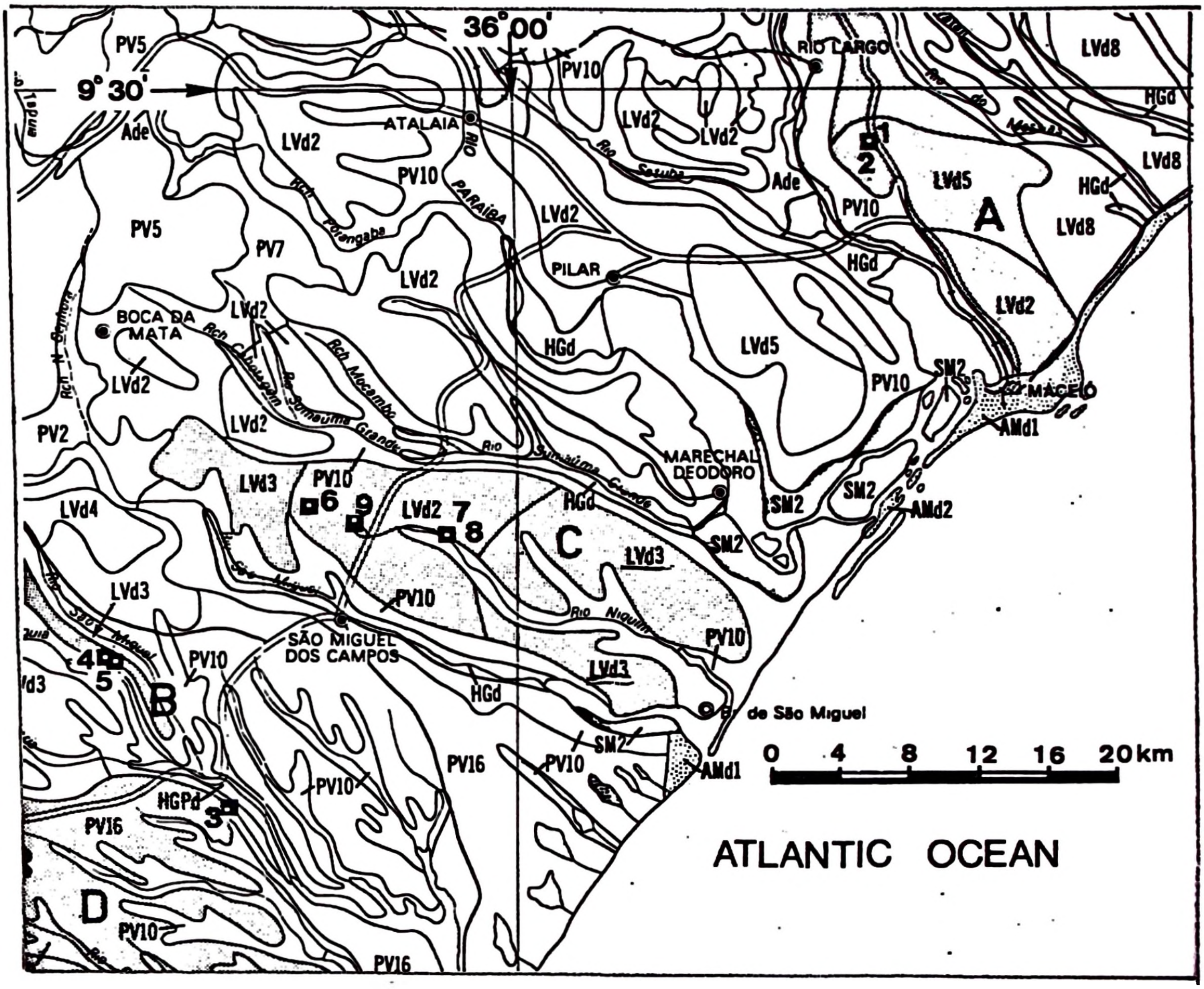
Complementary information about the distribution of the soil classes included in the Exploratory-Reconnaissance map, was obtained from semi-detailed soil surveys and topographic maps in the scale 1/25,000 done in 1971 by Lasa Engenharia in the area of Caete and Sinimbu sugar mills.

1.8.4.2. Sampled soils

Based on the information of soil survey data, nine profiles that represent the different soil types present in the top flat surfaces of the plateaux, were selected for this work.

The soil sampling was carried out in four tablelands (A, B, C and D) which are roughly parallel to each other and that slope towards the sea in NW-SE direction (map 4). Special care was taken to include the complete sequence of

Map 4. Soil map of the area (Jacomine el al., 1975).
Location of plateaux and studied soils.



LVd5 - Ass. Red Yellow Latosol Dystrophic, cohesive + Red Yellow Podzolic latosolic, both with prominent and moderate A horizon, clayey texture, semi-evergreen cerrado, level phase.

LVd2 - Ass. Red Yellow Latosol Dystrophic, cohesive + Red Yellow Podzolic latosolic, both with prominent and moderate A horizon, clayey texture, semi-evergreen forest, level phase.

LVd3 - Ass. Red Yellow Latosol Dystrophic, cohesive + Red Yellow Podzolic latosolic, both with clayey texture + Red Yellow Podzolic with fragipan, medium/clayey texture, all with moderate and prominent A horizon, semi-evergreen forest, level and slightly undulated phase.

PV16 - Ass. Red Yellow Podzolic with fragipan, medium/clayey texture + Red Yellow Podzolic latosolic clayey texture + Red Yellow Latosol Dystrophic, cohesive, clayey texture, all with prominent and moderate A horizon, semi-evergreen forest level phase.

→ Plateaux

→ Profiles

profiles varying from the typical Latosol, through the Latosol-Red Yellow Podzolic transitional soils, to the typical Red Yellow Podzolic of the Brazilian system of soil classification (from profiles 1 to 6). A couple of Podzols (profiles 7 and 8) and a Red Yellow Podzolic - Podzol intergrade (profile 9), occurring as minor inclusions in the studied area, were also sampled.

<u>Plateau A</u>

Profiles 1 and 2 belong to plateau A (map 4). Both profiles are developed in a clayey parent material. The local vegetation is semi-evergreen tropical cerrado and the slope less than 1%.

The first profile (well-drained) was sampled in the uppermost part of the plateau area (summit), and the second (moderately well-drained) in the lowest segment of the landscape, at about 300 m from the former (see scheme A).

They respectively correspond to the typic Red Yellow Latosol (Typic Haplustox) and to the Red Yellow Podzolic latosolic (Tropeptic Haplustox) included in the soil mapping unit LVd5 (map 4).

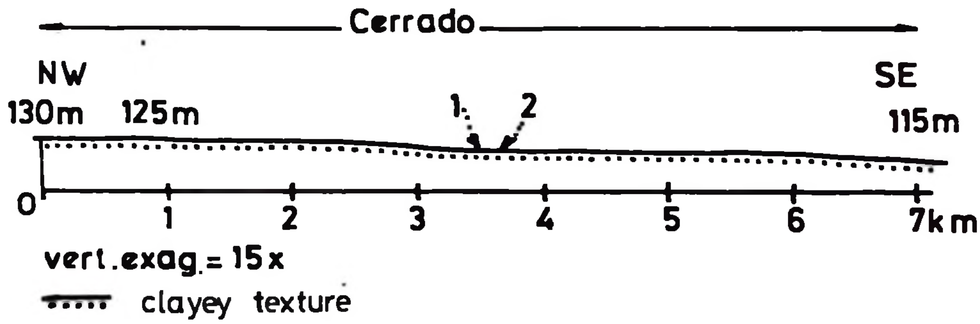
<u>Plateau B</u>

The profiles 4 and 5 are located on plateau B (map 4).They are formed on clayey original materials. The vegetation cover is semi-evergreen tropical forest and the slopes range from 1 to 3%.

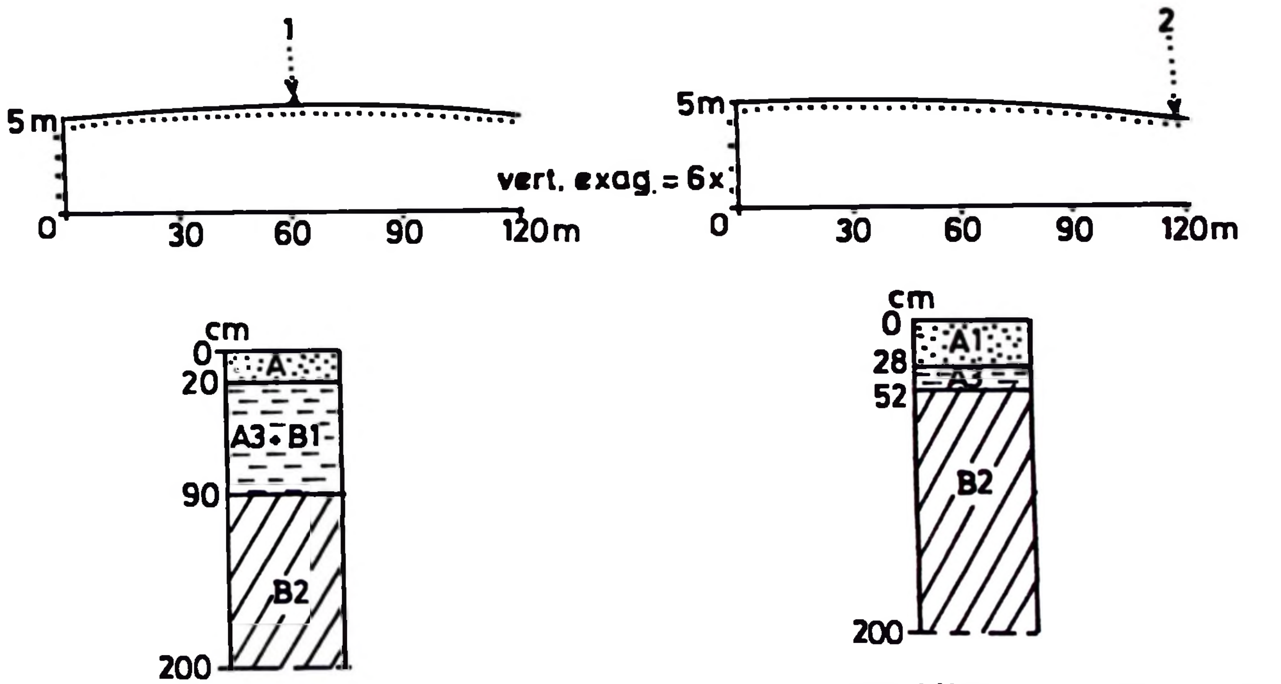
Profile 4 (well-drained) was sampled in the highest part of the relief, and profile 5 (moderately well-drained) in the bottom of an open drainage rill of about 70 cm depth, at 700 m from the first (see scheme B).

They respectively classify as Red Yellow Latosol podzolic (Oxic Paleustult) and typical Red Yellow Podzolic (Oxic Paleustult) included in the soil mapping unit LVd3 (map 4).

SCHEME A Topographic profile and vegetation



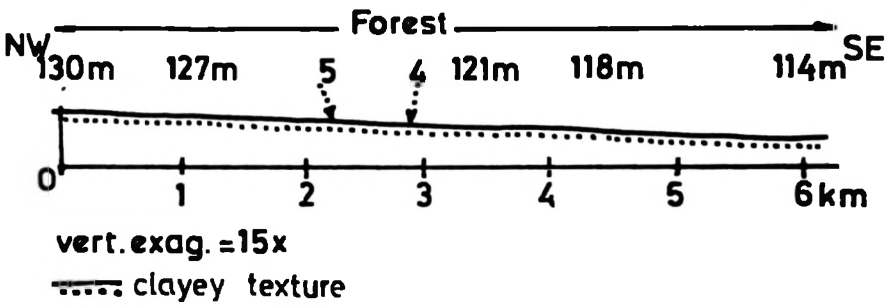
Topographic situation



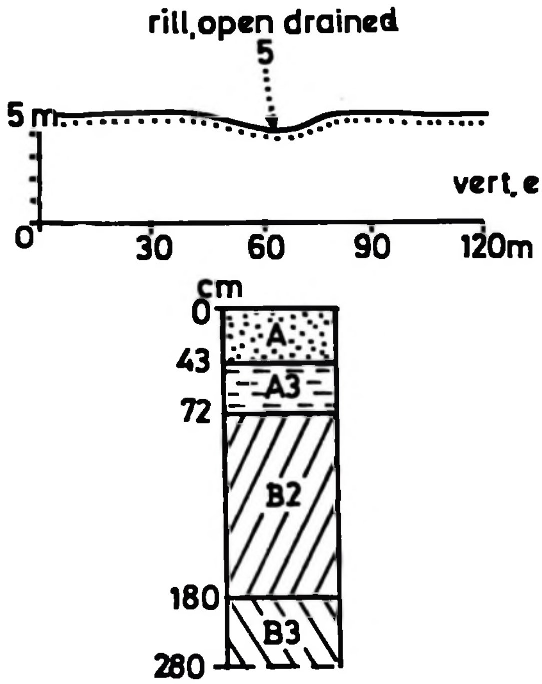
1_Typic Red Yellow Latosol
Typic Haplustox

2_Red Yellow Latosol,podzolic
Tropeptic Haplustox

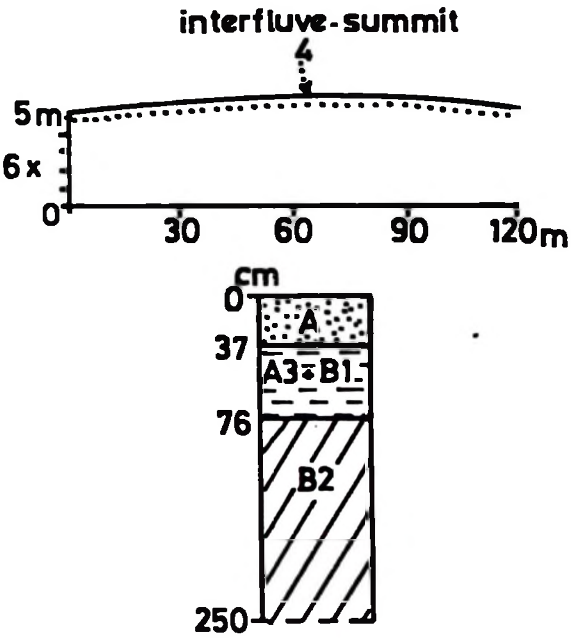
SCHEME B Topographic profile and vegetation



Topographic situation



5_Typic Red Yellow Podzolic
Oxic Paleustult



4_Red Yellow Latosol podzolic
Oxic Paleustult

Plateau C

Map 4 shows the location of profiles 6, 9, 7 and 8 on plateau C. The profiles 6 and 9 are both formed on clayey materials. The local vegetation is semi-evergreen tropical forest and the slopes are less than 2%. Profile 6 (well-drained to moderately well-drained) was sampled close to the uppermost segment of the relief (upper third) and profile 9 (mod. well drained) in a shallow close depression in the central part of the tableland (see scheme C). These profiles respectively classify as typical Red Yellow Podzolic (Oxic Paleustult) and as Red Yellow Podzolic-Podzol intergrade (Orthoxic Palehumult).

Profiles 7 and 8 are developed on sandy materials, the vegetation cover is cerrado and the slopes range from 0 to 1%. Both profiles (poorly drained) were sampled in a flat open depression located at the edge of the plateau and classify as Hydromorphic Podzols. According to Soil Taxonomy (1975), profile 7 is an Ultic, Arenic Tropaquod and profile 8 and Ultic, Aeric Tropaquods.

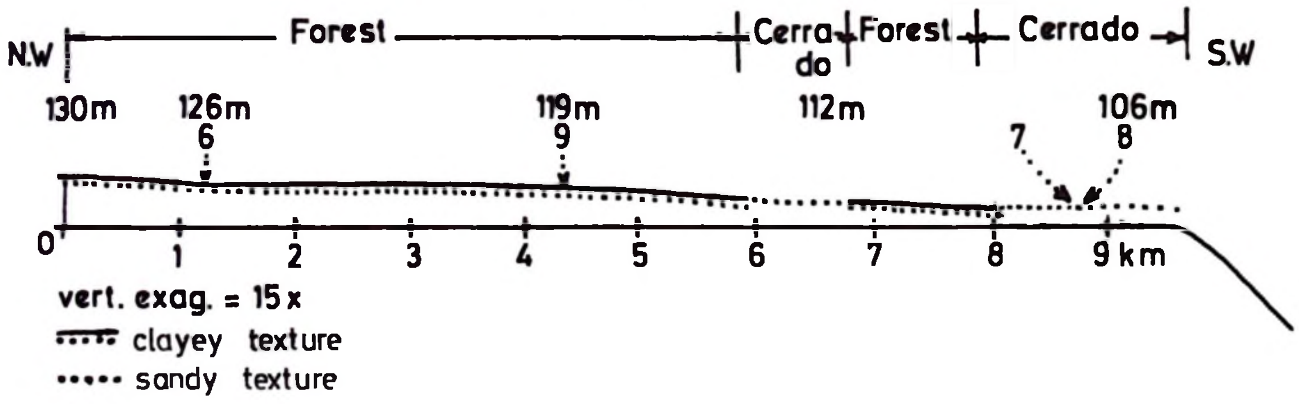
The soil classes corresponding to the profiles 7, 8 and 9, which occur as inclusions in the soil mapping unit LVd2, were excluded from the soil legend due to scale reasons. They were only reported in large scale soil maps (1/25,000).

Plateau D

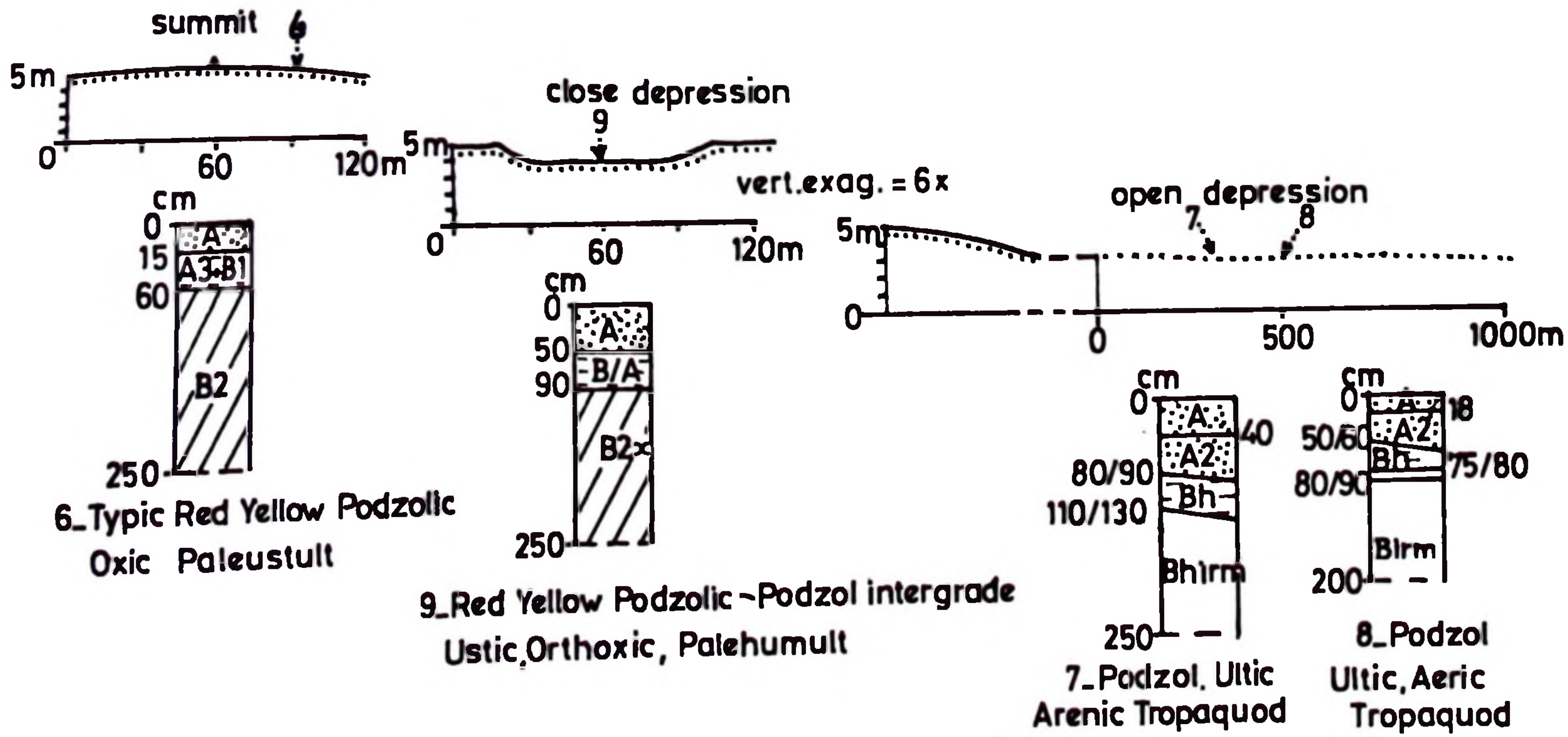
Profile 3 is located on plateau D (map 4). The parent material is clayey. The vegetation is semi-evergreen tropical forest and the slopes range from 0 to 2%.

This profile (well-drained to moderately well-drained) was sampled in the upper third sector of the relief (scheme D). It classifies as a Red Yellow Podzolic with fragipan (Oxic Paleustult) and constitutes the principal member included in the soil mapping unit PV16 (map 4).

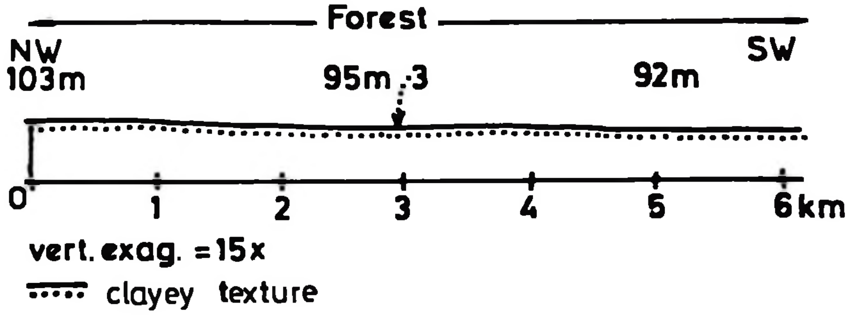
SCHEME C Topographic profile and vegetation



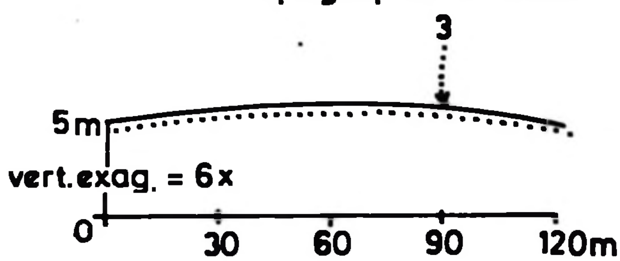
Topographic situation

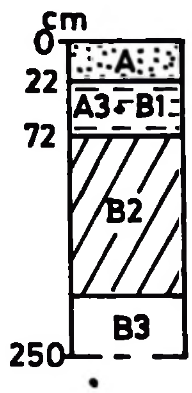


SCHEME D Topographic profile and vegetation



Topographic situation





3_ Typic Red Yellow Podzolic
Oxic Paleustult

CHAPTER 2 - MATERIALS AND METHODS

2.1. Materials

The materials used in this work include disturbed and undisturbed samples of the horizons forming the soils selected for this study.

Type of samples : a) bulk samples for physico-chemical, mineralogical and sedimentological analyses, and b) undisturbed samples in Kubiena boxes for the micromorphological study. All samples were taken from freshly dug pits.

2.2. Morphological descriptions

The morphological descriptions of the profiles were made according to the FAO "Guidelines for soil descriptions". The master horizon nomenclature was also presented according to the norms established by the Soil Survey Manual (1981).

2.3. Physico-chemical analyses

The physico-chemical characterization was carried out at the laboratory of the Geological Institute of the Ghent State University (Belgium), including the following determinations :

2.3.1. Organic carbon

Organic carbon was determined by wet combustion using potassium dichromate and sulfuric acid according to Walkley and Black, using one gram of ground soil sample. The carbon present as organic compound in the soil was estimated by oxidizing it with known excess of a solution of potassium dichromate in concentrated sulfuric acid, and back-titrating the unconsumed dichromate with a standard solution of ferrous ammonium sulphate using diphenylamine as an indicator.

2.3.2. Particle size distribution

The mechanical analysis has been carried out by the successive sedimentation method. The elementary particles were dissociated according to the following procedure : a) oxidation of the organic matter by hydrogen peroxide; b) destruction of ligands due to sesquioxides with diluted hydrocloric acid; c) dispersion with sodium hexametaphosphate. The fractions larger than 50μ were separated by sieving into very coarse sand (2-1 mm), coarse sand (1-0.5 mm), medium sand (0.5-0.25 mm), fine sand (0.25-0.1 mm) and very fine sand (0.1-0.05 mm). Clay contents were determined by difference.

2.3.3. Quantitative determination of the coarse and fine clay contents

The coarse (2-0.2μ) and fine (<0.2μ) clay contents were determined according to Jackson (1956). For the separation of the fine clay the centrifuging time was calculated using the following formula :

$$tm = \frac{63.0 \times 10^8 \; n \; \log_{10} R/S}{(Nm)^2 \quad (Dn)^2 \quad (AS)}$$

n = viscosity

R = distance from the ax of the centrifuge to the bottom of the tube (29 cm)

S = R - 10 cm = 19 cm

Nm = r.p.m. = 2000

Dm = particle size in μ (0.2μ)

AS = 2.65 - 1 = 1.65

tm = 43 min. 39 sec.

2.3.4. Soil reaction

The pH value has been measured by means of a pH meter using a glass electrode. The measurements were determined in a

1:1 soil-water and 1:1 soil-KCl 1N ratios, after equilibration for one day.

2.3.5. Exchangeable bases

Exchangeable bases are the bases present in the NH_4OAc solution, from the CEC determination method; Ca, Mg, K and Na were all determined by atomic absorption spectrophotometer.

2.3.6. Cation exchange capacity (CEC)

The cation exchange capacity was determined by displacement of all the cations with a buffer solution of NH_4OAc at pH 7.0.

The cation exchange capacity, by sum of cations, was estimated by adding exchangeable bases to the extractable acidity (KCl-TEA pH 8.2).

2.3.7. Base saturation

The sum of bases was respectively expressed in per cent of CEC (NH_4OAc) and CEC by sum of cations. The values were approximated to the nearest whole number.

2.3.8. Extractable acidity

A 5 grams sample in a glass centrifuge tube containing 50 ml KCl-TEA at pH 8.2 solution was put on a shaker for 30 minutes. The solution was then filtered under suction in a Buchner funnel. This was followed by 4 times leaching with 10 ml KCl. The leachate was latter transferred to a 100 ml flask and was filled up to the mark with KCl solution. A 25 ml aliquot was finally titrated to pH 4.5 with 0.05 N HCl. A blank was run for each series.

2.3.9. Extractable aluminum

Extraction by leaching with 1N KCl solution. Aluminium was determined by atomic absorption spectrophotometer.

2.3.10. Bulk densities

The bulk densities were determined by the clod method (Black, 1965) in triplicate samples. The clods were weighed in the air, then covered with paraffin and weighed again in the same way. In the next step the paraffin covered clods were weighed in water at controlled temperature. Finally correction due to the moisture content of the clod is made. The applied formula is the following:

$$B.D. = \frac{dw\ Wods}{\left[Wsa - Wspw + Wpa - \left(\frac{Wpa - dw}{dp} \right) \right]}$$

B.D. = bulk density of the soil

dw = density of water

Wods = water content $\dfrac{Wsa}{1 + \left[\frac{P}{100}\right]}$

Wsa = weight of soil in the air

Wsp = weight of soil plus paraffin in the air

Wspw = weight of soil plus paraffin in water

dp = density of paraffin

Wpa = weight of paraffin in the air

2.4. Taxonomy classification

The soil profiles included in this study were classified according to the following systems :

4.1. USDA Soil Taxonomy (1975).

4.2. FAO/UNESCO system.

4.3. INEAC system.

4.4. BRAZILIAN system.

2.5. Sedimentological study

Besides the routine mechanical analysis, and in order to detect possible sedimentological anomalies in the soil forming materials, a detailed granulometrical study of the sand fraction was carried out for all the soil horizons not affected by plowing. The fractions larger than 63μ were separated by sieving, previous destruction of organic matter. The sand fraction was latter treated with a concentrated hydrochloric acid (2N) solution, and let stand overnight at 70-80°C. The solution was poured out, and the sand washed and dried. The sand fraction (63-2000μm) obtained, was next divided in ten fractions by means of an appropriate set of sieves. The percentages of the fractions and their cumulative values were calculated.

From these data and with the aid of adequate computation programs, the mean, standard deviation, skewness and kurtosis were calculated for the sand distribution of each sample. The results were expressed in phi-units, where $\phi = -\log_2$ (diameter in mm).

The parameters were calculated by applying the following formulas (Friedman, 1962) :

$$\overline{X} = \frac{\Sigma f m\phi}{100} \qquad \text{mean}$$

$$\sigma 1 = \left[\frac{\Sigma f (m\phi - \overline{X}\phi)^2}{100}\right]^{\frac{1}{2}} \qquad \text{standard deviation}$$

$$\alpha 3 = \frac{1}{100} \cdot 6^{-3} \, \Sigma f (m\phi - \overline{X}\phi)^3 \qquad \text{skewness}$$

$$\alpha 4 = \frac{1}{100} \cdot 6^{-4} \, \Sigma f (m\phi - \overline{X}\phi)^4 \qquad \text{kurtosis}$$

2.6. Comparative particle size distribution (CPSD) index

The comparative particle size distribution index is the sum of the minimum values of the percentages of the particle size fractions in two samples (Langohr, R. et al., 1976). It corresponds to the area simultaneously covered by two histograms constructed from granulometrical data. An index of 100 indicates that the compared samples have identical particle size distributions, and an index of 0 indicates that the distributions do not overlap at all. Tests on duplicate samples carried out by Langohr, R. and Van Vliet, B. (1979) have shown that a CPSD index of 94-100 does not cover the sampling and analytical errors. Therefore, an index of 94 or more attests for an extremely high similarity. Between 90 and 94 the index points the samples which are very similar and between 85 and 90 the similarity can be considered to be still high.

2.7. Mineralogical analysis

The mineralogical analysis was carried out on the sand (50-250μ) and clay (<2μ) fractions. In order to study them weighed amounts of separate fine earth samples were employed and treated as follows.

2.7.1. Separation of the sand (>50μ) and clay (<2μ) fractions

2.7.1.1. Sand fraction

2.7.1.1.1. The sand fraction (50-250μ) resulting from the routine mechanical analysis was washed with 1N citric acid under ultrasonic treatment to facilitate the removal of grain coatings. This was followed by another washing with distilled water. The sand was dried in an air oven at 100°C and weighed. The heavy and light fractions were separated by bromoform (S.G. = 2.85), washed with alcohol, weighed and expressed as percentages of the total sand fraction. The heavy minerals were mounted on glass slides in Canada balsam (n = 1.537) at a temperature of 70-75°C.

The counting was done line by line, and each mineral (including opaques) occurring under the cross was identified and counted until the total number of grains reached 100. This was followed by an inventory of transparent minerals also until 100. The results thus obtained were recalculated and expressed as percentages.

2.7.1.1.2. The light minerals were mounted on glass slides with Vulsa Pol. resin and allowed to harden during two weeks. The material thus hardened was then ground with carborundum (600, 800, 1000) till obtaining gray first order colors for the quartz grains (more or less 30µ thickness). The surface of the light minerals was etched with hydrofluoric acid for 30 seconds and then rinsed with water. Next, they were successively treated with a saturated solution of cobaltinitrite and sodium rhodizonate (0.5 g in 20 ml water), in order to stain calcic and potassic feldspars respectively with red and yellow colors. Countings were not done, due to the scarcity of feldspars present.

2.7.1.2. Clay fraction

2.7.1.2.1. Particle size separation of the clay fraction

The fine earth was treated with H_2O_2 30% until all the organic matter was destroyed. The fraction <2µ was separated by dispersion with a solution of Na_2CO_3 2% at pH 9.0-9.5. After allowing to settle for 8 to 8.5 hours, the clay was separated by siphoning and flocculated at pH of about 6.0 by adding a solution of HCl 2% and NaCl. The clays were then washed free of the dispersing and flocculating agents using alcohol and acetone and distilled water until the washing liquid showed free of chloride. The clays were then dried, powdered and stored in test tubes. Chloride free samples from selected horizons of each profile were X-rayed. These samples were referred as untreated samples.

2.7.1.2.2. Mineralogical determination of clay minerals

The mineralogical determination of the clay minerals was carried out through the following procedures.

2.7.1.2.2.1. Removal and determination of iron and aluminum oxides

For iron and aluminum removal the citrate-dithionite method (Mehra and Jackson, 1960) was used with modifications by De Coninck et al. (1969). Citrate buffer (pH 7.3) was added to the samples followed by heating to 75-80°C for 15 minutes under continuous storring, previous addition of dithionite.

The determination of free iron and aluminum oxides was made with the aid of an atomic absorption spectrophotometer apparatus.

2.7.1.2.2.2. X-Ray diffraction

The X-ray diffractometric study in order to identify the clay minerals was carried out with a Philips apparatus, 40 Kv, 20 mA, with a $Cu_{\alpha}K$ radiation (A = 1.54 Å), Ni filter, lateral source 6° and a register velocity of 2°2θ/min. The divergent slit was 1°, the receiving slit 0.1 min. with 2^3 attenuation and range 400.

2.7.1.2.2.3. Differential thermal analysis (D.T.A.)

The differential thermal analysis was applied to samples previously studied by X-ray diffraction.

The diagrams were obtained by means of a Dupont thermal analyser 900 apparatus. Natural samples of about 20 mg were used, and subjected to temperature variations ranging from room temperature up to 800°C. The heating rate was 15°C/min. and the analysis was done in the air and in a N2 atmosphere, having Al_2O_3 as a standard.

2.7.1.2.2.4. Thermo-gravimetric analysis (T.G.A.)

The thermo-gravimetric analysis was applied to samples already studied by X-ray diffraction and differential thermal analysis.

A Dupont 950 thermo-gravimetric analyser was employed, and natural samples of about 20 mg were used. The samples were heated in the air from room temperature up to 900°C, with a heating rate of 15°C/min.

2.8. Micromorphology

2.8.1. Sampling and preparation of thin sections

Samples for micromorphological studies were obtained from undisturbed soil materials by means of Kubiena boxes. These samples were air dried and then impregnated under vacuum using Vulga polyester resin (Trade Mark TRA) with cobalt octoate (NL 49,1%) as accelerator and cyclohexanoneperoxide (Interox, 30% solution) as catalyst.

2.8.2. Description and point counting

The study of the thin micromorphological sections was performed with a Leitz petrographic microscope. The description of microstructure and porosity pattern, the fine and coarse materials of the soil matrix as well as their related distribution pattern, and the birefringence fabric of the fine material were done following Stoops and Jongerius (1975) and Stoops (1978). The pedological features were described according to Brewer (1964) and Stoops (1985, per. comm.)

The quantitative micromorphological analysis was made by point counting and up to 1200 points per thin section, with the aid of a special counting ocular.

The clay illuviation for the horizon and the profile clay illuviation indices were calculated according to Midema and Slager (1972), with modifications of Stoops (1978).

CHAPTER 3 - STUDIED SOILS, CHARACTERIZATION AND CLASSIFICATION

GEOMORPHOLOGICAL UNIT : PLATEAU A

3.1. Profile 1

I. Information of the site

Date of examination : 15/3/80
Author : D. Barrera
Location : 700 m W from km 12 of Maceio-Recife highway.
Approx. 35°44'W, 9°34'S
Elevation : 120 m
Land form : 1) physiographic position : plateau (see scheme A)
2) Microtopography : very slightly undulated
Slope : class 1 (0-1%)
Land-use : sugarcane (monoculture).

II. Information of the soil

Parent material : clayey sediments
Geological formation and lithology : Barreiras Group. Tertiary sediments.
Drainage : class 4 : well-drained.
Moisture conditions in profile : moist throughout
Depth of watertable : perched watertable at 160 cm depth
Presence of surface stone; rock outcrops : none.
Human influence : confined to plow layer.
Vegetation : semi-evergreen tropical cerrado.

3.1.1. Morphological description

The soil is deep, well-drained, yellowish brown, strickingly uniform throughout, especially when moist. The

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Drainage : class 4 : well-drained.
Moisture conditions in profile : moist throughout
Depth of watertable : perched watertable at 160 cm depth
Presence of surface stone; rock outcrops : none.
Human influence : confined to plow layer.
Vegetation : semi-evergreen tropical cerrado.

3.1.1. Morphological description

The soil is deep, well-drained, yellowish brown, strickingly uniform throughout, especially when moist. The structure is weak up to 160 cm depth, becoming moderate downwards. When dry, the consistence is hard to very hard in the Ap, A3 and B1 horizons. Roots are concentrated in the top 20 cm.

<u>Ap - 0-20 cm</u>. Dark brown (10 YR 3/3) moist and grayish brown (10 YR 5/2) dry; sandy clay loam; strong fine-medium granular; hard dry, friable moist, slightly plastic and slightly sticky wet; many fine and very fine pores; abundant fine roots; clear smooth boundary.

<u>A3 - 20-45 cm</u>. (AB) Yellowish brown (10 YR 5/4) moist, and pale brown (10 YR 7/4) dry; sandy clay; weak fine subangular, breaking into strong fine medium granular; very hard dry, friable moist, slightly plastic and slightly sticky wet; common fine pores; many fine roots; diffuse smooth boundary.

<u>B1 - 45-90 cm</u>. (BA) Yellowish brown (10 YR 5/8) moist, and yellow (10 YR 7/6) dry; sandy clay; weak fine subangular blocky breaking into weak fine-medium granular; hard dry, friable moist, slightly plastic and sticky wet; many fine pores; common roots; diffuse smooth boundary.

<u>B21 - 90-160 cm</u>. (B1) Brownish yellow (10 YR 6/8) moist, and yellowish brown (10 YR 5/8) dry; clay; few fine medium faint, diffuse, reddish yellow (5 YR 7/8) irregular mottles; weak to moderate fine-medium subangular blocky breaking into strong fine medium crumbly, slightly hard, dry, friable moist, plastic and sticky wet; many fine pores; common roots; clear smooth boundary.

<u>B22 - 160-200 cm</u>. (B2) Reddish yellow (7.5 YR 6/8) moist and strong brown (7.5 YR 5/8) dry; clay; few fine-medium faint distinct sharp, dark red mottles (2.5 YR 3/6); moderate fine-medium subangular blocky, breaking into strong fine medium granular; slightly hard dry, friable moist, plastic and sticky wet; common fine pores; common roots.

<u>Remarks</u> : a) The Ap horizon shows clear compaction.

b) Presence of Krotovinas in the B22 horizon.

( ) Horizon's nomenclature according to the Soil Survey Manual (1981).

3.1.2. Physico-chemical properties (see table 5)

The clay content gradually increases with depth from 38.6% in the Ap reaching its maximum in the B22 (58.6%). The sand fraction follows also a gradual but opposite trend from the top soil downwards, with 59% in the Ap and 38.0% in the B22. The medium and fine sand make up the greater proportion of the total sand fraction. The silt fraction is present in extremely low amounts (2.0-3.0%).

The silt/clay ratios are very low ranging from 0.04 in A3 and B21 to 0.06 in the Ap horizon, indicating extreme degree of weathering.

Bulk densities increase markedly in the top soil, with values ranging from 1.4 g/c.c. in the B2, to 1.7 g/c.c. in the Ap horizon.

The nutrient status for plant growth is very low. The cation exchange capacity per 100 grams of soil is uniform throughout and varies between 4.0 meq. and 4.7 meq. Exchangeable aluminum is low, with highest figures in the A3 (0.5 meq.) horizon, declining gradually with depth to reach 0.16 meq. in B22, and strongly decreasing in the overlaying Ap (0.22 meq.).

Base saturation is highest in the Ap horizon (28.0%) and lowest in the underlaying A3 (16.2%), increasing with depth to reach figures about 23.0% in the subsoil. Exchangeable contents of Ca, Mg, K, and Na are very low, being highest in the Ap and lowest in the A3.

The organic carbon content is highest in the Ap horizon (0.84%) and decreases gradually with depth.

The pH is very low and varies from 4.2 (pH/KCl) in the upper horizons to 4.7 in the subsoil.

Table 5. Physico-chemical properties of profile 1

Depth (cm)	Horizon	Size class and particle diameter (mm)								
		TOTAL			SAND					COARSE FRAGM.
		Sand	Silt	Clay	V.C.	C.	M.	F.	V.F.	> 2 mm
		2-0.05	0.05-0.002	< 0.002	2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	
0- 20	Ap	59.0	2.4	38.6	2.2	11.2	21.4	20.4	3.8	0
- 45	A3	52.7	2.0	45.3	1.1	10.4	20.4	16.8	4.0	0
- 90	B1	47.5	2.8	49.7	1.2	10.0	18.0	15.0	3.2	0
-160	B21	39.8	2.5	57.7	1.1	7.3	14.8	12.6	4.0	0
-200	B22	38.4	3.0	58.6	1.1	9.0	13.9	11.5	2.9	0

Depth (cm)	Organic carbon %	pH 1:1 KCl	pH 1:1 H_2O	Ext. Fe as Fe_2O_3 %	Ext. Al as Al_2O_3 %	Bulk density g/cm³	Silt/clay ratio	Coarse clay 2-0.2µ	Fine clay < 0.2µ	Fine clay/Tot. clay
0- 20	0.84	4.3	4.5	1.09	0.52	1.70	0.06	8.5	30.1	0.77
- 45	0.62	4.2	4.3	1.41	0.75	1.59	0.04	9.9	35.4	0.78
- 90	0.38	4.4	4.9	1.47	0.76	1.42	0.05	15.5	34.2	0.68
-160	0.32	4.5	4.8	2.02	0.85	1.42	0.04	22.8	34.9	0.65
-200	0.16	4.7	5.2	2.21	0.93	1.45	0.05	18.7	39.9	0.68

Depth (cm)	Extractable bases					Al 1NKCl	Extr. acidity KCl pH 8.2	C.E.C.				Base saturation (%)	
	Ca	Mg	K	Na	Sum			NH_4OAc	sum cations	NH_4OAc	E.C.E.C.	NH_4OAc	Sum cations
	meq./100g soil							meq./100g soil		meq./100g clay			
0- 20	0.51	0.22	0.31	0.12	1.16	0.22	4.2	4.1	5.36	10.6	3.57	28.0	21.6
- 45	0.28	0.11	0.16	0.10	0.65	0.50	4.0	4.0	4.65	8.9	2.53	16.2	14.0
- 90	0.40	0.22	0.10	0.07	0.79	0.34	3.5	4.0	4.29	8.9	2.77	19.7	18.0
-160	0.43	0.45	0.18	0.06	1.12	0.24	2.8	4.7	3.92	8.1	2.35	23.8	28.0
-200	0.32	0.52	0.03	0.07	0.94	0.16	2.3	4.1	3.24	7.0	1.87	22.9	29.0

3.1.3. Mineralogical composition

3.1.3.1. Sand fraction (50-250 µm)

In the sand fraction the light minerals are dominant, making 94 to 97 per cent (weight %) of the total sample in the different soil horizons.

The light fraction is composed of fissured and highly weathered quartz grains and no more than traces of feldspars (table 6). The heavy fraction includes mainly opaques (where magnetic minerals are the most frequent). X-ray analysis showed that the opaque minerals consist of magnetite, ilmenite, hematite and goethite. Among the transparent minerals zircon is dominant, followed by very low amounts of tourmaline and the occasional presence of rutile.

Table 6 . Mineralogical composition of the sand fraction (50-250µm) of profile 1

Hor.	Depth (cm)	Light minerals		Heavy minerals			
		Quartz	Feldspars	Opaques	Zircon	Tourma-line	Rutile
Ap	0- 20	100	-	88.2	10.2	1.0	tr.
A3	- 45	100	-	92.1	7.3	1.0	tr.
B1	- 90	>99	tr.	91.7	7.9	1.0	tr.
B21	-160	100	-	91.7	7.1	1.0	tr.
B22	-200	>99	tr.	90.0	9.7	1.0	tr.

tr. (traces) = <1%

3.1.3.2. Clay fraction (<2µm)

On the bases of X-ray reflexion intensities (fig. 2) kaolinite is the dominant mineral of the clay fraction in all horizons, followed by minor amounts of gibbsite, which as shown in table 7, is not apparent in horizon B1.

Table 7 also shows that these results are confirmed through D.T.A. and T.G.A. X-ray diffractograms also indicate the occurrence of anatase.

Table 7 . Mineralogical composition of the clay fraction (<2µm) of profile 1

Hor.	Depth (cm)	Clay fraction		
		X-ray	D.T.A.	T.G.A.
A3	20- 45	K, G, A	K	K5, G1
B1	- 90	K	-	K5, G1
B22	-200	K, G, A	K, G	K5, G1

Mineral code : K : kaolinite; G : gibbsite; A : anatase. Approx. weight fractions (T.G.A.) : 5 : more than half; 4 : half to one third; 3 : one third to one fifth; 2 : one fifth to one twentieth; 1 : less than one twentieth.

3.1.4. Sedimentology

The detailed particle size distribution of the fractions between 63 and 2000µ for A3, B1, B21 and B22 horizons which are considered without possibility of migration, or subjected to significant changes during soil forming processes, is given in table 8.

The cumulative frequencies were calculated for all fractions between 63 and 2000µm.

Tables 9 and 10 give respectively the cumulative frequencies of the fractions between 63 and 2000µm and the most important sedimentological parameters.

The cumulative curves plotted on probability scale are presented in fig. 5.

It can be observed that the A3 horizon shows an almost symmetrical, negatively skewed ($\alpha 3 = -0.04$) and platykurtic ($\alpha 4 = 0.61$) distribution curve, with a Mz value of 1.69 ϕ; the standard deviation ($61 = 0.9$) indicates that the material is moderately sorted (Friedmann, 1962).

The B1 horizon has also a nearly symmetric, negatively skewed ($\alpha 3 = -0.01$) and platykurtic ($\alpha 4 = 0.35$) distribution with a Mz value of 1.64 ϕ and a standard deviation of 0.92.

The B21 horizon shows a moderately asymmetrical, positively skewed ($\alpha 3\ \phi = 0.18$) platykurtic ($\alpha 4\ \phi = 0.17$) distribution; the mean Mz value is 1.63 ϕ and the standard deviation ($G1 = 0.95$) indicates a moderately sorted material.

The distribution curve of the B22 horizon is moderately asymmetric ($\alpha 3\ \phi = 0.23$) positively skewed, platykurtic ($\alpha 4 = 0.59$), with a Mz of 1.62 ϕ; a moderate sorting is indicated by a standard deviation of ($G1\ \phi = 0.93$).

Therefore, the profile under discussion may be considered as highly uniform from sedimentological viewpoint.

3.1.5. Micromorphology

A. Microstructure and pore pattern

The microstructure of the A3 horizon is mostly strong fine crumbly; the crumbs (1-2 mm ϕ) have fissured and vughy cavited intrapedal m.s. Very frequent interpedal compound packing pores are dominant; smooth and rough vughs mostly interconnected, smooth channels and fissures are also very frequently present.

In B1 the microstructure is dominantly spongy, with fissured and vughy cavited intrapedal m.s., that locally grades to 1) weak fine crumbly and to 2) weak very fine

Table 8 . Particle size distribution of the fractions between 63 and 2000μm

	1400 -2000	1000 -1400	710 -1000	500 - 710	355 - 500	250 - 355	180 -250	125 - 180	90 - 125	63 - 90
A3	0.0	2.9	5.87	17.6	17.6	22.4	15.6	12.6	5.8	1.46
B1	1.05	2.1	6.8	15.8	18.9	21.1	15.8	11.6	5.2	2.1
B21	1.2	2.4	5.9	15.5	18.8	25.9	9.4	10.6	6.0	3.6
B22	0.0	2.6	7.8	18.1	18.0	19.5	14.2	10.4	6.5	2.6

Table 9 . Cumulative frequencies of the fractions between 63 and 2000μm

	>1400	>1000	>710	>500	>355	>250	>180	>125	>90	>63
A3	0.0	2.9	8.8	25.4	43.0	64.4	80.0	92.6	98.5	99.5
B1	1.05	3.15	9.5	25.3	44.2	65.3	81.1	92.7	97.9	100.0
B21	1.2	3.6	9.5	25.0	43.8	69.7	79.1	89.7	95.7	99.3
B22	0.0	2.6	10.4	28.5	46.5	66.0	80.2	90.6	97.1	99.7

Table 10. Sedimentological parameters of the fractions between 63 and 2000μm

	Mz	1σ	3α	4α
A3	1.69	0.9	-0.04	0.61
B1	1.64	0.92	-0.01	0.35
B21	1.63	0.95	0.18	0.17
B22	1.62	0.23	0.23	0.59

crumbly; showing a pore pattern similar to the upper and lower soil horizons.

The B21 presents 1) weak crumbly microstructure with fissured and vughy cavited intrapedal m.s., and 2) moderate to weakly crumbly microstructure with fissured intrapedal m.s., where both types (1 and 2) grade to spongy. The pore pattern is similar to the overlaying horizons.

The lowermost B22 mostly shows a moderate crumbly microstructure; the crumbs (0.5-1.5 cm ø) have a fissured and vughy cavited intrapedal m.s. Locally it grades to spongy, with similar intrapedal m.s. The pore pattern is similar to the overlaying horizon.

Channel infillings are throughout observed, and mostly show weak and moderate very fine crumbly intrapedal m.s. Compound packing pores and fissures are dominant and respectively occupy interpedal and intrapedal positions.

B. Matrix

B1. Coarse material (>5µm)

Fine to coarse, sand-sized, angular, subangular and subrounded grains of quartz compose the coarse material throughout. The medium and coarse fractions present fissured and corroded grains. Runiquartz is common in all horizons and the infilling material - dark red - contrasts with the matrix color, except in the A3 horizon.

B2. Fine material (<5µm)

It is very pale brown, dotted in A3, yellowish in B1 and B21 and reddish yellow dotted in B22, composed of clay, oxihydrates and organic matter. The b-fabric pattern is very similar throughout where the undifferentiated type dominates. Dotted, parallel, striated and circular striated b-fabrics are subordinated and generally weakly expressed. The channel infillings present undifferentiated b-fabric.

B3. Coarse/fine related distribution

Single and double spaced gefuric to enaulic is dominant in A3, locally porphyric. In B1 mainly porphyric, with single and double spaced gefuric between big grains. In the lower B21 and B22 porphyric dominates and gefuric is locally present.

In channel infillings, the dominant type is enaulic; also gefuric is locally observed.

C. Organic matter

Organic matter is observed in the upper horizons as slightly and highly humified roots (o) and as fecal pellets (o).

D. Features

Coatings and infillings of limpid clay ranging from <10µm to 1 mm ø, occur in fissures, vughs and channels throughout the soil. They have a yellow color, strong continuous orientation and sharp boundaries.

Laminated coatings and infillings of limpid and speckled clay (from 30µm to 1 mm ø) occur in channels, vughs and packing pores. The color is yellow, the orientation strong and the boundaries are sharp.

Coatings and infillings of iron-rich clay, having 30µm ø, occur in vughs of the B21 horizon. They have a reddish color, a strong continuous orientation and sharp boundaries.

Fragments of clay coatings (0.2-0.5 mm ø), with strong and diffuse boundaries, occur in the fine mass and inside channel infillings.

Iron oxihydrate soil nodules of red color, rounded, ranging from 100 to 500µm, with sharp and diffuse boundaries, are frequent in the B1, B21 and B22 horizons.

Compounds nodules of red color, rounded (5-7 mm ø), with sharp boundaries, were observed in the B22 horizon. The coarse material includes quartz grains and runiquartz, and the fine material is composed of iron-rich clay. The related distributions are porphyric, similar to the enclosing soil matrix or showing a contrasting denser packing of the coarse material.

F. Quantification of illuviation features

The point counting results presented in table 11 show maximum illuviation percentages in the B22 (3.1%) and B24 (3.2%) horizons. The degree of clay illuviation is strong in B22, moderate in B21 and B24, and weak in other horizons, and the profile illuviation index is moderately high (343.3) as shown in table 12.

3.1.6. Classification

Although this profile has a dark Ap horizon, it is not thick enough to be umbric, and thus is an ochric epipedon. No clay skins were discerned in the field and the required clay increase for an argillic horizon is not met in spite of thin section showed 2.7% illuviation cutans in the horizon B22 as shown in table 11. On the other hand, the subsoil has the properties of an oxic horizon throughout. Therefore, the profile is classified as a member of the clayey, kaolinitic, isohyperthermic family of the TYPIC HAPLUSTOX.

Table 11 . Quantitative micromorphological analysis of soil components (by point counting) in volume per cent of total soil

Depth (cm)	Horizon	Pores	Coarse material	Fine material	Coatings	Frag.of coatings	Nodules
20- 45	A3	29.0	18.0	52.9	tr.	0.10	
- 90	B1	19.6	23.7	55.5	0.94	0.17	
-160	B21	25.4	21.9	51.8	0.60	0.28	
-200	B22	25.2	20.8	50.5	2.71	1.12	0.6

Table 12 . Degree of clay illuviation per horizon and profile clay illuviation index

Horizon	Thickness (cm)	% in situ + translocated illuviation features (on solid phase)	Degree of illuviation
A3	25	0.14	negligible
B1	45	1.38	moderate
B21	70	1.17	weak
B22	40	5.06	strong

Profile clay illuviation index = 349.9 per cent cm. Moderately high.

CLASSIFICATION ACCORDING TO OTHER SYSTEMS

FAO/UNESCO : Xanthic Ferralsol
BRAZILIAN SYSTEM : Red Yellow Latosol Dystrophic, moderate A horizon, clayey, semi-evergreen tropical cerrado, level phase
I.N.E.A.C. SYSTEM: Hygro-xero Ferralsol.

3.2. Profile 2

I. Information of the site

Date of examination : 17/3/80
Author : D. Barrera
Location : 250 m W from km 12 of Maceio-Recife highway. Approx. 35°44'W, 9°34'S.
Elevation : 120 m
Land form : 1) physiographic position : plateau (see scheme A)
2) microtopography : very slightly undulated
Slope : class 1 (0-1%)
Land-use : virgin soil

II. Information of the soil

Parent material : clayey sediments
Geological formation and lithology : Barreiras Group. Tertiary sediments.
Drainage : class 3-4 : well-drained - Moderately well-drained.
Moisture conditions in profile : dry throughout.
Depth of watertable : perched watertable between 45 and 60 cm depth
Presence of surface stone, rock outcrops : none.
Human influence : none.
Vegetation : semi-evergreen tropical cerrado.

3.2.1. Morphological description

It is a well-drained to moderately well-drained yellowish brown profile, rather uniform in aspect, particularly when moist. Structure is weak in the topsoil, moderate and moderate to strong in the upper part of the subsoil, becoming moderate with depth. Cohesion is particularly high when dry in the topsoil. Root penetration is poor, with roots concentrated in the upper 15 cm.

A1 - 0-30 cm. (A) Dark brown (10 YR 3/3) moist, grayish brown (10 YR 4/2) dry; sandy clay; very weak fine subangular blocky breaking into strong fine-medium crumbly; hard dry, friable moist, slightly plastic and sticky wet; many fine pores; abundant fine roots; gradual smooth boundary.

A3 - 30-45 cm. (B1 or AB) Yellowish brown (10 YR 5/4) moist, light yellowish brown (10 YR 6/4) dry; clay; weak medium subangular blocky breaking into moderate fine medium crumbly; hard dry, firable moist, slightly plastic and sticky wet; common-many roots; clear smooth boundary. Few, distinct, diffuse light red (2.5 YR 6/8) mottles.

B21 - 45-60 cm. (Bt1) Yellowish brown (10 YR 5/6) moist and light yellowish brown (10 YR 6/4) dry; clay; common, fine, prominent, sharp, red (2.5 YR 4/8) mottles; moderate, medium, subangular blocky breaking into moderate fine-medium, crumbly; very hard dry, friable firm moist; plastic and sticky wet; common roots; diffuse smooth boundary.

B22 - 60-100 cm. (Bt2) Yellow (10 YR 7/6) moist, and very pale brown (10 YR 8/4) dry; clay; moderate-strong, medium-coarse, subangular blocky breaking into moderate medium crumbly; hard dry, friable-firm moist, plastic and sticky wet; common very fine roots; diffuse smooth boundary.

B23 - 100-130 cm. (Bt3) Yellow (10 YR 7/6) moist, and very pale brown (10 YR 7/4) dry; clay; moderate medium-coarse subangular blocky breaking into moderate fine medium crumbly; hard dry, friable firm moist, plastic and sticky wet; few very fine roots; diffuse smooth boundary.

<u>B24 - 130-160 cm.</u> Yellowish brown (10 YR 5/6) moist, and
(Bt4) yellow (10 YR 7/6) dry; clay; moderate medium-coarse subangular blocky breaking into moderate fine-medium crumbly; hard dry, friable moist, plastic and sticky wet; few very fine roots; gradual smooth boundary.

<u>B3 - 160-200 cm</u>. Reddish yellow (7.5 YR 6/8) moist, and
(BC) pink (7.5 YR 7/4) dry; clay; moderate fine crumbly; slightly hard dry, very friable moist, plastic and sticky wet; very few fine roots.

<u>Remarks</u> : a) cracks when dry, from the top up to the upper part of the B23(t) horizon.

b) ( ) horizon's nomenclature according to the Soil Survey Manual (1981).

3.2.2. <u>Physico-chemical properties</u> (see table 13)

The results of the granulometrical analysis shown in table 13 indicate the dominance of the sand and clay fractions. Only very small amounts of silt are present throughout the profile (less than 3%). In the surface horizon the clay fraction represents 46.2%, increasing rather strongly in the underlaying A3 (59.1%); a new increase is observed in B22, B23 and B24 (about 66.0%), before reaching its maximum in the B3 (70.4%). The sand fraction presents an identical and opposite trend with depth, with 50.9% in A1 and 26.9% in B3. The medium and fine sand dominate the total sand fraction. The amounts of silt are very low and constant ranging from 1.9 to 2.9 in A1; therefore, very low silt/clay ratios (0.06 in the A1 and 0.03 in the other horizons) are found.

Bulk density shows maximal values (about 1.5 g/cc) in the A1 and B24, in the other horizons somewhat lower figures (about 1.4 g/cc) are present.

The cation exchange capacity varies from 4.5 meq. per 100 grams of soil in the A1 and A3 horizons to about 5.6 meq. in the major part of the subsoil. Exchangeable aluminum is rather low, being highest in the top A1 (0.84 meq.), gradually decreasing with depth to 0.08 meq. in the B3 horizon. Base saturation is rather low, being lowest in the A3 and B21 (about 12%), markedly increasing (about 33%) in the B24 and B3 horizons.

The pH is low but increases slightly in the subsoil from pH/KCl 4.2 in the A1 to 4.6 in the B3. Exchangeable contents of Ca, Mg, K and Na are low, decreasing from A1 (sum of bases = 0.86 meq.) to A3 (sum of bases = 0.57 meq.). In the B21 horizon however, higher contents are found (0.73 meq.) that progressively increase up to 1.78 meq. in B24.

The organic carbon content shows an irregular decreasing trend with depth. It is highest in the A1 horizon (0.78%), and drops to 0.54% in A3, B21 and B22 that show the same figures. A new marked decline takes place in the underlaying B23 and B24, which present values around 0.20%, followed by a slightly lower percentage in the lowermost B3 (0.15%) horizon.

3.2.3. Mineralogical composition

3.2.3.1. Sand fraction (50-250µm)

The sand fraction is dominated by the light minerals which constitute 94 to 97% (weight %) of the total sample throughout the soil.

The light fraction is formed by highly weathered and fissured grains of quartz and no more than traces of feldspars (table 14). The heavy fraction includes mainly opaques, where magnetic minerals are the most frequent. X-ray analysis showed that the opaque minerals consist of magnetite, ilmenite, hematite and goethite. Zircon is

Table 13. Physico-chemical properties of profile 2

Depth (cm)	Horizon	Size class and particle diameter (mm)								
		TOTAL			SAND					COARSE FRAGM.
		Sand	Silt	Clay	V.C.	C.	M.	F.	V.F.	> 2 mm
		2-0.05	0.05-0.002	< 0.002	2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	
0- 30	A1	50.9	2.9	46.2	0.8	8.0	20.4	19.4	4.1	0
- 45	A3	44.5	2.0	53.5	0.6	6.7	14.5	15.7	3.4	0
- 64	B21	38.7	2.2	59.1	1.0	6.9	15.0	12.6	3.2	0
-100	B22	32.7	1.9	65.4	1.0	6.6	11.3	11.1	2.7	0
-130	B23	30.9	2.7	66.4	0.8	6.4	11.2	9.6	2.9	0
-160	B24	30.0	2.3	68.3	0.9	6.4	10.5	9.7	2.5	0
-200	B3	26.9	2.7	70.4	0.6	5.3	10.0	8.4	2.6	0

Depth (cm)	Organic carbon %	pH		Ext. Fe as Fe_2O_3 %	Ext. Al as Al_2O_3 %	Bulk density g/cm³	Silt/clay ratio	Coarse clay 2-0.2µ	Fine clay < 0.2µ	Fine clay/Tot. clay
		1:1 KCl	1:1 H_2O							
0- 30	0.78	4.2	4.4	0.98	0.58	1.55	0.06	11.9	32.5	0.73
- 45	0.54	4.4	4.9	1.20	0.66	1.48	0.03	16.1	37.4	0.69
- 60	0.54	4.4	4.7	1.13	0.67	1.41	0.03	21.3	37.8	0.63
-100	0.54	4.4	5.1	1.35	0.65	1.43	0.02	25.5	39.9	0.69
-130	0.22	4.4	4.6	1.06	0.54	1.38	0.04	23.9	42.5	0.64
-160	0.20	4.6	4.8	1.28	0.64	1.52	0.03	22.1	42.2	0.61
-200	0.15	4.6	5.4	1.52	0.61	1.42	0.03	21.8	48.6	0.69

Depth (cm)	Extractable bases					Al 1NKCl	Extr. acidity KCl pH 8.2	C.E.C.				Base saturation (%)	
	Ca	Mg	K	Na	Sum			NH_4OAc	sum cations	NH_4OAc	E.C.E.C.	NH_4OAc	Sum cations
	meq./100g soil							meq./100g soil		meq./100g clay			
0- 30	0.40	0.26	0.08	0.12	0.86	0.84	4.6	4.3	5.5	9.3	3.8	20	16
- 45	0.29	0.15	0.03	0.10	0.57	0.60	4.0	4.6	4.6	8.6	2.0	12	12
- 60	0.37	0.22	0.04	0.10	0.73	0.60	3.3	5.7	4.0	9.7	2.2	13	18
-100	0.51	0.48	0.01	0.11	1.11	0.48	2.5	5.6	3.6	8.6	2.4	20	31
-130	0.49	0.52	0.01	0.12	1.14	0.32	4.3	5.5	5.4	8.3	2.2	21	20
-160	0.97	0.71	0.03	0.09	1.78	0.20	3.1	5.7	4.9	7.6	2.9	34	36
-200	0.68	0.67	0.08	0.13	1.56	0.08	3.2	4.8	4.8	6.9	2.3	32	32

dominant among the transparent minerals of the heavy fraction followed by very low amounts of tourmaline and rutile.

Table 14 . Mineralogical composition of the sand fraction (50-250μm) of profile 2

Hor.	Depth (cm)	Light minerals		Heavy minerals			
		Quartz	Feldspars	Opaques	Zircon	Tourma-line	Rutile
A1	0- 30	100	-	86.3	12.0	1.3	tr.
A3	- 45	100	-	90.3	7.5	< 1	-
B21	- 60	>99	tr.	88.7	10.9	"	-
B22	-100	>99	tr.	91.2	8.6	"	tr.
B23	-130	100	-	90.5	10.0	"	-
B24	-160	>99	tr.	88.5	15.6	"	-
B3	-200	>99	tr.	81.5	7.0	"	-

tr. (traces) = <1%

3.2.3.2. Clay fraction (<2μm)

X-ray diffractograms and T.G.A. traces both indicate the sole presence of kaolinite in the clay fraction of all horizons, whereas D.T.A. also points out the occurrence of gibbsite in most layers (table 15).

Table 15 . Mineralogical composition of the clay fraction (<2μm) of profile 2

Hor.	Depth (cm)	Clay fraction		
		X-ray	D.T.A.	T.G.A.
A1	0- 30	K	K, G	K5
B21	- 63	K	K, G	K5
B22	-100	K	K, G	K5
B33	-200	K	K	K5

Mineral code : K : kaolinite; G : gibbsite.

Approx. weight fractions (T.G.A.) : 5 : more than half; 4 : half to one third; 3 : one third to one fifth; 2 : one fifth to one twentieth; 1 : less than one twentieth.

3.2.4. Sedimentology

The detailed particle size distribution of the fractions between 63 and 2000 microns for A1, A3, B21, B22, B23, B24 and B3 horizons is given in table 16.

The cumulative frequencies were calculated for all fractions between 63 and 2000 microns.

Tables 17 and 18 give respectively the cumulative frequencies of the fractions between 63 and 2000 microns and the sedimentological parameters of each soil horizon.

The cumulative curves plotted on probability scale are given in fig. 6.

The horizon A1 shows an almost symmetrical positively skewed ($\alpha 3\ \phi = 0.05$) and platykurtic ($\alpha 4\ \phi = 0.56$) distribution, with a Mz ϕ of 1.82 and a standard deviation (G1 $\phi = 0.83$) that indicates a moderately sorted material.

The distribution curve of horizon A3 is moderately asymmetric negatively skewed ($\alpha 3\ \phi = -0.22$), platykurtic ($\alpha 4\ \phi = 0.36$), with a Mz ϕ value of 1.85, and showing similar sorting as the preceeding horizon (G1 $\phi = 0.96$).

The B21 horizon presents asymmetric negatively skewed ($\alpha 3\ \phi = -0.34$) and platykurtic ($\alpha 4\ \phi = 0.18$) distribution; a Mz ϕ value of 2.08, and the same sorting as the upper horizons (G1 $\phi = 0.87$).

The B22 horizons shows a weakly asymmetrical positively skewed ($\alpha 3\ \phi = 0.09$), platykurtic ($\alpha 4\ \phi = 0.39$) curve with a Mz ϕ of 1.71 and same sorting (G1 $\phi = 0.92$) as the upper horizons.

The B23 horizon curve is almost symmetric, positively skewed ($\alpha 3\ \phi = 0.03$), platykurtic ($\alpha 4\ \phi = 0.44$), and poorly sorted (G1 $\phi = 1.0$) with a Mz $\phi = 1.64$.

The distribution of horizon B24 is moderately asymmetric, positively skewed ($\alpha 3\ \phi = 0.19$), platykurtic ($\alpha 4\ \phi = 0.66$) with a Mz ϕ value of 1.66, and a standard deviation (G1 $\phi = 0.95$) indicating a moderate sorting.

The B3 distribution curve is moderately asymmetric, positively skewed ($\alpha 3\ \phi = 0.16$), platykurtic ($\alpha 4\ \phi = 0.68$) with a Mz ϕ of 1.61 and a standard deviation of 0.95 that indicates the same sorting class as the overlaying horizon.

The mean grain of particles is lowest in the B21 horizon (Mz $\phi = 2.08$) and increases in the upper and underlaying horizons. The top A3 and A1 show respectively Mz ϕ values of 1.85 and 1.82. In the subsoil, the contrast is particularly marked where Mz ϕ figures range from 1.71 in the B22 to 1.60 in the lowermost B3 horizon (see fig.

The standard deviations are rather uniform throughout, being highest in B23 (G1 $\phi = 1.0$) and lowest in the A1 (G1 $\phi = 0.83$) horizon.

The horizons A3 ($\alpha 3\ \phi = -0.22$) and B21 ($\alpha 3\ \phi = -0.34$) are both negatively skewed, clearly contrasting - particularly the latter - with the almost symmetrical distributions found in A1 ($\alpha 3\ \phi = 0.05$), B22 ($\alpha 3\ \phi = 0.09$) and B23 ($\alpha 3\ \phi = 0.03$) and with the positively skewed distributions of B24 ($\alpha 3\ \phi = 0.19$) and B3 ($\alpha 3\ \phi = 0.16$) (see fig.

The Kurtosis values indicate platykurtic distributions throughout, where the B21 ($\alpha 4\ \phi = 0.18$) is detached from other horizons, showing the most peaked curve.

Table 16 . Particle size distribution of the fractions between 63 and 2000µm

	1400 -2000	1000 -1400	710 -1000	500 - 710	355 -500	250 - 355	180 - 250	125 - 180	90 -125	63 - 90
A1	0.0	1.0	3.0	14.0	14.0	23.0	19.0	15.0	8.0	2.0
A3	1.2	1.2	5.9	11.9	15.5	21.4	16.8	14.3	8.3	3.6
B21	0.0	1.3	3.9	5.2	15.6	15.6	23.4	23.4	6.5	5.2
B22	0.8	1.5	5.4	16.9	16.9	21.5	15.3	12.2	6.1	3.1
B23	1.7	2.6	7.7	15.5	17.2	18.9	15.5	10.3	6.9	3.4
B24	0.0	2.5	7.6	18.5	16.8	18.5	16.8	8.4	8.4	2.5
B3	0.0	3.3	8.3	18.3	16.6	20.0	13.3	11.6	6.6	1.7

Table 17 . Cumulative frequencies of the fractions between 63 and 2000µm

	>1400	>1000	>710	>500	>355	>250	>180	>125	>90	>63
A1	0.0	1.0	4.0	18.0	32.0	55.0	74.0	89.0	97.0	99.0
A3	1.2	2.4	8.3	20.2	35.7	57.1	73.9	89.2	97.5	100.0
B21	0.0	1.3	5.2	10.4	26.0	41.6	65.0	88.4	94.4	100.0
B22	0.8	2.3	7.7	24.6	41.5	63.0	78.3	90.5	96.6	99.7
B23	1.7	4.3	12.0	27.5	44.7	63.6	79.1	89.4	96.3	99.7
B24	0.0	2.5	10.1	28.6	45.4	63.9	80.7	89.1	97.5	100.0
B3	0.0	3.3	11.6	29.9	46.5	66.5	79.8	91.4	98.0	99.7

Table 18 . Sedimentological parameters of the fractions between 63 and 2000µm

	Mz	1σ	3α	4α
A1	1.82	0.83	0.05	0.56
A3	1.85	0.96	-0.22	0.36
B21	2.08	0.87	-0.34	0.18
B22	1.71	0.92	0.09	0.39
B23	1.64	1.00	0.03	0.44
B24	1.65	0.95	0.19	0.66
B3	1.60	0.94	0.16	0.68

Thus, the profile under discussion is considered rather uniform from sedimentological viewpoint with the exception of the B21 horizon, which differs in most parameters with respect to the overlaying and especially with the underlaying horizons.

3.2.5. Micromorphology

A. Microstructure and pore pattern

Moderate and strong very fine crumbly microstructures with fissures intrapedal m.s. dominate in the A3 horizon; very locally moderate crumbly microstructure having fissured and vughy cavited intrapedal m.s.is also observed. Very frequent intrapedal compound interpedal packing pores are dominant; very frequent fissures, frequent smooth channels and common smooth and rough vughs frequently interconnected are also present.

The B21 horizon shows 1) a moderate crumbly microstructure with fissured and vughy cavited intrapedal m.s. and 2) strong to moderate fine crumbly microstructure with fissured intrapedal m.s. The pore pattern is similar to the overlaying A3 horizon and also the frequency of vughs and fissures, with the exception of channels that become common.

In B22 and B23 weak crumbly and spongy microstructures are dominant, both having fissured and vughy cavited intrapedal m.s. The pore pattern is similar to the overlaying soil horizon.

In the B24 horizon the microstructure is mostly fissured and vughy cavited, grading to weak crumbly. The pore pattern is similar to the B23.

Granular channel infillings are present throughout the profile and show moderate and strongly developed very fine crumbly microstructure with fissured intrapedal m.s. Very frequent interpedal compound packing pores and interconnected vughs are dominant; frequent intrapedal fissures were also observed.

B. Matrix

B1. Coarse material ($>5\mu m$)

Fine to coarse sand sized quartz grains, angular, subangular and subrounded shaped, compose the coarse material in all horizons.
The grains are commonly fissured and corroded. Frequent runiquartz, filled with dark red sesquioxides-rich material, are present in all soil horizons, except in B21. Some ubiquists are rarely observed.

B2. Fine material ($<5\mu m$)

The fine material is composed mostly of clay, oxihydrates and organic matter. The color is yellowish brown, dotted in the upper A3 horizon, pale brown and yellowish brown in B21, yellow dotted in B23 and pink dotted in B24. Undifferentiated b-fabric is dominant throughout, and dotted and circular striated (generally very weakly expressed) types subordinated. In the B24 horizon, a parallel striated type is also locally present.

In channel infillings, the dominant b-fabric is undifferentiated; very weak circular striated and dotted b-fabrics are respectively found around and inside microaggregates (pellets) as subordinate types.

B3. Coarse/fine related distribution

Open gefuric to enaulic is dominant in the A3 horizon; very locally enaulic and porphyric. In B21 porphyric and gefuric types are dominant; locally enaulic. The underlaying horizons show porphyric related distributions throughout.

C. Organic matter

Penetration is observed only in the upper horizons (A1, A3 and parts of B21) under the form of roots and thoroughly humified organic material.

D. Features

Coatings and infillings of limpid clay of variable size (about 20 µm ∅) are present in the B horizon, located in fissures, vughs and channels. They are yellow, strongly oriented with sharp boundaries and more abundant in deeper layers.

Laminated coatings and infillings of limpid and speckled clay, ranging from 40µm to 0.9 mm ∅, occur in vughs and channels. The color is yellow, the orientation strong, the boundaries are sharp and they are more frequent with depth.

Fragments of clay coatings dat range from 0.2 to 0.5 mm ∅, with diffuse and sharp boundaries, occur in the fine material and in channel infillings throughout the soil.

Coatings formed by iron-rich clay were only observed in the B21 horizon, located on vughs and channel walls and on top of yellow clay coatings. They have sharp boundaries and show reddish yellow and dark red colors.

Red sesquioxidic undifferentiated nodules of 100 to 400μ ∅, mostly rounded with sharp and diffuse boundaries, are frequent in the upper horizons and very frequent in the subsoil.

E. Quantification of illuviation features

The results of point counting for quantification of illuviation is presented in table 19. Clay illuviation percentages show maximum values in the B22 horizon (3.1%) and B24 horizon (3.2%).

The degree of clay illuviation per horizon and the profile clay illuviation index are shown in table 20.

The degree of clay illuviation is strong in B22, moderate in B21 and B24, and weak in other horizons. The clay illuviation index for the whole profile is moderately high (343.3).

3.2.6. Classification

This profile was studied in 1977 during the First International Soil Classification Workshop, carried out in Brazil. According to Camargo and Beinroth (1978), "Soils of this general morphology developed on unconsolidated sedimentary materials are widespread in the humid tropics and were mentioned to occur in Amazonia (Camargo, Sombroek, Rosateli), West Africa and the Cameroons (Moormann) and the Congo Basin (Smith et al., Pedology, 1975). They present difficult and ill-defined transitions between Oxisols (Haplorthox and others) and Ultisols (Paleudults or Kandiudults). They may or may not have a "textural" or argillic horizon, cutans are frequently present but at greater depth, so that an oxic horizon as defined in Soil Taxonomy is present above an argillic." Although, some participants recognized the presence of clay skins in the

Table 19 . Quantitative micromorphological analysis of soil components (by point counting) in volume per cent of total soil

Depth (cm)	Horizon	Pores	Coarse material	Fine material	Coatings	Fragm.of coatings	Roots
30- 45	A3	29.3	23.8	45.5	0.0	0.22	0.67
- 60	B21	17.9	26.9	53.9	1.2	0.16	
-100	B22	19.4	14.6	62.4	3.1	0.48	
-130	B23	16.5	17.2	65.5	0.35	0.35	
-160	B24	16.0	17.6	63.2	3.2	0.0	

Table 20 . Degree of clay illuviation per horizon and profile clay illuviation index

Horizon	Thickness (cm)	% in situ + translocated illuviation features (on solid phase)	Degree of illuviation
A3	15	0.31	weak
B21	15	1.59	moderate
B22	40	4.4	strong
B23	30	0.82	weak
B24	30	3.84	moderate
Profile clay illuviation index = 343.3 per cent cm. Moderately high.			

B horizon, the observed pedon was considered to have a thin oxic horizon underlain by an argillic horizon. It was agreed that the soil is in the Oxisol side of the borderline. Consequently, the profile was generally classified as a Typic Haplustox but some preferred a tropeptic subgroup.

The profile has a dark A1 horizon that fulfils the requirements of an umbric epipedon. No clay skins were observed in the field and the necessary clay increase for an argillic horizon is not present. Anyhow, thin sections showed more than 1% clay cutans in the major part of the B2 horizon (table 19). Moreover, the subsoil has the properties of an oxic horizon and the structure is moderate throughout. Thus, the profile is classified as a member of the clayey, kaolinitic, isohyperthermic family of the TROPEPTIC HAPLUSTOX.

CLASSIFICATION ACCORDING TO OTHER SYSTEMS

FAO/UNESCO	:	Xanthic Ferralsol
BRAZILIAN SYSTEM	:	Red Yellow Latosol, Dystrophic, podzolic, moderate A horizon, clayey, semi-evergreen tropical cerrado, level phase.
I.N.E.A.C. SYSTEM	:	Hygro-xero Ferralsol slightly Ferralsolic.

GEOMORPHOLOGICAL UNIT : PLATEAU B

3.3. Profile 4

I. Information of the site

Date of examination : 10/1/80
Author : D. Barrera
Location : Sininbú mill. Fazenda Gitirana (M 21).
Approx. 36°14'W, 9°49'S
Elevation : 120 m
Land form : 1) physiographic position : plateau
(see scheme B)
2) microtopography : slightly undulated
Slope : class 1 (0-1%)
Land-use : sugarcane (monoculture).

II. Information of the soil

Parent material : clayey sediments
Geological formation and lithology : Barreiras Group.
Tertiary sediments.
Drainage : class 4 : well-drained
Moisture conditions in the profile : dry throughout
Depth of groundwater table : unknown, no influence on
the profile
Presence of surface stone, rock outcrops : none.
Human influence : confined top plow layer
Vegetation : semi-evergreen tropical forest.

3.3.1. Morphological description

The profile is deep, well-drained, yellowish brown in the upper subsoil and yellow with depth, with very uniform aspect throughout. Structure is weak in all horizons. Cohesion is high in the top soil, that shows hard consistence when dry. Roots concentrate in the top 15 cm.

Ap - 0-15 cm. (Ap) Very dark gray (10 YR 4/3) moist, and dark gray (10 YR 4/2) dry; sandy clay loam; weak-moderate medium granular; many very fine and medium-coarse pores; hard, firm, non-sticky, non-plastic; frequent roots; smooth gradual boundary.

A12 - 15-37 cm. (A) Dark grayish brown (10 YR 4/2) moist, and gray (10 YR 5/1) dry; sandy clay loam; weak, fine-medium granular; many fine and very fine pores; and gew medium-coarse pores; hard, firm, slightly plastic and sticky; common roots; smooth gradual boundary.

A3 - 37-60 cm. (Bt1) Dark gray (10 YR 4/1) moist, and light brownish gray (10 YR 6/2) dry; sandy clay; weak fine subangular blocky, and fine medium granular; many fine and very fine pores, and common medium pores; slightly hard, friable, plastic and sticky; few roots; smooth gradual boundary.

B1 - 60-96 cm. (Bt2) Dark yellowish brown (10 YR 4/4) moist, and yellowish brown (10 YR 5/4) dry; sandy clay; weak fine subangular blocky; many fine and very fine pores; and few medium ones; slightly hard, friable, plastic, sticky; very few roots; smooth clear gradual boundary.

B21 - 96-140 cm. (Bt3) Dark yellowish brown (10 YR 4/4) moist and light yellowish brown (10 YR 6/4) dry; sandy clay; weak fine subangular blocky; many fine and very fine pores; and few medium ones; hard, friable, plastic and sticky; very few roots; smooth gradual boundary.

B22 - 140-200 cm. (Bt4) Brownish yellow (10 YR 6/6) moist, and very pale brown (10 YR 8/4) dry; clay; weak fine subangular blocky; many fine and very fine pores; slightly hard, friable, plastic and sticky; very few roots; smooth gradual boundary.

B23 - 200-250 cm. (Bt5) Yellow (10 YR 7/6) moist, and very pale brown (10 YR 8/4) dry; clay; weak, very fine subangular blocky; slightly hard, very friable, plastic and slightly sticky.

Remark : ( ) Horizon's nomenclature according to the Soil Survey Manual (1981).

3.3.2. Physico-chemical properties (see table 21)

The clay and the sand are the dominant fractions throughout. Very low amounts of silt are found in the whole profile (max. 3.6%). The clay content increases gradually from the top Ap horizon (21.5%) to the deepest B23 (65.1%). The increases of clay are stronger in the top soil. The sand fraction follows a similar and opposite trend with depth, from 76.0% in the Ap to 31.3% in the B23. The medium and fine sand have nearly equal percentages making up the larger proportion of the total sand fraction. The silt distribution is very uniform throughout, slightly increasing in the lower subsoil.

Silt/clay ratios are very low, ranging from 0.11 in the Ap to 0.04 in the B22.

Bulk densities increase markedly in the top soil, from 1.45 g/cc in the B21 to 1.71 in the Ap horizon. The B23 horizon (1.38 g/cc) presents the lowest value.

The cation exchange capacities per 100 grams of soil varies from 3.7 meq. in the A3 to 6.3 meq. in the B22. The subsoil shows somewhat higher values than the top soil. Exchangeable aluminum is very low throughout, being highest in the A3 (0.26 meq.). Base saturation shows maximum values in the Ap (83.0%) decreasing towards the B22 (17.3%); in the B23 the base saturation increases again to 33.6%. Exchangeable contents of Ca, Mg, K and Na are low, being highest in the top Ap horizon, and lowest in the A3 horizon.

The organic carbon content declines gradually from the Ap (1.08%) to the B1 (0.24%), and remains constant in the subsoil.

The pH is low and rather uniform in the whole profile, ranging from 4.8 (pH/KCl) in the A12 to 4.1 in the B22.

Table 21. Physico-chemical properties of profile 4

Depth (cm)	Horizon	Size class and particle diameter (mm)								
		TOTAL			SAND					COARSE FRAGM.
		Sand	Silt	Clay	V.C	C.	M.	F.	V.F	> 2 mm
		2-0.05	0.05-0.002	< 0.002	2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	
0- 15	Ap	76.1	2.4	21.5	2.5	16.3	26.1	26.3	4.8	0
- 37	A12	66.6	2.6	30.8	2.8	14.0	22.6	21.6	5.6	0
- 60	A3	55.3	2.6	42.1	1.6	11.5	18.2	19.1	4.7	0
- 96	B1	51.3	2.4	46.3	2.9	12.7	17.5	14.0	4.0	0
-140	B21	43.0	2.6	54.4	2.2	10.8	14.0	12.0	4.0	0
-200	B22	34.5	3.5	62.0	1.9	8.5	9.8	10.4	3.8	0
-250	B23	31.3	3.6	65.1	1.2	7.6	9.0	9.7	3.9	0

Depth (cm)	Organic carbon %	pH 1:1 KCl	pH 1:1 H_2O	Ext. Fe as Fe_2O_3 %	Ext. Al as Al_2O_3 %	Bulk density g/cm³	Silt/ clay ratio	Coarse clay 2-0.2µ	Fine clay < 0.2µ	Fine clay/ Tot. clay
0- 15	1.08	4.6	5.4	0.48	-	1.71	0.11	2.0	19.5	0.90
- 37	0.7	4.8	5.6	0.67	1.19	1.67	0.08	4.9	25.9	0.84
- 60	0.42	4.5	5.2	0.81	0.96	1.62	0.06	9.5	32.6	0.77
- 96	0.24	4.6	5.3	1.03	0.97	1.57	0.05	10.1	36.2	0.78
-140	0.22	4.4	5.1	1.05	0.91	1.45	0.04	19.3	35.1	0.64
-200	0.20	4.1	4.7	1.25	0.92	1.53	0.05	17.3	44.7	0.72
-250	0.20	4.6	5.2	1.17	0.80	1.38	0.05	16.7	41.0	0.71

Depth (cm)	Extractable bases					Al 1NKCl	Extr. acidity KCl pH 8.2	C.E.C.				Base saturation (%)	
	Ca	Mg	K	Na	Sum			NH_4OAc	sum cations	NH_4OAc	E.C.E.C.	NH_4OAc	Sum cations
	meq./100g soil							meq./100g soil		meq./100g clay			
0- 15	2.17	0.33	0.10	0.07	2.67	0.18	4.0	4.2	6.7	19.6	17.0	63.6	40.0
- 37	2.22	0.26	0.01	0.09	2.58	0.12	3.5	3.7	6.1	12.2	8.8	69.7	42.4
- 60	1.44	0.19	0.0	0.08	1.71	0.26	3.8	4.2	5.5	10.0	4.7	40.7	31.0
-96	1.70	0.26	0.0	0.08	2.04	0.12	4.0	4.3	6.0	9.4	2.2	47.4	33.7
-140	1.59	0.41	0.0	0.07	2.07	0.14	4.1	5.1	6.2	9.4	4.0	40.5	33.5
-200	0.68	0.30	0.02	0.09	1.09	0.20	3.0	6.3	4.1	10.2	2.0	17.3	26.6
-250	1.28	0.30	0.01	0.09	1.68	0.02	3.7	5.0	5.4	8.7	2.9	33.6	31.2

3.3.3. Mineralogical composition

3.3.3.1. Sand fraction (50-250µm)

The sand fraction is dominated by the light minerals which range from 91 to 97 per cent (weight %) of the total sample in the different soil horizons.

The light fraction is formed by quartz and traces of feldspars (table 22). The heavy fraction includes mainly opaques, where magnetic minerals are the most frequent. X-ray analysis showed that the opaque minerals consist of magnetite, hematite, goethite and ilmenite. Zircon is the dominant transparent mineral of the heavy fraction followed by very low amounts of tourmaline and rutile.

Table 22 . Mineralogical composition of the sand fraction (50-250µm) of profile 4

Hor.	Depth (cm)	Light minerals		Heavy minerals			
		Quartz	Feldspars	Opaques	Zircon	Tourma-line	Rutile
Ap	0- 15	>99	tr.	96.7	2.6	tr.	tr.
A12	- 37	100	-	95.5	2.5	"	"
A3	- 60	100	-	94.5	4.5	"	"
B1	- 90	>99	tr.	65.2	3.4	"	"
B21	-140	>99	tr.	96.1	3.0	"	"
B22	-200	100	-	93.6	5.4	"	"
B23	-250	>99	tr.	92.6	6.5	"	-

tr. (traces) = <1%

3.3.3.2. Clay fraction (<2µm)

The results of X-ray diffractometry, D.T.A. and T.G.A. presented in table 23 show kaolinite as the sole mineral present in the clay fraction of all horizons. Only D.T.A.

traces indicate besides kaolinite the presence of gibbsite in the A12 horizon.

Table 23 . Mineralogical composition of the clay fraction (<2µm) of profile 4

Hor.	Depth (cm)	Clay fraction		
		X-ray	D.T.A.	T.G.A.
A12	15- 37	K	K, G	K5
A3	- 60	K	-	-
B1	- 90	K	K	K5
B23	-250	K	K	K5

Mineral code : K : kaolinite; G : gibbsite.
Approx. weight fractions (T.G.A.) : 5 : more than half; 4 : half to one third; 3 : one third to one fifth; 2 : one fifth to one twentieth; 1 : less than one twentieth.

3.3.4. Sedimentology

Table 24 shows the detailed particle size distribution of the fractions between 63 and 2000µm for A12, A3, B1, B21, B22 and B23 horizons.

Tables 25 and 26 give respectively the cumulative frequencies of the fractions between 63 and 2000µm and the sedimentological parameters of each horizon.

The cumulative curves drawn in probability scale are shown in fig. 7.

The A12 horizon shows an almost symmetric ($\alpha 3\ \phi = 0.09$) and platykurtic distribution ($\alpha 4\ \phi = 0.54$), with a Mz value of 1.50 ϕ and a moderately sorted material ($G1\ \phi = 0.99$).

The distribution curve of the A3 horizon is asymmetric, positively skewed ($\alpha 3\ \phi$ = 0.21), platykurtic ($\alpha 4\ \phi$ = 0.56); the Mz value is 1.52 and the sorting is similar as the horizon above (G1 ϕ = 0.99).

The B1 horizon distribution is nearly symmetric, positively skewed ($\alpha 3\ \phi$ = 0.04), platykurtic ($\alpha 4\ \phi$ = 0.58), with a Mz value of 1.50 ϕ and having similar sorting as the preceeding horizons (G1 ϕ = 1.06).

The distribution of the B21 horizon is slightly asymmetric, positively skewed ($\alpha 3\ \phi$ = 0.11), platykurtic ($\alpha 4\ \phi$ = 0.63); the Mz value is 1.57 ϕ and a (G1 ϕ = 1.05) indicates some sorting class as the above horizons.

The B22 distribution curve shows a moderately positive ($\alpha 3\ \phi$ = 0.19) asymmetry and platykurtic ($\alpha 4\ \phi$ = 0.66) distribution, with a Mz value of 1.48 ϕ and a (G1 ϕ = 1.10) poorly sorted material (Folk and Ward, 1957).

The B23 distribution curve is almost symmetric, positively skewed ($\alpha 3\ \phi$ = 0.03), platykurtic ($\alpha 4\ \phi$ = 0.67); the Mz value is 1.61 ϕ and the sorting is similar as the rest of the profile (G1 ϕ = 1.10).

The mean grain size of particles is very similar throughout, being lowest in B23 (Mz ϕ = 1.61) and highest in the B22 (Mz ϕ = 1.48)

The standard deviations present also a highly homogeneous pattern, very slight increasing in the lower horizons. The figures range from G1 ϕ = 0.97 in A12 to G1 ϕ = 1.11 in B22.

The skewness are positive and varies from almost symmetric in B23 ($\alpha 3\ \phi$ = 0.03) to moderate in the A3 horizon ($\alpha 3\ \phi$ = 0.21).

Table 24 . Particle size distribution of the fractions between 63 and 2000µm

	1400 -2000	1000 -1400	710 -1000	500 -710	355 - 500	250 - 355	180 -250	125 - 180	90 -125	63 -90
A12	1.5	3.7	9.8	18.0	18.0	17.3	14.3	9.7	6.0	1.5
A3	0.9	4.4	8.8	19.3	17.0	17.5	12.2	10.5	6.1	2.6
B1	3.0	5.1	9.2	17.3	15.3	17.3	13.3	10.2	6.1	3.0
B21	2.4	2.4	9.7	19.5	14.6	15.8	13.3	11.0	7.3	3.6
B22	2.8	5.5	9.7	20.8	12.5	16.6	12.4	6.9	8.3	4.2
B23	3.0	3.0	9.2	16.9	15.5	15.3	12.3	12.3	7.7	4.6

Table 25 . Cumulative frequencies of the fractions between 63 and 2000µm

	>1400	>1000	>710	>500	>355	>250	>180	>125	>90	>63
A12	1.5	5.2	15.0	33.0	51.0	68.3	82.6	92.3	98.3	99.8
A3	0.9	5.3	14.1	33.4	50.4	67.9	80.1	90.6	96.7	99.3
B1	3.0	8.1	17.3	34.6	49.9	67.2	80.5	90.7	96.8	99.8
B21	2.4	4.8	14.5	34.0	48.6	64.4	77.7	88.7	96.0	99.6
B22	2.8	8.3	18.0	38.8	51.3	67.9	80.3	87.2	95.5	99.7
B23	3.0	6.0	15.2	32.1	47.6	62.9	75.2	87.5	95.2	99.8

Table 26 . Sedimentological parameters of the fractions between 63 and 2000µm

	Mz	1σ	3α	4α
A12	1.50	0.97	0.09	0.54
A3	1.52	0.99	0.21	0.56
B1	1.50	1.06	0.04	0.58
B21	1.57	1.05	0.11	0.63
B22	1.48	1.11	0.19	0.66
B23	1.61	1.10	0.03	0.67

The Kurtosis is very uniform and gradually increases with depth from the $\alpha 4\ \phi = 0.54$ (A12) to the $\alpha 4\ \phi = 0.65$ in the deepest B23.

Consequently, from sedimentological point of view, the parent materials of the different soil horizons are very similar in the whole profile.

3.3.5. Micromorphology

A. Microstructure and pore pattern

The observed microstructures in the A3 horizon are :
1) moderate medium crumbly (crumbs of about 5 mm ø), having fissured and vughy cavited intrapedal m.s., and
2) moderate fine crumbly grading to spongy occasionally showing fissured intrapedal m.s. Locally, strong crumbly with fissured intrapedal m.s. is present. Very frequent interpedal compound packing pores are dominant; smooth channels, rough and smooth vughs (many interconnected) and fissures are frequent.

In the underlaying B1 and B21 horizons the microstructure is spongy with fissured and vughy cavited intrapedal m.s. It locally grades to moderate and strong fine crumbly and to moderate crumbly, both showing fissured and vughy cavited intrapedal m.s. The same pore pattern as the overlaying A3 is here observed, where intrapedal vughs (mostly interconnected) and fissures (few µm ø) are very frequent and dominant; smooth channels are frequent and compound packing pores are very frequent.

In the B22 horizon the dominant microstructures are :
1) moderate medium and crumbly (crumbs from 3 to 10 mm ø) and 2) spongy, both having fissured and vughy cavited intrapedal m.s. The pore pattern is similar to the overlaying horizon.

The lowermost B23 horizon mostly shows weak crumbly microstructure (crumbs of about 5 mm ø) very frequently grading to spongy, with fissured and vughy cavited intrapedal m.s. The pore pattern is similar to the B22.

Channel infillings were observed throughout the profile and show weak to moderate fine crumbly microstructure, with mostly fissured intrapedal m.s. Very frequent interpedal compound packing pores and interconnected vughs dominate.

B. Matrix

B1. Coarse material (>5µm)

Fine to coarse sand sized quartz grains, angular, subangular and subrounded shaped, compose the coarse material throughout.

The grains frequently present fissures. Runiquartz are observed in all horizons.

B2. Fine material (<5µm)

The fine material is mostly composed of clay and very low amounts of oxihydrates. The colors are brownish in the A3, brownish yellow and yellow in the B1 and the B21, and reddish brown in the B22 and the B23 horizons. Undifferentiated b-fabric is dominant in all horizons; dotted and circular striated are locally observed.

In the channel infillings, undifferentiated b-fabric is also dominant; locally circular striated and dotted are present.

B3. Coarse/fine related distribution

Simple and double spaced gefuric, grading to enaulic, dominates in the A3 horizon, porphyric is subordinated. In the B1 and B21 horizons, porphyric and gefuric are equally present. In the underlaying horizons, porphyric dominates and gefuric locally occurs; in channel infillings the dominant type is enaulic, and gefuric subordinated.

C. Organic matter

Partially decomposed roots are very frequent in the A3 horizon, becoming rare with depth.

D. Features

Coatings and infillings of limpid clay are present from A3 to B23, located in vughs and channels, with strong continuous orientation, yellow color and sharp boundaries.

Laminated coatings and infillings of limpid well speckled clay ranging from 30 to 50µm ø are frequent in the A3 and very frequent in the subsoil, located in vughs and channels. The color is mostly yellow, with strong continuous orientation and sharp boundaries.

Fragments of clay coatings (0.1-0.4 mm ø) with sharp and diffuse boundaries are common in the fine material and inside channel infillings.

Compound nodules of red color, rounded (6-13 mm ø) with sharp boundaries are observed in the B22. The coarse material includes quartz grains and runiquartz, the fine fraction is composed of iron-rich clay. The related distribution is porphyric and reddish coatings and infillings strongly oriented, having sharp boundaries, as well as dark red isotropic coatings and infillings are mostly present in vughs and channels.

Red undifferentiated sesquioxidic nodules, rounded (0.3 mm ø) and sometimes including small quartz grains, were observed in the B22 and B23 horizons.

E. Quantification of illuviation features

The results of point counting for quantification of clay illuviation are presented in table 27. Clay illuviation percentages do not show any definite trend with depth, where B22 (4.22%) presents the highest value and B23 (0.66%) the lowest. In consequence, the degree of clay illuviation is strong in B22 and moderate in overlaying and underlaying horizons as shown in table 28 . The clay illuviation index for the whole profile is moderately high (684.4).

3.3.6. Classification

No matter the profile shows a dark Ap horizon having a basa saturation higher than 50%, it is not thick enough to be mollic; therefore, it is an ochric epipedon.

Clay skins were not observed in the field, but thin sections showed more than 1% clay cutans from the A3 horizon to the B22 horizon (table 27). The clay content increases gradually with depth and the illuvial/eluvial ratio between the A12 and the A3 horizons is more than 1.2, thus fulfilling the requirements for an argillic horizon; from the B horizon downwards the clay content remains constant. Furthermore, the subsoil has the properties of an oxic horizon.

Table 27. Quantitative micromorphological analysis of soil components (by point counting) in volume per cent of total soil

Depth (cm)	Horizon	Pores	Coarse material	Fine material	Coatings	Fragm. of coatings	Nodules
37- 60	A3	15.3	31.3	51.9	1.9	0.2	0.0
- 96	B1	16.7	32.0	48.0	2.9	0.4	0.0
-140	B21	20.2	24.2	53.6	1.0	0.4	0.63
-200	B22	14.3	19.7	46.9	4.22	0.7	14.0
-250	B23	18.3	16.3	65.1	0.66	0.4	0.0

Table 28. Degree of clay illuviation per horizon and profile clay illuviation index

Horizon	Thickness (cm)	% in situ + translocated illuviation features (on solid phase)	Degree of illuviation
A3	23	2.46	moderate
B1	36	3.93	moderate
B21	44	1.74	moderate
B22	60	5.7	strong
B23	50	1.3	moderate
Profile clay illuviation index = 684.4 per cent cm. Moderately high.			

Therefore, the profile is classified as a member of the clayey, kaolinitic, isohyperthermic family of the OXIC PALEUSTULTS.

CLASSIFICATION ACCORDING TO OTHER SYSTEMS

FAO/UNESCO : Ferric Acrisol
BRAZILIAN SYSTEM : Red Yellow Podzolic Dystrophic, latosolic, low clay activity, prominent A horizon, clayey, semi-evergreen tropical forest, level phase.
I.N.E.A.C. SYSTEM : Hygro-xero Ferrisol.

3.4. Profile 5

I. Information of the site

Date of examination : 15/10/80
Author : D. Barrera
Location : Sininbú mill. Fazenda Gitirana (M 14)
Approx. 36°14' W, 9°49' S
Elevation : 120 m
Land form : 1) physiographic position : plateau (see scheme B)
2) microtopography : slightly undulated
Slope : class 1 (0-1%)
Land-use : sugarcane (monoculture).

II. Information of the soil

Parent material : clayey sediments
Geological formation and lithology : Barreiras Group. Tertiary sediments.
Drainage : class 4-3: well drained to mod.well drained
Moisture conditions in profile : dry throughout

Therefore, the profile is classified as a member of the clayey, kaolinitic, isohyperthermic family of the OXIC PALEUSTULTS.

CLASSIFICATION ACCORDING TO OTHER SYSTEMS

FAO/UNESCO : Ferric Acrisol
BRAZILIAN SYSTEM : Red Yellow Podzolic Dystrophic, latosolic, low clay activity, prominent A horizon, clayey, semi-evergreen tropical forest, level phase.
I.N.E.A.C. SYSTEM : Hygro-xero Ferrisol.

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Parent material : clayey sediments
Geological formation and lithology : Barreiras Group. Tertiary sediments.
Drainage : class 4-3: well drained to mod.well drained
Moisture conditions in profile : dry throughout

Depth of watertable : temporary watertable between 72 and 120 cm depth.
Presence of surface stone, rock outcrops : none.
Human influence : confined to plow layer.
Vegetation : semi-evergreen tropical forest.

3.4.1. Morphological description

The profile is deep, well-drained to moderately well-drained, having brownish yellow color. Horizonation between the A and the B horizons is distinct, emphasized by the presence of stronger structure development and by the presence of abundant mottling, that occur in the top part of the B2 horizon. Cohesion is high in the upper layers (Ap and A12) where the dry consistence is hard. Root distribution is normal, concentrated in the upper 20 cm.

Ap - 0-20 cm. Very dark gray (10 YR 3/1) moist, and dark gray (10 YR 4/1) dry; sandy clay loam; weak-moderate medium granular; hard, firm, non-plastic, non-sticky; many very fine and fine pores; frequent roots; gradual smooth boundary.

A12 - 20-43 cm. (A) Dark grayish brown (10 YR 4/2) moist, and dark gray (10 YR 4/1) dry; sandy clay loam; weak fine-very fine subangular blocky; many fine and very fine pores; hard, firm, slightly plastic, slightly sticky; common roots; gradual smooth boundary.

A3 - 43-72 cm. (Bt1) Brown-dark brown (10 YR 4/3) moist, and yellowish brown (10 YR 5/4) dry; sandy clay loam; weak fine subangular blocky and fine medium granular; many fine and very fine; slightly hard, friable, slightly plastic and sticky; few roots; smooth gradual boundary.

B21t - 82-120 cm. (Bt2) Light yellowish brown (10 YR 6/4) moist and pale brown (10 YR 3/) dry; clay;very few fine-medium faint diffuse red (2.5 YR 4/2) mottles; clay; weak-moderate subangular blocky; slightly hard, friable, plastic and sticky; many fine and very fine pores and few medium ones; very few roots; smooth gradual boundary.

B22t - 120-145 cm. Brownish yellow (10 YR 6/6) moist and
(Bt3) very pale brown (10 YR 7/4) dry; common, fine and medium, distinct, diffuse red (2.5 YR 4/8) mottles; clay; weak subangular blocky; slightly hard, friable; plastic and sticky; many fine and very fine pores; very few roots; smooth diffuse boundary.

B23 - 145-180 cm. Brownish yellow (10 YR 6/6) moist, and
(Bt4) very pale brown (10 YR 7/4) dry; clay; very weak fine subangular blocky; slightly hard, friable, plastic and sticky; many fine and very fine pores; very few roots; smooth gradual boundary.

B31 - 180-225 cm. Brownish yellow (10 YR 6/8) moist, and
(BC1) yellow (10 YR 7/6) dry; clay; weak fine granular to subgranular blocky; soft, very friable, plastic and sticky; very few roots; smooth diffuse boundary.

B32 - 225-280 cm. Brownish yellow (10 YR 6/8) moist, and
(BC2) yellow (10 YR 7/6) dry; clay; weak fine granular; very friable, plastic and sticky; very few roots.

Remarks : ( ) horizon's nomenclature according to the Soil Survey Manual (1981).

3.4.2. Physico-chemical properties (see table 29)

The results of the granulometrical analysis indicate the dominance of the sand and clay fractions. Silt is present in very low amounts throughout (max. 4.1%). In the uppermost Ap, the clay represents 23.2%, increasing gradually downwards, to reach its maximum in the B22 (58.6%). In the deeper horizon, it remains constant. A rather strong increase occurs between A12 (27.2%) and A3 (34.1%), and from the latter to B21 (49.1%); also between B21 and B22 a remarkable increase is found (from 49.1% to 58.6%). The sand fraction presents a similar and opposite trend downwards, with 74.1% in the Ap and 38.9% in the B22. The medium and fine sand having equal percentages make up the larger proportion of the total sand fraction. The distribution of the silt fraction is very uniform with depth, and gradually increases from B23 downwards.

Silt/clay ratios are very low, varying between 0.11 (Ap) and 0.04 (B22).

Bulk densities are highest in the A12 (1.70 g/cc) and the Ap (1.72 g/cc), decreasing with depth to reach 1.39 g/cc in the B32.

The cation exchange capacity varies from 3.8 meq. per 100 grams soil in the A12 and A3 horizons to about 6.9 meq. in the major part of the subsoil. Exchangeable aluminum is fairly low, being highest in the A12 (0.60 meq.) and the A3 (0.52 meq.) and mostly absent in the subsoil. Exchangeable Ca, Mg, K and Na are very low throughout and somewhat higher in the subsoil, ranging from 0.97 meq. in the A3 to 2.54 meq. in the B22. Base saturation is rather uniform; highest in the Ap and the B21 (about 45%) and lowest in the A12 (25.5%).

The organic carbon content decreases with depth from the Ap (0.8%) to the B23 (0.22%), remaining virtually constant in deeper horizons.

3.4.3. Mineralogical composition

3.4.3.1. Sand fraction (50-250µm)

The light minerals dominate the sand fraction and range from 91 to 97% (weight %) of the total sample in the different soil horizons.

Highly weathered and fissured quartz grains and traces of feldspars compose the light mineral suite (table 30).
The heavy fraction includes mostly opaques, where magnetic

Table 29. Physico-chemical properties of profile 5

Depth (cm)	Horizon	Size class and particle diameter (mm)								
		TOTAL			SAND					COARSE FRAGM.
		Sand	Silt	Clay	V.C.	C.	M.	F.	V.F.	> 2 mm
		2-0.05	0.05-0.002	< 0.002	2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	
0- 20	Ap	74.1	2.7	23.2	2.1	14.6	25.1	27.4	4.9	0
- 43	A12	70.4	2.4	27.2	3.4	15.6	24.1	22.4	4.9	0
- 72	A3	63.4	2.5	34.1	2.5	14.5	21.1	20.7	4.6	0
-120	B21	48.4	2.5	49.1	2.7	11.8	15.5	14.7	3.7	0
-145	B22	38.9	2.5	58.6	2.7	10.1	11.7	10.5	3.9	0
-180	B23	39.7	3.3	57.0	2.3	10.0	11.7	11.9	3.8	0
-225	B31	38.8	3.8	57.4	2.2	9.9	11.6	11.3	3.8	0
-280	B32	39.2	4.1	56.7	2.1	10.4	11.6	11.3	3.8	0

Depth (cm)	Organic carbon %	pH 1:1 KCl	pH 1:1 H_2O	Ext. Fe as Fe_2O_3 %	Ext. Al as Al_2O_3 %	Bulk density g/cm³	Silt/clay ratio	Coarse clay 2-0.2µ	Fine clay < 0.2µ	Fine clay/Tot. clay
0- 20	0.80	4.1	4.9	0.52	-	1.70	0.11	3.9	19.3	0.83
- 43	0.66	4.0	4.5	0.60	1.14	1.67	0.08	4.8	22.4	0.82
- 72	0.68	4.1	4.7	0.79	1.18	1.65	0.07	7.8	26.3	0.77
-120	0.44	4.4	5.1	1.17	0.99	1.69	0.05	17.9	31.2	0.63
-145	0.30	4.5	5.2	1.62	1.08	1.65	0.04	19.9	38.7	0.66
-180	0.22	4.6	5.3	1.55	0.97	1.69	0.05	16.9	40.1	0.70
-225	0.22	4.7	5.2	1.52	0.91	1.52	0.06	17.2	40.2	0.70
-280	0.20	4.9	5.5	1.41	0.73	1.39	0.08	-	-	-

Depth (cm)	Extractable bases					Al 1NKCl	Extr. acidity KCl pH 8.2	C.E.C.				Base saturation (%)	
	Ca	Mg	K	Na	Sum			NH_4OAc	sum cations	NH_4OAc	E.C.E.C.	NH_4OAc	Sum cations
	meq./100g soil							meq./100g soil		meq./100g clay			
0- 20	1.19	0.41	0.12	0.06	1.78	0.20	4.04	4.0	5.8	17.5	8.5	44.5	30.5
- 43	0.56	0.19	0.11	0.11	0.97	0.60	4.46	3.8	5.4	14.1	5.8	25.5	17.8
- 72	0.90	0.26	0.08	0.09	1.33	0.52	4.08	3.8	5.4	11.3	5.4	35.0	24.5
-120	1.62	0.33	0.03	0.07	2.05	0.16	4.58	4.5	6.6	9.2	4.5	45.5	30.9
-145	1.80	0.63	0.03	0.08	2.54	0.0	4.88	7.1	7.4	12.2	4.3	35.7	34.6
-180	1.68	0.56	0.02	0.08	2.34	0.0	4.40	6.9	6.7	12.2	4.1	34.4	34.7
-225	1.58	0.67	0.02	0.07	2.34	0.0	4.35	6.8	6.7	11.9	4.0	34.4	34.9
-280	1.25	0.74	0.01	0.09	2.09	0.0	3.90	5.8	6.0	10.4	3.7	36.0	34.8

minerals are dominant. X-ray analysis showed that the opaque minerals consist of magnetite, hematite, goethite and ilmenite. Among the transparent minerals, zircon is the dominant, followed by very low amounts of tourmaline and the occasional presence of rutile.

Table 30 . Mineralogical composition of the sand fraction (50-250μm) of profile 5

Hor.	Depth (cm)	Light minerals		Heavy minerals			
		Quartz	Feldspars	Opaques	Zircon	Tourma-line	Rutile
Ap	0- 20	100	0.0	92.4	7.0	tr.	0.0
A12	- 43	100	0.0	91.8	7.7	"	0.0
A3	- 72	100	0.0	93.5	5.6	"	0.0
B21	-120	>99	tr.	95.5	3.7	"	0.0
B22	-145	>99	"	93.6	5.8	"	0.0
B23	-180	>99	"	94.2	4.9	"	0.0
B31	-225	100	0.0	95.6	3.9	"	0.0
B32	-280	100	0.0	96.2	2.9	"	0.0

tr. (traces) = <1%.

3.4.3.2. Clay fraction (<2μm)

The mineralogical composition of the clay fraction as determined by X-ray diffractometry, D.T.A. and T.G.A., presented in table 31, indicates the only presence of kaolinite in all horizons of this profile.

Table 31 . Mineralogical composition of the clay fraction (<2μm) of profile 5

Hor.	Depth (cm)	Clay fraction		
		X-ray	D.T.A.	T.G.A.
A12	20- 43	K	K	K5
A3	- 72	K	-	-
B22	-145	K	K	K5
B31	-225	K	K	K5

Mineral code : K : kaolinite; G : gibbsite.
Approx. weight fractions (T.G.A.) : 5 : more than half; 4 : half to one third; 3 : one third to one fifth; 2 : one fifth to one twentieth; 1 : less than one twentieth.

3.4.4. Sedimentology

The detailed particle size distribution between 63 and 2000 microns for the horizons A12, A3, B21, B22, B23, B31 and B32 is presented in table 32.

The cumulative frequencies for all fractions between 63 and 2000 microns and the sedimentological parameters are respectively given in tables 33 and 34.

The cumulative curves plotted on probability scale are presented in fig. 8.

The A12 horizon shows an almost symmetric, positively skewed ($\alpha 3\ \phi = 0.08$) and platykurtic ($\alpha 4\ \phi = 0.53$) distribution, with a Mz value of 1.52 ϕ and a standard deviation ($G1\ \phi = 0.98$) which indicates a moderate sorting of the material (Folk and Ward, 1957).

- The distribution curve of horizon A3 is somewhat asymmetrical positively skewed ($\alpha3\ \phi = 0.06$), platykurtic ($\alpha4\ \phi = 0.62$), the Mz value is 1.58 ϕ and the sorting ($G1\ \phi = 1.01$) is similar as the horizon above.

- The distribution of the B21 horizon is moderately asymmetric, positively skewed ($\alpha3\ \phi = 0.15$), platykurtic ($\alpha4\ \phi = 0.49$), the Mz value is 1.57 ϕ and the standard deviation of ($G1\ \phi = 0.99$) indicates the same sorting class as the preceeding horizons.

- The B22 horizon shows a nearly symmetric, positively skewed ($\alpha3\ \phi = 0.08$), platykurtic ($\alpha4\ \phi = 0.68$) distribution, with a Mz of 1.53 ϕ and same sorting ($G1\ \phi = 1.09$) as the overlaying horizons.

- The B23 horizon distribution is very weakly asymmetric and positively skewed ($\alpha3\ \phi = 0.09$), platykurtic ($\alpha4\ \phi = 0.56$), with a Mz of 1.59 ϕ and a standard deviation ($G1\ \phi = 1.10$) that indicates poorly sorting.

- The distribution of the B31 horizon is moderately asymmetric, positively skewed ($\alpha3\ \phi = 0.12$), platykurtic ($\alpha4\ \phi = 0.54$), with a Mz value of 1.59 ϕ and a standard deviation ($G1\ \phi = 1.05$) indicating the same sorting as the overlaying horizon.

- The B32 horizon distribution curve is asymmetric, having positive skewness ($\alpha3\ \phi = 0.31$), platykurtic ($\alpha4\ \phi = 0.73$), with a Mz of 1.40 ϕ and showing the same sorting ($G1\ \phi = 1.03$) as the B31 horizon.

The mean particle size distribution pattern is highly homogeneous throughout, except for the lowest B32 ($Mz\ \phi = 1.40$), which shows a somewhat lower value when compared with the rest of the profile (see table 34).

The standard deviations are very similar along the whole profile.

The asymmetry is always positive, from very weak to moderate, and very similar throughout. Only the B32 horizon ($\alpha 3\ \phi = 0.31$) presents a definite asymmetric curve.

The peakedness of all the horizons is flat and rather similar from the A12 to the B31 horizon. The B32 horizon shows a somewhat flatter curve than the overlaying horizons.

Thus, the parent material of the lowermost B32 horizon appears somewhat different from sedimentological point of view, with respect to the highly uniform parent material where the overlaying horizons were formed.

3.4.5. Micromorphology

A. Microstructure and pore pattern

The microstructures of the A12 and A3 horizons are mostly strong and moderate fine crumbly grading to spongy, with fissured and vughy cavited intrapedal m.s. Locally, in the A12, very fine crumbly (crumbs about 10 mm ø) microstructure comprising fissures and vughs is also present. Very frequent interpedal compound packing pores and smooth vughs mostly interconnected, are dominant; followed by very frequent fissures.

In the subsoil (B21, B22 and B23 horizons) the microstructure is spongy with fissured and vughy cavited intrapedal m.s. It normally grades to 1) moderate fine crumbly (crumbs reach 12 mm) and to 2) moderate very fine crumbly, which occasionally shows fissured intrapedal m.s. Very frequent interconnected vughs (mostly rough) and fissures are dominant; frequent interpedal compound packing pores and smooth channels are also present.

Table 32 . Particle size distribution of the fractions between 63 and 2000µm

	1400 -2000	1000 -1400	710 -1000	500 -710	355 -500	250 -355	180 -250	125 -180	90 -125	63 -90
A12	1.4	3.4	9.8	18.4	17.4	18.2	14.0	9.8	5.6	2.0
A3	1.6	3.3	8.2	19.0	16.6	16.6	13.3	12.4	6.6	2.5
B21	1.0	4.0	7.1	19.4	17.4	18.4	13.3	10.2	6.1	3.0
B22	2.6	5.1	8.9	19.2	14.1	15.4	12.8	11.5	6.4	3.8
B23	2.6	5.1	7.7	15.4	17.9	16.6	11.5	11.5	5.1	6.4
B31	2.6	5.2	7.3	15.4	17.9	16.6	11.4	11.3	4.9	6.8
B32	1.3	3.4	17.3	20.0	12.0	16.0	10.7	12.0	4.0	2.7

Table 33 . Cumulative frequencies of the fractions between 63 and 2000µm

	>1400	>1000	>710	>500	>355	>250	>180	>125	>90	>63
A12	1.4	4.8	14.6	33.0	50.4	68.6	82.6	92.4	98.0	100.0
A3	1.6	4.3	12.5	31.5	48.1	64.7	78.0	90.4	97.0	99.5
B21	1.0	5.0	12.1	31.5	48.9	67.3	80.6	90.8	96.9	99.9
B22	2.6	7.7	16.6	35.8	49.9	65.3	78.1	89.6	96.0	99.8
B23	2.6	7.7	15.4	30.8	48.7	65.3	76.8	88.3	93.4	99.8
B31	2.6	7.8	15.1	30.5	48.4	65.0	76.4	87.7	92.6	99.4
B32	1.3	4.7	22.0	42.0	54.0	70.0	80.7	92.7	97.7	99.4

Table 34 . Sedimentological parameters of the fractions between 63 and 2000µm

	Mz	1σ	3α	4α
A12	1.52	0.98	0.08	0.53
A3	1.58	1.01	0.06	0.62
B21	1.57	0.99	0.15	0.49
B22	1.53	1.09	0.08	0.68
B23	1.59	1.10	0.09	0.56
B31	1.59	1.11	0.12	0.54
B32	1.40	1.03	0.31	0.73

In the lowermost B3, the observed microstructures are 1) weak crumbly (crumbs 10 to 15 mm ø) with fissured and vughy cavited intrapedal m.s., and 2) strong and moderate very fine crumbly grading to spongy, having fissures and vughy cavited intrapedal m.s.

Channel infillings are very frequent throughout the profile and mostly show strong very fine crumbly microstructure, with occasional fissured intrapedal m.s. The pore pattern is similar to the subsoil horizons.

B. Matrix

B1. Coarse material (>5µm)

It is composed of angular, subangular and subrounded quartz grains from fine to coarse sand size. Fissured grains are common, particularly in the medium and coarse fractions. Runiquartz is generally present.

B2. Fine material (<5µm)

The fine material is brownish in the A12 and A3 horizons, yellowish in B21, B22 and B23, and reddish dotted in B31, mainly composed by kaolinitic clay and oxihydrates. Undifferentiated b-fabric is the only type present in A12 and largely dominant in the other horizons, where weakly expressed dotted and circular striated are locally present.

In channel infillings, the dominant b-fabric is undifferentiated; locally very weak dotted and circular striated are present.

B3. Coarse/fine related distribution

Enaulic to gefuric intergrades are dominant in the upper A12 and A3 horizons, locally, among finer grains, single, double and close porphyric. Underlaying horizons are mostly porphyric (single, double, open) and locally gefuric (single to open) between coarser grains.

In channel infillings, enaulic and gefuric types are observed.

C. Organic matter

Partially decomposed roots are frequent in the A12 horizon.

D. Features

Coatings of limpid kaolinitic clay are present in all horizons, ranging from few microns ø (less than 10) to about 0.1 mm ø. They occur in fissures, vughs and channels. They have yellow colors, weak to strong orientation and the boundaries are sharp and diffuse. In the upper A12 and A3 horizons they are rare to occasional, becoming frequent in the B2 horizon.

Laminated coatings and infillings composed of limpid and speckled clay are commonly observed in the B2 and B31 horizons; the size varies from 0.2 to 0.3 mm ø, occurring in vughs and channels. The color is yellow, with strong continuous orientation and sharp boundaries.

Coatings and infillings of iron-rich clay are frequently present throughout; their size ranges from 0.1 mm to 0.5 and occur mostly in vughs and channels. They show reddish colors, strong continuous orientation and sharp and diffuse boundaries.

Fragments of clay coatings (0.1-0.5 mm ∅) with sharp and diffuse boundaries are present throughout, located in the fine mass and inside channel infillings. Their frequency follows the clay coatings distribution.

Channel infillings (V.F.) are present in all horizons, ranging from 1 to 6 mm ∅, containing angular and rounded microaggregates and sand grains, and frequently showing darker color than the enclosing material.

E. Quantification of illuviation features

The results of point counting presented in table show that the percentages of clay coatings increase with depth from A12 (0.22%) to B23 (10.0%) and decreases in B31 (1.5%).

Therefore, the degree of clay illuviation (table) is very strong in the B2 horizon, decreasing in the upper and lower horizons. The clay illuviation index for the entire profile is very high (1204.8).

3.4.6. Classification

Although the profile has a dark Ap horizon, it is not thick enough to be umbric and therefore is an ochric epipedon.

During the field work only few, and doubtful clay skins were recognized in the B2 horizon. Thin sections confirmed not only the presence of abundant clay cutans throughout the B2, but also showed their presence in the overlaying A3 (1.7%) and A12 (0.22%) horizons. The clay content gradually increases with depth and the illuvial/ eluvial clay ratio between the A12 and A3 horizons is above 1.2, thus attending the requirements of the argil-

Table 35 . Quantitative micromorphological analysis of soil components (by point counting) in volume per cent of total soil

Depth (cm)	Horizon	Pores	Coarse material	Fine material	Coatings	Fragm.of coatings	Nodules	Roots
20- 43	A12	20.4	45.0	33.0	0.22	0.11	-	1.21
- 82	A3	16.4	47.0	34.3	1.7	0.45	-	
-120	B21	16.2	25.9	52.8	5.1	0.84	-	
-145	B22	15.0	20.3	57.6	6.8	0.3	-	
-180	B23	16.2	17.4	54.5	10.1	1.2	-	
-225	B31	22.5	14.2	61.1	1.5	0.44	0.17	

Table 36 . Degree of clay illuviation per horizon and profile clay illuviation index

Horizon	Thickness (cm)	% in situ + translocated illuviation features (on solid phase)	Degree of illuviation
A12	23	0.33	weak
A3	39	2.55	moderate
B21	38	8.15	very strong
B22	25	8.30	very strong
B23	35	13.50	very strong
B31	45	2.50	moderate
Profile clay illuviation index = 1204.8 per cent cm. Very high.			

lic horizons. From the B22 horizons downwards the clay content remains constant. Moreover, the subsoil has the properties of an oxic horizon.

Consequently, the profile is classified as a member of the clayey, kaolinitic, isohyperthermic family of the OXIC PALEUSTULTS.

CLASSIFICATION ACCORDING TO OTHER SYSTEMS

FAO/UNESCO	:	Ferric Acrisol.
BRAZILIAN SYSTEM	:	Red Yellow Podzolic, Dystrophic, low clay activity, prominent A horizon, clayey, semi-evergreen tropical forest, level phase
I.N.E.A.C. SYSTEM	:	Hygro-xero Ferrisol.

GEOMORPHOLOGICAL UNIT : PLATEAU C

3.5. Profile 6

I. Information of the site

Date of examination : 7/4/1980
Author : D. Barrera
Location : Caete mill. 3.5 km right from km 77 of
Maceió-Aracaju highway.
Approx. 36°05'W, 9°44'S.
Elevation : 125 m
Land form : 1) physiographic position : plateau
(see scheme C)
2) microtopography : very slightly undulated
Slope : class 1 (0-1%)
Land-use : sugarcane (monoculture).

II. Information of the soil

Parent material : clayey sediments
Geological formation and lithology : Barreiras Group.
Tertiary sediments.
Drainage : class 4 : well-drained
Moisture conditions in profile : dry throughout
Depth of groundwater table : unknown, no influence on
the profile.
Presence of surface stone, rock outcrops : none.
Human influence: confined to plow layer
Vegetation : semi-evergreen tropical forest

3.5.1. Morphological description

It is a deep, well-drained to moderately well-drained yellowish brown profile. Horizon differentiation between the transitional A3-B1 and the top of the B2 is fairly distinct and mostly remarked by the presence of mottling which starts in the B21. Structure is moderate in the Ap and A12, and weak long the rest of the profile. Cohesion is particularly high in the horizons B1, B21 and B22, that show hard consistence when dry. Root distribution is normal concentrated in the top 25 cm.

Ap - 0-12 cm. Very dark grayish brown (10 YR 3/2) moist, and dark grayish brown (10 YR 4/2) dry; sandy clay loam; weak moderate-fine subangular blocky and moderate medium granular; slightly hard, friable, plastic, sticky; many very fine and medium pores; many roots; smooth clear boundary.

A12 - 12-25 cm. (A) Very dark grayish brown (10 YR 3/2), moist, and very dark gray (10 YR 3/1)dry; sandy clay loam; weak moderate-fine subangular blocky, and moderate medium granular; slightly hard, friable, plastic and sticky; many very fine and medium pores; many roots; smooth clear boundary.

A3 - 25-43 cm. (AB or BA) Brown-dark brown (10 YR 4/3) moist; and brown (10 YR 5/3) dry; sandy clay; weak to moderate fine subangular blocky; slightly hard, friable, plastic and sticky; many very fine and fine pores, common roots; smooth gradual boundary.

B1 - 43-60 cm. (Bt1) Yellowish brown (10 YR 5/4) moist, and very pale brown (10 YR 7/4) dry; sandy clay; weak fine subangular blocky; hard, friable, plastic, sticky; many fine and very fine pores, and few medium ones; few roots; smooth clear boundary.

B21t - 60-135 cm. (Bt2) Yellowish brown (10 YR 6/6) moist, and light yellowish brown (10 YR 7/4) dry; common, fine and medium distinct diffuse yellowish red (5 YR 5/8) mottles; clay; very weak fine subangular blocky;(massive aspect in situ); hard, friable, plastic, sticky; many fine and very fine pores, and few medium ones; very few roots; smooth diffuse boundary.

B22t - 135-200 cm. (Bt3) Brownish yellow (10 YR 6/6) moist, and yellow (10 YR 7/6) dry; common fine and medium distinct diffuse red (2.5 YR 4/8) mottles; clay; very weak fine subangular blocky (massive aspect in situ); hard; friable, plastic and sticky; many fine and very fine pores; very few roots; smooth diffuse boundary.

B23 - 200-250 cm. (Bt4) Yellowish brown (10 YR 5/8) moist, and brownish yellow (10 YR 6/8) dry; clay; very weak, fine subangular blocky; slightly hard, friable, plastic, sticky; many fine and very fine pores, and few medium ones; very few roots.

Remarks : ( ) Horizon's nomenclature according to the Soil Survey Manual (1981).

3.5.2. Physico-chemical properties (table 37)

The results of the textural analysis point out the dominance of clay and sand in the fine earth. The silt fraction represents less than 4.2%. Clay gradually increases with depth from 29.8% in the Ap to about 70.0% in the deepest horizons. Markedly clay increases take place in the top soil, and in the upper subsoil :
1) from Ap (29.8%) to A12 (37.5%), from A12 to A3 (44.5%), from A3 to B1 (52.4%), and between the latter and B21 (62.8%). The sand fraction follows a similar but opposite decreasing trend with depth, from 67.8% in the top to about 26.0% in the lowest B22 and B23 horizons. The amounts of silt are very low and increase with depth from 2.3% in the A3 to 4.1% in the B23.

Silt/clay ratios are always very low, with somewhat higher figures in the top soil.

Bulk densities follow an increasing trend from the lowermost B23 (1.5 g/cc) to the top Ap (1.69 g/cc) horizon.

The cation exchange capacity per 100 g of soil is rather uniform throughout and somewhat higher in the subsoil; highest values are found in the B22 (7.2 meq.) and lowest in the A3 (4.1 meq.) horizon. Base saturation is highest in the upper Ap (53.5%) and A12 (40.2%) and lowest in the B1 (13.6%) and B23 (11.6%). Exchangeable bases are low and present similar trend throughout. Exchangeable aluminum shows fairly low values, being highest in the B1 horizon (0.78 meq.) and in the overlying A3 and A12 (0.62 meq.). The lowest figures are present in the Ap (0.22 meq.) and B22 (0.24 meq.) horizons.

The organic carbon content is highest in the Ap (1.48%) and regularly declines with depth to reach 0.18% in the lowermost B23 horizon.

The pH values are rather uniform throughout, ranging from 4.1 (pH/KCl) in the B1 to 4.5 in the Ap horizon.

3.5.3. Mineralogical composition

3.5.3.1. Sand fraction (50-250μm)

Light minerals are dominant in the light fraction, making 89 to 93% (weight %) of the total sample in the different soil horizons.

Fissured and highly weathered quartz grains and no more than traces of feldspars compose the light fraction (table 38). The heavy suite includes mainly opaques, where magnetic minerals are the most frequent. X-ray analysis shows that the opaque minerals consist of magnetite, ilmenite, hematite and goethite. Among the transparent minerals zircon is dominant, followed by very low amounts of tourmaline and the occasional presence of rutile.

3.5.3.2. Clay fraction (<2μm)

X-ray diffractograms indicate kaolinite as the unique mineral present in the clay fraction throughout the soil. D.T.A. and T.G.A. showed besides the presence of kaolinite that of minor amounts of gibbsite (table 39).

Table 37. Physico-chemical properties of profile 6

Depth (cm)	Horizon	Size class and particle diameter (mm)								
		TOTAL			SAND					COARSE FRAGM.
		Sand	Silt	Clay	V.C.	C.	M.	F.	V.F.	> 2 mm
		2-0.05	0.05-0.002	< 0.002	2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	
0- 12	Ap	67.8	2.4	29.8	2.2	15.3	22.2	23.4	4.7	0
- 25	A12	60.2	2.3	37.5	1.9	14.5	20.2	18.8	4.8	0
- 43	A3	53.2	2.3	44.5	3.0	13.5	17.4	15.4	3.9	0
- 60	B1	44.9	2.7	52.4	2.3	10.5	14.0	14.2	3.9	0
-135	B21	34.5	2.7	62.8	1.2	8.6	10.8	10.3	3.6	0
-200	B22	25.6	4.0	70.4	1.3	6.4	7.7	7.2	3.0	0
-250	B23	25.9	4.1	70.0	1.5	6.0	7.7	7.7	3.0	0

Depth (cm)	Organic carbon %	pH 1:1 KCl	pH 1:1 H_2O	Ext. Fe as Fe_2O_3 %	Ext. Al as Al_2O_3 %	Bulk density g/cm³	Silt/clay ratio	Coarse clay 2-0.2µ	Fine clay < 0.2µ	Fine clay/Tot. clay
0- 12	1.48	4.5	5.2	0.58	0.40	1.69	0.08	6.3	23.5	0.78
- 25	0.80	4.2	4.6	0.66	0.48	1.64	0.06	13.5	24.0	0.64
- 43	0.64	4.2	4.7	1.12	0.61	1.57	0.05	11.5	33.0	0.74
- 60	0.48	4.1	4.7	1.34	0.67	1.56	0.05	15.4	37.0	0.70
-135	0.28	4.4	5.0	1.70	0.68	1.65	0.04	20.0	42.8	0.68
-200	0.20	4.4	5.2	2.21	0.75	1.53	0.05	20.7	44.2	0.68
-250	0.18	4.4	5.1	2.0	0.82	1.50	0.05	-	-	-

Depth (cm)	Extractable bases (meq./100g soil)					Al 1NKCl	Extr. acidity KCl pH 8.2	C.E.C. meq./100g soil		C.E.C. meq./100g clay		Base saturation (%)	
	Ca	Mg	K	Na	Sum			NH_4OAc	sum cations	NH_4OAc	E.C.E.C.	NH_4OAc	sum cations
0- 12	2.19	0.52	0.13	0.25	2.89	0.22	5.1	5.4	8.0	18.2	10.4	53.5	36.1
- 25	0.87	0.48	0.10	0.08	1.73	0.62	6.1	4.3	7.8	11.6	6.3	40.2	22.0
- 43	0.68	0.11	0.02	0.08	0.89	0.62	6.3	4.1	7.1	9.4	3.4	21.7	12.4
- 60	0.44	0.19	0.01	0.07	0.71	0.78	5.6	5.2	6.3	11.0	3.1	13.6	11.2
-135	0.90	0.33	0.01	0.08	1.32	0.30	2.6	6.8	3.9	10.8	2.6	20.8	33.8
-200	0.56	0.63	0.03	0.08	1.30	0.24	3.7	7.2	5.0	8.5	2.2	23.6	26.0
-250	0.37	0.33	0.05	0.09	0.84	0.38	3.8	5.5	4.6	11.3	1.7	11.6	18.2

Table 38. Mineral composition of the sand fraction (50-250μm) of profile 6

Hor.	Depth (cm)	Light minerals		Heavy minerals			
		Quartz	Feldspars	Opaques	Zircon	Tourma-line	Rutile
Ap	0- 12	100	0.0	92.9	6.3	tr.	0.0
A2	- 25	>99	tr.	89.9	9.3	"	"
A3	- 43	100	0.0	89.0	10.5	"	"
B1	- 60	100	"	90.0	8.7	"	"
B21	-135	100	"	89.0	10.4	"	tr.
B22	-200	>99	tr.	90.6	9.0	"	"
B23	-250	100	0.0	90.1	9.1	"	0.0

tr. (traces) = <1%.

Table 39. Mineralogical composition of the clay fraction (<2μm) of profile 6

Hor.	Depth (cm)	Clay fraction		
		X-ray	D.T.A.	T.G.A.
A12	12- 25	K	K, G	K5, G1
A3	- 43	K	-	-
B21	-135	K	K, G	K5, G1
B22	-200	K	K, G	K5, G1

Mineral code : K : kaolinite; G : gibbsite.
Approx. weight fraction (T.G.A.) : 5 : more than half; 4 : half to one third; 3 : one third to one fifth; 2 : one fifth to one twentieth; 1 : less than one twentieth.

3.5.4. Sedimentology

The detailed particle size distribution of the fractions between 63 and 2000 microns for the A12, A3, B1, B21, B22 and B23 horizons is given in table 40.

The cumulative frequencies of the fractions between 63 and 2000 microns and the sedimentological parameters are respectively shown in tables 41 and 42.

The cumulative curves drawn in probability scale are presented in fig. 9.

- The horizon A12 shows moderately asymmetric and positively skewed ($\alpha 3\ \phi = 0.15$), platykurtic ($\alpha 4\ \phi = 0.62$) distribution, with a Mz value of 1.54 ϕ and a standard deviation ($G1\ \phi = 0.97$) that indicates a moderate sorted material.

- The distribution curve of the A3 horizon is asymmetric, with positive skewness ($\alpha 3\ \phi = 0.25$), platykurtic ($\alpha 4\ \phi = 0.55$), with a Mz of 1.51 ϕ and showing similar sorting ($G1\ \phi = 1.02$) as the preceeding horizon.

- The B1 horizon distribution is moderately asymmetric, positively skewed ($\alpha 3\ \phi = 0.14$), platykurtic ($\alpha 4\ \phi = 0.65$) with a Mz of 1.59 ϕ and having a similar sorting ($G1\ \phi = 1.05$) as the upper horizons.

- The distribution for horizon B21 is asymmetric, positively skewed ($\alpha 3\ \phi = 0.22$), platykurtic ($\alpha 4\ \phi = 0.63$); tne value for the Mz is 1.61 ϕ and the standard deviation ($G1\ \phi = 1.05$) indicates a moderate sorting.

- The horizon B22 shows a moderately asymmetric, positively skewed, ($\alpha 3\ \phi = 0.17$), platykurtic ($\alpha 4\ \phi = 0.77$) distribution, with a Mz value of 1.57 ϕ and a standard deviation (G1 ϕ = 1.09) indicating similar sorting as the above horizon.

- The distribution curve of horizon B23 is moderately asymmetric, positively skewed ($\alpha 3\ \phi = 0.09$), platykurtic, with a Mz value of 1.52 and showing similar sorting (G1 ϕ = 1.05) as the rest of the profile.

The mean grain size of particles is very similar for all the horizons,

The standard deviations also present an extremely uniform pattern, with figures about G1 ϕ = 1.0.

The skewness values are rather similar in all horizons, ranging from $\alpha 3\ \phi = 0.09$ in the B23 to $\alpha 3\ \phi = 0.25$ in the A3 .

The kurtosis is very uniform throughout, being highest in the B22 ($\alpha 4\ \phi = 0.77$) and lowest in the A3 ($\alpha 4\ \phi = 0.55$).

Therefore, it is concluded that the parent material is, from sedimentological viewpoint, uniform in the whole profile.

3.5.5. Micromorphology

A. Microstructure and pore pattern

The microstructure of the A12 horizon is strong and moderate very fine crumbly intergrading to spongy, with fissures and vughy cavited intrapedal m.s. Locally, moderate medium crumbly (crumbs 2-3 mm ϕ) showing occasional fissured intrapedal m.s. is present. Very frequent interpedal compound packing pores and vughs normally interconnected, are

Table 40 . Particle size distribution of the fractions between 63 and 2000μm

	1400 - 2000	1000 -1400	710 -1000	500 - 710	355 -500	250 -355	180 -250	125 - 180	90 -125	63 - 90
A12	0.7	3.7	8.9	20.4	17.0	17.5	12.6	11.8	5.2	2.2
A3	0.9	4.5	10.2	19.5	15.7	17.5	12.9	9.2	5.5	3.7
B1	1.1	4.5	9.1	18.1	14.7	17.0	13.6	11.4	5.7	4.5
B21	1.4	2.9	10.1	17.4	15.9	15.9	13.1	10.2	8.7	4.3
B22	2.0	3.0	13.5	16.5	12.5	18.8	12.5	10.2	8.4	2.0
B23	1.2	4.8	13.0	14.2	14.2	19.0	9.4	11.8	7.1	4.8

Table 41 . Cumulative frequencies of the fractions between 63 and 2000μm

	>1400	>1000	>710	>500	>355	>250	>180	>125	>90	>63
A12	0.7	4.4	13.3	33.7	50.7	68.2	80.8	93.2	98.4	100.0
A3	0.9	5.4	15.6	35.1	50.8	68.3	81.2	90.4	95.4	99.6
B1	1.1	5.6	14.7	32.8	47.5	64.5	79.1	89.5	95.2	99.7
B21	1.4	4.3	14.4	31.8	47.7	63.6	76.7	86.9	95.6	99.9
B22	2.0	5.0	18.5	35.0	47.5	66.3	78.8	89.0	97.4	99.4
B23	1.2	6.0	19.0	33.2	47.4	66.4	75.8	87.6	94.7	99.5

Table 42 . Sedimentological parameters of the fractions between 63 and 2000μm

	Mz	1σ	3α	4α
A12	1.54	0.97	0.15	0.62
A3	1.51	1.02	0.25	0.55
B1	1.59	1.05	0.14	0.65
B21	1.61	1.05	0.22	0.63
B22	1.57	1.09	0.17	0.77
B23	1.52	1.05	0.09	0.75

dominant. Also very frequent fissures of few µm ø and frequent smooth channels were observed.

The transitional A3 and B1 horizons are dominantly spongy, with fissured and vughy cavited intrapedal m.s. that locally grades to 1) weak coarse crumbly (crumbs about 10 mm ø), with fissured and vughy cavited intrapedal m.s., and to 2) weak very fine crumbly, with fissured cavited intrapedal m.s. Very frequent fissures (few µm ø) and rough and smooth vughs mostly interconnected are dominant, and frequent smooth channels subordinated.

In the B21 and B22 horizons moderate coarse crumbly (crumbs about 10 mm ø) microstructure, with fissured and vughy cavited intrapedal m.s., and strong very fine granular macrostructure with occasional fissured cavited intrapedal m.s. were observed. The pore pattern is similar to the overlaying B1 horizon.

The lowermost B23 horizon presents strong and moderate coarse crumbly microstructure (crumbs from 5-7 mm ø), witn fissured and vughy cavited intrapedal m.s.; frequently grading to spongy. The pore pattern is similar to the overlaying soil horizon.

Channel infillings are present in the whole profile and show mostly strong and weak very fine granular microstructure. Locally strong and weak very fine crumbly with fissured intrapedal m.s. is observed. Very frequent interpedal compound packing pores are dominant, followed by common fissures.

B. Matrix

B1. Coarse material (>5μm)

Fine to coarse sand-sized, angular, subangular and subrounded grains of quartz, compose the coarse material throughout. Fissured and corroded grains are frequently observed, Runiquartz are common.

B2. Fine material (≤5μm)

It is brownish yellow in the A12 and A3 horizons and turn to yellowish with depth, composed of kaolinitic clay and oxihydrates. In the top layers, the fine material is darker, due to the higher organic matter content. Undifferentiated b-fabric is dominant throughout, and exclusive in the uppermost A12 horizon. Dotted, circular striated, poro-striated are subordinated and weakly expressed. In channel infillings, only undifferentiate b-fabric was observed.

B3. Coarse/fine related distribution

Single and double spaced gefuric to enaulic is dominant in horizon A12, locally porphyric. In the A3 mostly porphyric with locally close gefuric and enaulic .
In the underlaying horizons, porphyric is largely dominant and gefuric is locally present. In channel infillings, enaulic and gefuric types are the most frequent.

C. Organic matter

In the upper horizons the organic matter is occasionally apparent as humified root remains and as fecal pellets.

D. Features

Coatings and infillings of limpid kaolinitic clay ranging from 10µm to about 0.9 mm ø occur in fissures, vughs and channels in almost the whole profile. The color is yellow, the orientation weak to strong and the boundaries from diffuse to sharp. In the top layers they are rare, and very frequent in the upper part of the B2 horizon.

Laminated coatings and infillings of limpid and speckled clay are found in the B2 horizon; their size ranges from 30µm to 1.0 mm ø, mostly occurring in vughs and channels, they have a yellow color, strong continuous orientation and sharp boundaries.

Coatings of iron-rich clay were observed in the subsoil (B21 and B22 horizons); their size ranges from 0.2 mm to 0.4 mm ø; they are located in vughs and channels. They have reddish colors, strong continuous orientation and rather sharp boundaries.

Fragments of clay coatings about 0.25 mm ø with sharp and diffuse boundaries occur in the fine mass and inside channel infillings; they are more frequently observed in the A3 and B1 horizons.

Loose channel infillings of microaggregates and quartz grains are observed throughout the profile. They are tabular shaped and range from 1-6 mm ø.

In the subsoil they are readily identified as they are mostly located between crumbs (defining structure). In upper horizons, where the material appears totally reworked, their recognition is difficult, particularly in the transitional A3 and B1 horizons.

E. Quantification of illuviation features

The results of point counting for quantification of clay illuviation are presented in table 43. Clay coatings show highest percentages in the B2 horizon (B21 = 7.0% and B22 = 4.2%) and were not observed in the top A12. The degree of clay illuviation, shown in table 44, is very strong in the B21 and strong in the B22 horizons, where figures are highest. The clay illuviation index for the total profile is very high.

3.5.6. Classification

The upper Ap and A12 horizons are dark but not thick enough to be umbric, thus forming an ochric epipedon. In the field uncertain patchy clay skins were observed in the top of the B horizon. Thin sections showed the presence of clay cutans throughout the B horizon and also in the overlaying A3 (table 43). The clay content increases gradually with depth and the clay increase requirea for an argillic horizon is reached between Ap and A3 (clay ratio 1.2), and from A3 to B1 (>8% absolute clay). From the horizon B22 downwards the clay content is constant. Moreover, the subsoil has the properties of an oxic horizon.

Thus, the profile is classified as a member of the clayey, kaolinitic, isohyperthermic family of the OXIC PALEUSTULTS.

CLASSIFICATION ACCORDING TO THE OTHER SYSTEMS

FAO/UNESCO SYSTEM	:	Ferric Acrisol
BRAZILIAN SYSTEM	:	Red Yellow Podzolic, Dystrophic, low clay activity, prominent A horizon, clayey, semi-evergreen tropical forest, level phase
I.N.E.A.C. SYSTEM	:	Hygro-xero Ferrisol.

Table 43 . Quantitative micromorphological analysis of soil components (by point counting) expressed in volume per cent of total soil

Depth (cm)	Horizon	Pores	Coarse material	Fine material	Coatings	Fragm.of coatings	Nodules
12- 25	A12	23.2	41.2	35.7	0.0	0.0	-
- 43	A3	12.6	35.7	51.5	0.31	0.31	-
- 60	B1	18.3	21.5	57.8	2.12	0.26	-
-135	B21	13.0	17.9	61.9	7.06	0.0	-
-200	B22	15.9	10.7	68.8	4.17	0.15	0.30
-250	B23	23.9	18.4	54.9	1.49	0.24	1.00

Table 44 . Degree of clay illuviation per horizon and profile clay illuviation index

Horizon	Thickness (cm)	% in situ + translocated illuviation features (on solid phase)	Degree of illuviation
A12	13	0.0	-
A3	18	0.7	weak
B1	17	2.9	moderate
B21	75	8.1	very strong
B22	65	5.1	strong
B23	50	2.3	moderate
Profile clay illuviation index = 1118.4 per cent. Very high.			

3.6. Profile 9

I. Information of the site

Date of examination : 28/5/1980
Author : D. Barrera
Location : Caete mill. 1.5 km right from km 73 of Maceio-Aracaju highway.
Elevation : 125 m
Land form : 1) physiographic position : plateau (see scheme C)
2) microtopography : nil.
Slope : class 1 (0-1%)
Land-use : sugarcane (monoculture)

II. Information of the soil

Parent material : sandy clay sediments
Geological formation and lithology : Barreiras Group. Tertiary sediments.
Drainage : class 3 . moderately well-drained
Moisture conditions in profile : dry throughout
Depth of groundwater table : perched watertable above the B2 horizon
Presence of surface stone, rock outcrops : none
Human influence : confined to plow layer
Vegetation : semi-evergreen tropical forest.

3.6.1. Morphological description

The profile is deep, imperfectly drained, with brown and grayish colors. Horizonation is rather contrasting, having a clear-abrupt transition between the B/A and B21x horizons. Structure is moderate throughout; subangular blocky in the top soil and angular blocky in the subsoil, wnere organic coatings, iron-rich coatings and red mottles take place. Cohesion is very high in the subsoil - B21x and B22x horizons - that presents extremely hard consistence when dry. Root distribution is normal and rather deep, with most of the roots concentrated in the top 20 cm.

<u>Ap - 0-20 cm</u>. Dark yellowish brown (10 YR 2.5/1) moist; and dark yellowish brown (10 YR 3/1) dry; sandy clay loam; weak very fine granular; slightly hard, friable, non-plastic, slightly sticky; abundant roots; abrupt smooth boundary.

<u>A12 - 20-50 cm</u>. Brown-dark brown (10 YR 4/2) moist, and
(A) dark gray (10 YR 4/1) dry; sandy clay; weak fine subangular blocky, and moderate medium granular; many very fine and medium pores; hard, friable, plastic, sticky; many roots; gradual smooth boundary.

<u>B/A - 50-90 cm</u>. Dark gray (10 YR 4/1) moist, and gray-
(E/B) light gray (10 YR 6/1) dry; sandy clay; moderate medium subangular blocky; hard, firm, plastic, sticky; common roots; clear irregular boundary.

<u>B21x - 90-150 cm</u>. Pale brown (10 YR 6/3) moist, and slight
(B1x) gray (10 YR 7/2) dry; clay; massive and moderate medium subangular blocky; very-extremely hard; very friable, slightly plastic, slightly sticky; very few roots; clear smooth boundary.

<u>B22x - 150-250 cm</u>. Light gray (10 YR 7/2) moist, and white
(B2x) (10 YR 8/1) dry; clay (massive) and moderate medium subangular blocky; extremely hard, friable, slightly plastic, slightly sticky; no roots.

<u>Remarks</u> : Massive incorporation of organic matter (filter cake).

B21x : organic matter infiltration,stains, dark gray (10 YR 4/1) dry.

B22x : red stains (till 40 cm length) 2.5 YR 4/6 dry, common, medium and coarse, distinct, clear.

( ) : horizon's nomenclature according to the Soil Survey Manual (1981)

3.6.2. Physico-chemical properties (table 45)

The results of the mechanical analysis (table 45) show that the sand and clay fractions are dominant in the upper 150 cm of the profile, where the silt increases with depth from less than 2.9% to 12%. Below that depth, the clay is largely dominant (58.7%), followed by 22.8% of silt and 18.5% of sand. The clay content increases rather strongly from the Ap (31.4%) to the underlaying A12 (43.2%) and from the B/A (46.7%) to the B2x horizons (about 58.0%). The silt which is very low in Ap (2.0%), A2 (2.0%) and B/A (2.8%) raises markedly in B21x (12.2%) and B22x (22.8%). The medium and fine sand make up the larger proportion of the total sand fraction.

Silt/clay ratios are very low in Ap, A2 and B/A (from 0.03 to 0.06), and significantly higher in B21x (0.21) and B22x (0.38).

Bulk densities are highest in the lowermost B22x (1.59 g/cc) horizon.

The nutrient status for plant growth is very low. The cation exchange capacities per 100 grams of soil are highest in B21x (9.0 meq.) and in the Ap (8.1 meq.) horizons; lower values are found in the B22x (4.2 meq.), B/A (2.8 meq.) and Ap (2.9 meq.).

Exchangeable aluminum is absent in the Ap horizon and low in other horizons (from 0.5 to 1.0 meq.). This results in a relatively high base saturation in Ap (54.1%), A12 (39.3%) and B/A (38.5%), that markedly decline in the subsoil, particularly in the B21x (8.52%) horizon.

The pH (H_2O and KCl) are highest in the Ap and B21x horizons, intermediary in B22x and lowest in A12 and B/A horizons.

Table 45. Physico-chemical properties of profile 9

Depth (cm)	Horizon	Size class and particle diameter (mm)								COARSE FRAGM.
		TOTAL			SAND					
		Sand	Silt	Clay	V.C.	C.	M.	F.	V.F.	> 2 mm
		2-0.05	0.05-0.002	< 0.002	2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	
0- 20	Ap	66.6	2.0	31.4	2.7	21.3	23.2	15.6	3.8	0
- 50	A12	55.3	1.5	43.2	2.2	17.0	18.4	13.3	4.4	0
- 90	B/1	50.5	2.8	46.7	2.7	14.9	16.4	12.6	3.9	0
-150	B21 x	29.9	12.2	57.9	1.2	6.9	8.4	8.2	5.2	0
-250	B22 x	18.5	22.8	58.7	0.9	4.1	5.3	5.4	2.8	0

Depth (cm)	Organic carbon %	pH 1:1 KCl	pH 1:1 H_2O	Ext. Fe as Fe_2O_3 %	Ext. Al as Al_2O_3 %	Bulk density g/cm³	Silt/clay ratio	Coarse clay 2-0.2µ	Fine clay < 0.2µ	Fine clay/Tot. clay
0- 20	2.34	5.7	6.3	0.19	0.31	1.56	0.06	11.3	20.1	0.64
- 50	1.0	4.3	5.0	0.21	0.43	1.45	0.03	15.5	27.7	0.64
- 90	0.46	4.3	4.9	0.17	0.51	1.39	0.06	16.3	30.4	0.65
-150	1.12	4.7	5.4	0.13	2.21	1.38	0.21	55.0	2.9	0.05
-250	0.22	4.5	5.1	0.40	0.61	1.59	0.38	26.7	20.7	0.35

Depth (cm)	Extractable bases					Al 1NKCl	Extr. acidity KCl pH 8.2	C.E.C.				Base saturation (%)	
	Ca	Mg	K	Na	Sum			NH_4OAc	sum cations	NH_4OAc	E.C.E.C.	NH_4OAc	Sum cations
	meq./100g soil							meq./100g soil		meq./100g clay			
0- 20	13.22	3.1	0.51	0.16	17.0	0.0	0.66	8.1	17.7	25.7	17.0	54.1	96.0
- 50	0.51	0.33	0.17	0.13	1.14	0.98	2.62	2.9	3.8	6.9	4.9	39.3	30.0
- 90	0.44	0.33	0.15	0.16	1.08	1.0	5.3	2.8	6.4	5.9	4.5	38.5	17.0
-150	0.46	0.15	0.08	0.12	0.81	0.56	5.1	9.0	6.0	15.5	2.36	8.52	13.6
-250	0.57	0.19	0.01	0.16	0.93	0.52	2.5	4.2	3.5	8.9	3.05	22.1	26.8

The organic carbon content is rather high in the Ap (2.34%) and strongly decreases with depth to 1% in the A12 and 0.46% in the B/A.

3.6.3. Mineralogical composition

3.6.3.1. Sand fraction (50-250µm)

The sand fraction is dominated by the light minerals that constitute 91 to 96% (weight %) of the total sample throughout the soil.

The light fraction is formed by highly weathered and fissured quartz grains and traces of feldspars (table 46). The heavy fraction is mainly formed by opaques, where magnetic minerals are dominant. X-ray analysis showed that the opaque minerals consist of magnetite, ilmenite, hematite and goethite. Zircon is dominant among the transparent minerals of the heavy fraction followed by very low amounts of tourmaline and rutile.

Table 46 . Mineralogical composition of the sand fraction (50-250µm) of profile 9

Hor.	Depth (cm)	Light minerals		Heavy minerals			
		Quartz	Feldspars	Opaques	Zircon	Tourmaline	Rutile
Ap	0- 20	100	0.0	92.7	6.5	tr.	0.0
A12	- 50	>99	tr.	89.4	10.0	"	"
B/A	- 90	"	"	96.8	2.5	0.0	"
B21x	-150	"	"	95.6	5.04	tr.	"
B22x	-250	"	"	89.2	10.4	"	"

tr. (traces) = <1%.

3.6.3.2. Clay fraction (<2μm)

X-ray analysis results presented in table 47 show that the clay fraction of all horizons is only composed of kaolinite. D.T.A. and T.G.A. confirmed this result and also determined the occurrence of minor amounts of gibbsite throughout.

Table 47 . Mineralogical composition of the clay fraction (<2μm)of profile 9

Hor.	Depth (cm)	Clay fraction		
		X-ray	D.T.A.	T.G.A.
A12	20- 50	K	K, G	K5, G1
B21x	-150	K	K, G	K5, G1
B22x	-250	K	K, G	K5, G1

Mineral code : K : kaolinite; G : gibbsite.
Approx. weight fractions (T.G.A.) : 5 : more than half; 4 : half to one third; 3 : one third to one fifth; 2 : one fifth to one twentieth; 1 : less than one twentieth.

3.6.4. Sedimentology

The detailed particle size distribution of the fractions between 63 and 2000 microns of the A12, B/A, B21x and B22x horizons are shown in table 48 . They are supposed not to migrate or to suffer significant changes during the soil formation.

Tables 49 and 50 give respectively the cumulative frequencies of the fractions between 63 and 2000 microns and the sedimentological parameters.

The cumulative curves plotted on probability paper were drawn in fig. 10.

The A2 horizon shows a strongly, positively skewed ($\alpha 3\ \phi = 0.46$) and platykurtic distribution ($\alpha 4\ \phi = 0.38$), with a Mz value of 1.38 ϕ and a standard deviation ($G1\ \phi = 0.98$) indicating a moderately sorted material (Folk and Ward, 1957).

The distribution curve of the B/A horizon is asymmetric, positively skewed ($\alpha 3\ \phi = 0.24$), platykurtic ($\alpha 4\ \phi = 0.47$); the Mz value is 1.43 ϕ and shows similar sorting as the preceeding horizon ($G2\ \phi = 1.04$).

The B21x horizon presents a moderately asymmetric, positively skewed ($\alpha 3\ \phi = 0.14$) and platykurtic ($\alpha 4\ \phi = 0.86$) distribution curve, a Mz value of 1.61 ϕ and similar sorting as the upper horizons ($G1\ \phi = 1.15$).

The B22x horizon shows a symmetric ($\alpha 3\ \phi = 0.0$) and platykurtic ($\alpha 4\ \phi = 0.99$) distribution, with a Mz value of 1.69 ϕ and similar sorting as the rest of the profile ($G1\ \phi = 1.24$).

The upper A12 and B/A horizons, with respectively Mz values of 1.38 ϕ and 1.43 ϕ are very similar and somewhat coarser than the also highly similar subsurface B21x ($Mz\ \phi = 1.61$) and B22x ($Mz\ \phi = 1.65$) horizons (see table 50).

The values of the standard deviations gradually increase with depth, from $G1\ \phi = 0.95$ in the A12 to $G1\ \phi = 1.24$ in the B22x horizon.

The skewness grades from a markedly asymmetric, positively skewed distribution in the uppermost A12 ($\alpha 3\ \phi = 0.46$) to a perfectly symmetric curve in the lowest B22x ($\alpha 3\ \phi = 0.00$) horizon, with intermediary values in the B/A ($\alpha 3\ \phi = 0.24$) and B21x ($\alpha 3\ \phi = 0.14$) horizons.

Table 48 . Particle size distribution of the fractions between 63 and 2000μm

	1400 -2000	1000 -1400	710 -1000	500 -710	355 -500	250 -355	180 -250	125 -180	90 -125	63 - 90
A12	0.90	3.70	13.1	23.3	17.7	15.9	9.3	8.4	4.7	2.8
B/A	1.90	5.70	10.4	21.9	18.0	15.3	12.3	7.6	4.5	3.4
B21x	2.50	2.50	15.0	12.5	17.5	15.0	10.0	7.5	12.5	5.0
B22x	3.80	5.80	9.6	15.4	11.5	15.3	7.70	11.5	11.5	7.7

Table 49 . Cumulative frequencies of the fractions between 63 and 2000μm

	>1400	>1000	>710	>500	>355	>250	>180	>125	>90	>63
A2	0.90	4.60	17.7	41.0	58.7	74.6	83.9	92.3	97.0	99.8
B/A	1.90	7.60	18.0	39.9	57.9	73.2	85.5	93.1	97.6	100.0
B21x	2.50	5.0	20.0	32.5	50.0	65.0	75.0	82.5	95.0	100.0
B22x	3.80	9.60	19.2	34.6	46.1	61.4	69.1	80.6	92.1	99.8

Table 50 . Sedimentological parameters of the fractions between 63 and 2000μm

	Mz	1σ	3α	4α
A2	1.38	0.98	0.46	0.38
B/A	1.43	1.04	0.24	0.47
B21x	1.61	1.15	0.14	0.86
B22x	1.65	1.24	0.00	0.99

No matter, all distributions are platykurtic, the top A12 ($\alpha 4\ \phi = 0.38$) and B/A ($\alpha 4\ \phi = 0.47$) present clearly more peaked curves than the underlaying B21x ($\alpha 4\ \phi = 0.86$) and B22x ($\alpha 4\ \phi = 0.99$).

Most of the parameters indicate the extreme sedimentological similarity between the uppermost A12 and B/A horizons, which are somewhat different from sedimentological point of view with respect to the also highly similar B21x and B22x horizons.

3.6.5. Micromorphology

A. Microstructure and pore pattern

Weak, moderate and strong very fine crumbly microstructures with fissured and vughy cavited intrapedal m.s. are dominant in the A12 and B/A horizons. Locally, strong and moderate medium crumbly (crumbs of 2-5 mm ø), with fissured and vughy cavited intrapedal m.s. is also present. Very frequent interpedal compound packing pores and vughs mostly interconnected, are dominant, and very frequent smooth channels and fissures of few µm ø, subordinated.

In the B21x horizon, the microstructure is spongy, grading to moderate crumbly (crumbs of 10-20 mm ø), having fissured and vughy cavited intrapedal m.s. Very frequent rough and smooth vughs frequently interconnected and smooth fissures dominate; smooth channels are frequent.

Channel infillings are present in all horizons and in most cases show strong very fine crumbly microstructure, with fissured and vughy cavited intrapedal m.s. Interpedal compound packing pores and interconnected vughs are mostly present; intrapedal fissures are subordinated.

B. Matrix

B1. Coarse material (>5μm)

Sand-sized, angular, subangular and subrounded grains of highly weathered quartz, compose the coarse material throughout.

B2. Fine material (<5μm)

In the A12 and B21x horizons the fine material is darker because of the higher organic matter contents.
Undifferentiated b-fabric is present in all horizons.
Very rarely dotted b-fabric, very weakly expressed, was also observed.
In channel infillings undifferentiated b-fabric is exclusively present.

B3. Coarse/fine related distribution

The dominant related distribution in the upper A12 and B/A horizons is porphyric and locally enaulic. The subsoil (B21x and B22x) is porphyric throughout.

In channel infillings, the dominant type is enaulic; also gefuric is locally present.

C. Organic matter

Root fragments, partly decomposed, were observed in the A12 horizon.

D. Features

Coatings and infillings of parallel layers of limpid and speckled yellow clay are frequently found in the subsoil B21x horizon, the sizes range from 50μm to about 150μm, occurring in vughs, packing pores, channels and fissures. They present strong continuous orientation, sharp boundaries and are frequently fissured.

Fragments of limpid yellow coatings, about 100 microns ø, are frequently present in the fine mass. They have rather sharp boundaries and strong continuous orientation.

Channel infillings (V.F.) are present in the whole profile, ranging from 1.0 to 1.5 mm ø, generally formed by dark brown microaggregates of fine material and quartz grains. Their identification becomes easier in the subsoil.

Laminated coatings of pale yellow and black parallel layers are frequently observed in the B21x horizon. They range from 50 to 100µm ø and mostly occur in vughs and channels.

Highly humified organic (monomorphic) coatings and infillings of few µm ø (<10) are frequently observed in fissures and on top of grains of the B21x horizon. They have smooth and rugose surfaces and their boundaries are sharp.

E. Quantification of illuviation features

The results of point counting for quantification of clay illuviation are presented in table 51. No illuviation features were observed in the upper A12 and B/A horizons. Only the horizon B21x present 3.5% of coatings and infillings and 0.27% fragments of illuvial features. The lowermost B22x horizon was not sampled.

Table 51. Quantitative micromorphological analysis of soil components (by point counting) expressed in volume per cent of total soil

Depth (cm)	Hor.	Pores	Coarse material	Fine material	Coatings	Frag. of coatings
20- 50	A12	28.32	28.04	43.62	0.0	0.0
50- 90	B/A	27.35	23.27	49.37	0.0	0.0
90-150	B21x	12.80	18.00	65.20	3.5	0.27

3.6.6. Classification

This profile has a dark Ap horizon which is not thick enough to be mollic, and thus it is an ochric epipedon, underlain by an albic horizon occurring between 50 and 90 cm. Below that depth, a clayey highly cohesive subsoil (B21x and B22x horizons) is present showing in the upper part (B21x) a rather high organic matter content. The properties of an oxic horizon are present throughout, except in the Ap. No clay skins were observed in the field but thin sections showed 3.5% illuviation cutans in the B21x, and also organic coatings on grains and pores. The clay content gradually increases with depth and remains constant from B21x downwards; the requirements for an argillic horizon are reached between Ap and A12, and between B21x and B22x.

Thus considering the ustic soil moisture regime and the low activity of the clay fraction, the profile is classified as a mamber of the USTIC, ORTHOXIC PALEHUMULTS.

CLASSIFICATION ACCORDING TO OTHER SYSTEMS

FAO/UNESCO SYSTEM : Orthic Acrisol

BRAZILIAN SYSTEM : Red Yellow Podzolic-Podzol intergrade, distrophic, with fragipan, low clay activity, weak A horizon, clayey,semi-evergreen tropical forest, level phase.

3.7. Profile 7

I. Information of the site

Date of examination : 17/5/1980
Author : D. Barrera
Location : Caeté mill. 5 km left from km 74 of Maceió-
Aracaju highway.
Approx. 36°05'W, 9°44'S.
Elevation : 102 m.
Land form : 1) physiographic position : plateau
(see scheme C)
2) microtopography : nil.
Slope : class 1 (0-1%)
Land-use : sugarcane (monoculture) and cerrado.

II. General information of the soil

Parent material : sandy sediments
Drainage : class 2-1 : imperfectly drained-poorly drained
Moisture conditions of the profile : dry throughout.
Depth of groundwater table : G.W.T. oscillates between
the ortstein and the top soil during the
rainy season.
Presence of surface stone, rock outcrops : none.
Vegetation : low and not dense, semi-evergreen tropical
cerrado.
Human influence : confined to plow layer. Massive additions
of organic matter (filter cake).

3.7.1. Morphological description

The profile is deep, imperfectly to poorly drained, snowing contrasting soil properties between a structureless sandy epipedon which lies on top of an indurated clayey B (ortstein) horizon at 110 cm depth. Root penetration is poor, concentrated in the upper 15 cm

Ap - 0-15 cm. Very dark gray (10 YR 3/1) moist, and dark gray (10 YR 4/1) dry; sand; single grain, weak fine granular; many fine and very fine common medium pores; soft, very friable, non-plastic, non-sticky; abundant roots; gradual smooth boundary.

A12 - 15-40 cm. Dark gray (10 YR 4/1) moist, and gray-
(A) light gray (10 YR 6/2) dry; sand; single grain; many very fine pores; loose, non-plastic, non-sticky; common roots; smooth diffuse boundary.

A22 - 80/90 cm. Light brownish gray (10 YR 6/2) moist, and
(E) light gray (10 YR 7/1) dry; sand; single grain; many very fine pores; loose, non-plastic, non-sticky; few roots; wavy abrupt boundary.

Bh - 80/90-110/130 cm. Very dark gray (10 YR 3/1) moist, and very dark grayish brown (10 YR 3/2) dry; loamy sand; single grain; weak fine subangular blocky; slightly hard, friable, slightly plastic, slightly sticky; many very fine pores; few roots; clear wavy boundary.

B21 h.ir.m. - 110/130-175 cm. Brownish yellow (10 YR 6/8)
(B1 h.s.m.) moist, and very pale yellow (10 YR 8/3) dry;[1] clay; strong medium-coarse subangular blocky and platy; very hard, very firm, slightly plastic, slightly sticky; few pores; humus accumulation and red (2.5 YR 5/8) coatings between structure elements; many old decomposed roots and very few living ones; clear wavy boundary.

B22 h.ir.m. - 175-250 cm. Very pale brown (10 YR 5/4)
(B2 h.s.m.) moist, and yellowish brown (10 YR 7/4) dry; [2] clay; massive; very-extremely hard, very-extremely firm, slightly plastic, slightly sticky; many old root channels with accumulation of organic material; reddish brown (5 YR 4/4) and organic matter and iron stains along fracture planes; few pores; no roots.

Remarks : B21 - 1. Few, fine, faint-distinct reddish brown (2.5 YR 5/4) mottles.
B22 - 2. Common, medium, prominent, yellowish-red (5 YR 5/8) mottles.

The Bh horizon is discontinuous.

Thin iron pan (± 1 cm thick) in B21 h.ir.m.

( ) Horizon's nomenclature according to the Soil Survey Manual (1981).

3.7.2. Physico-chemical properties (table 52)

The results of the mechanical analysis (table 52) indicate the almost exclusive presence of sand in the upper horizons in contrast with the subsoil where the clay makes up the dominant fraction. The silt content is very low throughout ranging from 2.0 to 4.8%, except in the B21 h.ir.m. horizon where it reaches 13.2%. In the surface Ap, A21 and A22 horizons, the clay fraction represents respectively 6.0, 0.2 and 2.3%, markedly increasing to 14.9% in the Bh, and from the latter to the underlaying B2 h.ir.m. (about 53.0%). The medium and fine sand are the dominant sizes of the total sand fraction.

Silt/clay ratios are widely different throughout, not following any definite trend; its values range from 0.05 in the B22 h.ir.m. to 11.0 in the A12 horizon.

Bulk densities were determined only in the subsoil; the figures were 1.72 g/cc in the B21 h.ir.m. and 1.60 in the B22 h.ir.m.

The cation exchange capacities per 100 grams of soil are low and very low; the higher values are present in the top Ap horizon (7.4 meq.) and in the B horizon (values about 9.0 meq.). In the A21 (0.5 meq.) and A22 (1.2 meq.) the lowest values occur.

Exchangeable aluminum is very low in the Ap (0.14 meq.) and A3 (0.18 meq.) horizons; absent in A2, markedly increasing in the major part of the subsoil (Bh = 2.16 meq.; B21 h.ir.m. = 0.48; B22 h.ir.m. = 2.38 meq.). Base saturation is significantly higher in the top soil where the figures range from about 33% in the Ap and A3, to 80% in the A2 horizon; the subsoil (Bh, B21 h.ir.m. and B22 h.ir.m.) show percentages around 3 and 4. Exchangeable Ca, Mg, K and Na are very low throughout, being highest in the Ap horizon (sum of bases = 2.24 meq.) and strongly declining in lower horizons where a slight decreasing trend with depth is observed (from about 0.4 meq. in the A2 to 0.3 meq. in the B22 h.ir.m. horizon).

The organic carbon content is irregularly distributed with depth, being highest in the Ap (2.98%) and lowest in the underlaying A2 (0.2%) horizon. It increases in the A3 (0.44%) and Bh (1.9%), to decrease again in the B21 h.ir.m. (1.48%), before reaching 2.56% in the lowermost B22 h.ir.m. horizon.

The pH (KCl) values are very low and increase with depth, from the Ap (3.2) to the B21 h.ir.m. (4.6) horizon, slightly decreasing in the B22 h.ir.m. (4.2) horizon.

3.7.3. Mineralogical composition

3.7.3.1. Sand fraction (50-250µm)

The light materials are dominant in the sand fraction, ranging from 97 to 98% (weight %) of the total sample throughout the soil.

The light fraction is composed of fissured and highly weathered quartz grains and traces of feldspars (table 53). The heavy fraction includes mainly opaques, where magnetic minerals are the most frequent. X-ray analysis shows that the opaque minerals mainly consist of magnetite, ilmenite, hematite and goethite. Zircon is dominant among the transparent minerals, followed by very low amounts of tourmaline and the occasional presence of rutile.

Table 52. Physico-chemical properties of profile 7

Depth (cm)	Horizon	Size class and particle diameter (mm)								
		TOTAL			SAND					COARSE FRAGM.
		Sand	Silt	Clay	V.C.	C.	M.	F.	V.F.	> 2 mm
		2-0.05	0.05-0.002	< 0.002	2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	
0- 15	Ap	92.0	2.0	6.0	0.7	21.1	38.7	26.2	5.4	0
- 40	A12	97.6	2.2	0.2	1.9	18.9	37.0	33.1	6.6	0
-80/90	Az	95.1	2.6	2.3	1.9	16.7	34.8	34.3	6.9	0
-110/130	Bh	80.3	4.8	14.9	4.1	19.7	27.8	23.2	5.5	0
-175	B21 hirm	34.0	13.2	52.8	0.7	7.1	12.0	10.9	3.3	0
-250	B22 hirm	43.6	3.1	53.2	1.4	10.1	14.3	14.0	3.9	0

Depth (cm)	Organic carbon %	pH		Ext. Fe as Fe_2O_3 %	Ext. Al as Al_2O_3 %	Bulk density g/cm³	Silt/clay ratio
		1:1 KCl	1:1 H_2O				
0- 15	2.98	4.7	5.3	-	-	-	0.33
- 40	0.20	5.1	5.5	-	-	-	11.0
-80/90	0.44	4.9	5.2	-	-	-	1.13
-110/130	1.90	3.9	4.5	-	-	-	0.32
-125	1.48	4.2	4.8	0.96	2.24	1.72	0.05
-250	2.56	4.0	4.6	0.05	1.49	1.60	0.25

Depth (cm)	Extractable bases					Al 1NKCl	Extr. acidity KCl pH 8.2	C.E.C.				Base saturation (%)	
	Ca	Mg	K	Na	Sum			NH_4OAc	Sum cations	NH_4OAc	E.C.E.C.	NH_4OAc	Sum cations
	meq./100g soil							meq./100g soil		meq./100g clay			
0- 15	1.5	0.56	0.09	0.09	2.24	0.14	8.1	7.4	10.32	123.5	39.6	30.2	21.7
- 40	0.16	0.15	0.02	0.07	0.4	0.0	1.2	0.5	1.60	250.0	0.40	80.0	25.0
-80/90	0.26	0.10	0.01	0.05	0.42	0.18	1.7	1.2	2.1	52.2	26.0	35.0	20.0
-110/130	0.10	0.17	0.02	0.06	0.35	2.16	9.4	8.2	9.7	55.1	16.8	4.3	3.5
-125	0.07	0.15	0.02	0.08	0.32	0.48	11.0	10.3	11.3	19.5	2.0	3.1	2.8
-250	0.15	0.07	0.03	0.07	0.32	2.38	10.9	9.9	11.2	18.5	5.0	3.2	2.8

Table 53 . Mineralogical composition of the sand fraction (50-250 μm) of profile 7

Hor.	Depth (cm)	Light minerals		Heavy minerals			
		Quartz	Feldspars	Opaques	Zircon	Tourma-line	Rutile
Ap	0- 15	100	0.0	89.0	10.2	tr.	tr.
A12	- 40	100	"	90.9	8.5	"	0.0
A2	-50/90	100	"	84.6	15.1	"	"
Bh	-110/130	100	"	86.4	11.8	"	"
B21 h.ir.m.	-175	>99	tr.	91.9	7.5	"	"
B22 h.ir.m.	-250	100	0.0	87.8	11.8	"	"

tr. (traces) = <1%.

3.7.3.2. Clay fraction (<2μm)

As shown in table 54 the X-ray analysis indicates the only presence of kaolinite in the clay fraction of all the horizons. This result is confirmed through D.T.A. and T.G.A. which also pointed out the occurrence of minor quantities of gibbsite.

Table 54 . Mineralogical composition of the clay fraction (<2μm) of profile 7

Hor.	Depth (cm)	Clay fraction		
		X-ray	D.T.A.	T.G.A.
B21 h.ir.m.	110/130 -175	K	K, G	K5, G1
B22 h.ir.m.	175-250	K	K, G	K5, G1

Mineral code : K : kaolinite; G : gibbsite.

Approx. weight fractions (T.G.A.) : 5 : more than half; 4 : half to one third; 3 : one third to one fifth; 2 : one fifth to one twentieth; 1 : less than one twentieth.

3.7.4. Sedimentology

The detailed particle size distribution of the fractions between 63 and 2000 microns of the A12, A2, Bh, B21 h.ir.m. and B22 h.ir.m. horizons is given in table 55.

The cumulative frequencies were calculated for all fractions between 63 and 2000 microns.

Tables 56 and 57 give respectively the cumulative frequencies of the fractions between 63 and 2000 microns and the sedimentological parameters for each soil horizon.

The cumulative curves plotted on probability scale are given in fig. 11.

The A12 horizon shows a symmetric ($\alpha 3\ \phi = 0.00$), and platykurtic ($\alpha 4\ \phi = 0.41$) distribution, with a Mz value of 1.94 ϕ and a standard deviation (Gl ϕ = 0.83) which indicates a moderate sorted material.

The distribution curve of the A2 horizon is almost symmetric, negatively skewed ($\alpha 3\ \phi = -0.02$), platykurtic ($\alpha 4\ \phi = 0.10$), with a Mz of 1.87 ϕ and having the same sorting as the preceeding horizon (Gl ϕ = 0.83).

The Bh horizon distribution is moderately asymmetric ($\alpha 3\ \phi = 0.11$), platykurtic ($\alpha 4\ \phi = 0.68$), with a Mz of 1.73 ϕ, having similar sorting (Gl ϕ = 0.91) as the upper horizons.

The distribution for the B21 h.ir.m. horizon is moderately asymmetric ($\alpha 3\ \phi = 0.16$), platykurtic ($\alpha 4\ \phi = 0.66$), with a Mz value of 1.67 ϕ and the standard deviation Gl ϕ = 0.96 that indicates a moderate sorting.

The B22 h.ir.m. distribution curve is asymmetric ($\alpha 3\ \phi = 0.31$), platykurtic ($\alpha 4\ \phi = 0.57$), the Mz value is 1.59 ϕ

and the standard deviation (G1 ∅ = 0.94) shows the same sorting as the other horizons.

The mean grain size of the particles is lowest in the top A12 (Mz = 1.94 ∅) horizon, increasing gradually witn deptn to reach the highest figures in the B22 h.ir.m. horizon (Mz = 1.59).

The standard deviation is rather uniform in all horizons, with somewhat higher figures in the subsoil. It varies from G1 ∅ = 0.83 in the A12 and A2 horizons to G1 ∅ = 0.96 in the B21 h.ir.m. horizon.

A marked increase in the asymmetry with depth is indicated by the values of the skewness. The upper A12 and A2 horizons show asymmetric distributions (α3 ∅ = about 0.0) that become moderate in the underlaying Bh and B21 h.ir.m. (α3 ∅ = between 0.1 and 0.2) and clearly asymmetric in the lowermost B22 h.ir.m. (α3 ∅ = 0.35) (see table 57).

No matter, all the horizons have platykurtic distributions; the A2 (α4 ∅ = 0.10) presents a markedly more peaked curve than the other horizons, especially when compared with tne underlaying Bh (α4 ∅ = 0.68) and B21 h.ir.m. (α4 ∅ = 0.66).

Most of the parameters indicate a slight sedimentological difference between the parent materials of the uppermost A (A12 and A2) and the parent material of underlaying horizons.

Table 55 . Particle size distribution of the fractions between 63 and 2000μm

	1400 -2000	1000 -1400	710 -1000	500 -710	355 -500	250 -355	180 -250	125 -180	90 -125	63 -90
A12	0.0	1.1	1.6	10.4	17.4	23.5	18.6	16.3	8.2	2.8
A2	0.5	0.5	3.2	10.6	16.5	26.6	18.6	13.8	6.9	2.6
Bh	0.0	1.8	6.1	16.5	17.2	19.6	15.3	14.1	6.7	2.4
B21 hirm	0.0	3.2	6.4	17.7	17.7	17.7	14.5	12.9	6.4	3.2
B22 hirm	0.0	2.1	8.5	20.2	19.2	16.9	13.7	10.6	5.3	3.2

Table 56 . Cumulative frequencies of the fractions between 63 and 2000μm

	>1400	>1000	>710	>500	>355	>250	>180	>125	>90	>63
A12	0.0	1.1	2.7	13.1	30.5	54.0	72.6	88.9	97.1	99.9
A2	0.5	1.0	4.2	14.8	31.3	57.9	76.5	90.3	97.2	99.8
Bh	0.0	1.8	7.9	24.4	41.6	61.2	76.5	90.6	97.3	99.7
B21 hirm	0.0	3.2	9.6	27.3	45.0	62.7	77.2	90.1	96.5	99.7
B22 hirm	0.0	2.1	10.6	30.8	50.0	66.9	80.6	91.2	96.5	99.7

Table 57 . Sedimentological parameters of the fractions between 63 and 2000μm

	Mz	1_σ	3_α	4_α
A12	1.94	0.83	0.00	0.41
A2	1.87	0.83	-0.02	0.10
Bh	1.73	0.91	0.11	0.68
B21 hirm	1.67	0.96	0.16	0.66
B22 hirm	1.59	0.94	0.35	0.57

3.7.5. Micromorphology

A. Microstructure and pore pattern

The B21 h.ir.m. horizon shows weak crumbly microstructure with fissured and vughy cavited intrapedal m.s., and strong to weak very fine crumbly with fissured intrapedal m.s.; both types grade to spongy. Very frequent smooth fissures (few µm ø) and vughs many times interconnected, dominate; smooth channels (0.7 to 2 mm ø) are frequent.

The underlaying B22 h.ir.m. horizon presents a spongy microstructure with fissured and vughy cavited intrapedal m.s. Very frequent interconnected vughs ranging from 20 to 100 µm are dominant; smooth fissures of few µm ø are also very frequent, and channels of 0.7 mm are occasionally present.

Channel infillings were observed in both horizons, that show moderate and strong very fine crumbly microstructure, with fissured and occasionally vughy cavited intrapedal m. s. Very frequent interpedal compound packing pores and vughs are mainly observed.

B. Matrix

B1. Coarse material (>5µm)

Fine to coarse sand sized, mostly subangular and subrounded grains of quartz form the coarse material of the B21 h.ir. m. and B22 h.ir.m. horizons. All grain sizes present fissures and/or corrosion features, indicating extreme weathering.

B2. Fine material (≤5µm)

It is mostly yellow in the B21 h.ir.m. and brown to dark brown in the B22 h.ir.m., composed of clay, oxihydrates and organic matter. Both horizons present a dominant undifferentiated b-fabric. Dotted, parallel straited, circular striated and poro-striated b-fabric are occasionally observed.

Channel infillings only show undifferentiated b-fabric.

B3. Coarse/fine related distribution

In both horizons (B21 h.ir.m. and B22 h.ir.m.), single spaced porphyric related distributions are dominant, and gefuric are locally present.

In the channel infillings, enaulic and gefuric types are observed.

C. Organic matter

Organic matter stains the fine mass, particularly in the B22 h.ir.m. horizon, that has a darker color. Other forms of organic matter are described further within the special features.

D. Features

Coatings and infillings composed of limpid kaolinitic clay are present in the B21 h.ir.m. and B22 h.ir.m. horizons; their size ranges from 20 microns to about 1 mm ø. They occur in vughs and channels, have yellow color, strong continuous orientation, sharp boundaries and are very frequent in both horizons.

Coatings and infillings of speckled and limpid clay layers were very frequently observed in the subsoil (B21 h.ir.m. and B22 h.ir.m.); the size varies from 50 microns to 500 microns ø, have yellow color and are located in fissures, vughs and channels.

Reddish hyaline clay coatings are frequently seen in the B21 h.ir.m. and B22 h.ir.m. horizons. They are located in vughs. The orientation is strong and the limits are sharp.

Reddish isotropic coatings and infillings of 20 to 300μm very frequently occur in fissures, channels and on top of grains, in the B21 h.ir.m. horizon. They have sharp boundaries, smooth walls and red color, indicating the presence of a fluctuating watertable.

Fragments of clay coatings of 100 to about 200 μm ø are frequently present in the fine mass of the B21 h.ir.m. and B22 h.ir.m. horizons. Boundaries are rather sharp and the orientation is generally weak.

Highly humified organic (monomorphic) coatings and infillings of few to 40 μm ø very frequently occur in fissures, pores and grains in the subsoil horizons. They are smooth or rugose with sharp boundaries, and have a black color. Besides the general staining of the fine mass, the fissures appear to be plugged by organic matter accumulations. Most of the quartz grains are partially coated by a very thin organic cover. In channels, the deposition of organic coatings on top of pre-existing clay coatings is frequently observed.

E. <u>Quantification of illuviation features</u>

Point counting results are shown in table 58 . The percentage of clay coatings is highest in the upper part of the subsoil. The horizons B21 h.ir.m. and B22 h.ir.m. respectively present 11.6% and 3.4% coatings. The upper Ap, A21 and A22 horizons were not sampled.

Thus, the degree of clay illuviation shown in table 59 is very strong for B21 h.ir.m. and strong for B22 h.ir.m. The clay illuviation index for the whole profile is very high (1180.5 per cent.cm).

3.7.6. Classification

The profile has a dark Ap horizon which is not thick enough to be umbric and therefore is an ochric epipedon; underlain by a thick albic horizon that extends up to 90 cm. Below that depth a dark discontinuous Bh horizon lies on top of a clayey indurated 'ortstein' (B21 h.ir.m. and B22 h.ir.m. horizons) where organic matter and iron sesquioxide accumulations are apparent, and which looses its extremely hard consistence after heating. The micromorphological study of the 'ortstein' shows the presence of silt size pellets and organic coatings on grains and pores; features that also define a spodic horizon. Moreover, abundant illuviation cutans were observed in thin sections as shown in table 58.

Therefore, the presence of abundant illuviation cutans in the subsoil horizons (B21 h.ir.m. and B22 h.ir.m.), the lack of an umbric epipedon and the existence of a thick epipedon composed almost entirely of quartz grains, classify the profile as a member of the skeletal, siliceous, isohyperthermic family of the ULTIC, AERIC ARENIC TROPAQUODS.

Table 58 . Quantitative micromorphological analysis of soil components (by point counting) expressed in volume per cent of total soil

Depth (cm)	Horizon	Pores	Coarse material	Fine material	Coatings	Fragm.of coatings
110/130-175	B21 h. ir. m.	10.7	27.0	50.6	11.6	0.0
175-250	B22 h. ir. m.	21.0	26.3	49.2	3.4	0.0

Table 59 .Degree of clay illuviation per horizon and profile clay illuviation index

Horizon	Thickness (cm)	% in situ + translocated illuviation features (on solid phase)	Degree of illuviation
B21 h. ir. m.	65	13.2	very strong
B22 h. ir. m.	75	4.3	strong
Profile clay illuviation index = 1180.5 per cent cm. Very high.			

CLASSIFICATION ACCORDING TO OTHER SYSTEMS

FAO/UNESCO	: Placic Podzol
BRAZILIAN SYSTEM	: Podzol, with duripan, moderate A horizon, sandy texture, semi-evergreen tropical cerrado, level phase.
AMERICAN SYSTEM 1938	: Ground-Water Podzol.

3.8. Profile 8

I. Information of the site

Date of examination : 25/5/1980
Author : D. Barrera
Location : Caeté mill. 4 km left from km 74 of Maceió-Aracaju highway.
Approx. 36°05'W, 9°44'S.
Elevation : 102 m
Land form : 1) physiographic position : plateau (see scheme C)
2) surrounding land form : slightly undulated
3) microtopography: nil.
Slope : class
Land-use : sugarcane (monoculture).

II. Information of the soil

Parent material : sandy sediments
Geological formation and lithology : Barreiras Group. Tertiary sediments.
Drainage : class 1 : poorly drained.
Moisture conditions in the profile : dry throughout.
Depth of the groundwater table : reaches the soil surface during the rainy season.
Presence of surface stone, rock outcrops : none.

Human influence : confined to plow layer

Vegetation : low and not dense semi-evergreen tropical cerrado.

3.8.1. Morphological description

It is a deep, imperfectly to poorly drained profile showing a strickingly contrast between a free grain sandy epipedon of about 80 cm thick underlayed by an indurated fine textured B horizon. Root penetration is concentrated in the upper 20 cm.

Ap - 0-18 cm. Very dark gray (10 YR 3/1) moist, and dark gray (10 YR 4/1) dry; sandy; single grain; loose, non-plastic, non-sticky; many fine and medium pores; abundant roots; smooth clear boundary.

A2 - 18/50/60 cm. (E) Light brownish gray (10 YR 6/2) moist, and light gray (10 YR 7/1) dry; sand; single grains; loose non-plastic, non-sticky; many fine and medium pores; common roots; wavy clear boundary.

Bh - 50/60-75/80 cm. Dark brown (10 YR 3/3) moist, and very dark gray (10 YR 3/1) dry; sandy clay loam; massive; rare roots; wavy abrupt boundary.

B21 h.ir.m. - 75/80-90 cm. (B1 h.s.m.) Light yellowish brown (10 YR 6/4) moist, and very pale brown (10 YR 7/4) dry; sandy clay loam; massive breaking into medium and coarse granular and subangular blocky; non-sticky, non-plastic; few pores; no roots; irregular clear boundary; few fine prominent yellowish red (5 YR 4/6), clear and diffuse mottles.

B22 ir.m. - 90-200 cm. (B2 s.m.) Very pale brown (10 YR 7/4) moist, and very pale brown (10 YR 8/3) dry; sandy clay loam; massive breaking into medium and coarse granular and subangular blocky; extremely hard, extremely firm, non-plastic, non-sticky; few pores no roots, common, medium and coarse yellowish-red (2.5 YR 5/8, distinct; clear and diffuse mottles.

<u>Remarks</u> :-B21 h.ir.m. (B1 s.m.) : presence of yellowish red (5 YR 4/8) and reddish yellow stains along fracture plains; large old decomposed roots. Very dark gray (10 YR 3/1) stains along aggregates surfaces.

-B22 ir.m. (B2 s.m.) : sometimes rounded organic matter and Fe sesquioxides accumulation. The type of yellowish red stains described in the preceeding horizon tend to disappear.

-The Bh horizon is not continuous.

-( ) Horizon's nomenclature according to the Soil Survey Manual (1981).

3.8.2. <u>Physico-chemical properties</u> (table 60)

The results of the mechanical analysis indicate a contrasting textural difference between the upper and subsoil layers, where the sand fraction dominates in the whole profile.

The silt is very low (around 2.5%) in the Ap, B2 and Bh horizons, markedly increasing in the B2 (about 16.0%). In the top Ap (1.2%) and A2 (0.0%), the clay fraction is virtually absent, increasing very strongly in the Bh (24.8%) and B21 h.ir.m.(20.6%) and reaching its maximum in the deepest B22 ir.m. (30.2%) horizon. The sand fraction makes more than 92% in the Ap, A2 and Bh, decreasing to 62.9% in the B21 h.ir.m. and 53.6% in the B22 ir.m. The medium and fine sand dominate the total sand fraction.

Silt/clay ratios are very variable, not following any trend with depth, with highest values occurring in the Ap (1.9) and lowest in the Bh (0.11) horizon.

The bulk densities in the subsoil range from about 1.72 g/cc in the B21 h.ir.m. and B22 ir.m. to 1.43 g/cc in the overlaying Bh horizon.

The cation exchange capacity varies from 0.4 meq. per 100 grams of soil in the A2 horizon to 5.72 meq. in the B22 ir.m.; other horizons show intermediary values. Exchangeable aluminum is absent in the upper Ap and A2, highest in the Bh (1.16 meq.) and decreases with depth to reach 0.28 meq. in the B22 ir.m. horizon. Exchangeable contents of Ca, Mg, K and Na are very low, strongly decreasing from Ap (sum of bases = 2.44 meq.) to the underlaying horizons where the sum of bases ranges from 0.33 to 0.52 meq.

Base saturation is about 80% in the top Ap and A2 horizons and decreases very strongly in the subsoil, with lowest values in the B22 ir.m. horizon (6.3%).

The organic carbon content in the Ap (1.42%) horizon is followed by a strong decrease in the underlaying A2 (0.20%); in the Bh (3.32%) the highest amounts are present, declining with depth to 2.82% in the B21 h.ir.m. and 0.46% in the deepest B22 ir.m.

The pH (KCl) is low, decreasing from the top Ap (4.7) horizon to the underlaying A2 (3.9); in the deeper horizons it increases reaching pH 4.9 in the B22 ir.m.

3.8.3. Mineralogical composition

3.8.3.1. Sand fraction (50-250μm)

The sand fraction is dominated by the light minerals that range from 96 to 98 per cent (weight %) of the total sample throughout the soil.

The light fraction is formed by highly weathered and fissured grains of quartz and traces of feldspars (table 61). The heavy fraction includes mainly opaques, where magnetic

Table 60. Physico-chemical properties of profile 8

Depth (cm)	Horizon	Size class and particle diameter (mm)								
		TOTAL			SAND					COARSE FRAGM.
		Sand	Silt	Clay	V.C.	C.	M.	F.	V.F.	> 2 mm
		2-0.05	0.05-0.002	< 0.002	2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	
0- 18	Ap	93.5	2.3	1.2	1.5	26.6	38.0	22.0	5.1	0
-50/60	A2	97.8	2.2	0.0	2.4	17.2	34.7	37.5	5.8	0
-75/80	B4	92.4	2.8	24.8	2.6	19.0	25.3	20.0	5.5	0
- 90	B21 hirm	62.9	16.5	20.6	1.6	11.9	18.0	26.6	4.8	0
-200	B22 hirm	53.6	16.2	30.2	2.3	12.4	18.7	15.4	4.8	0

Depth (cm)	Organic carbon %	pH		Ext. Fe as Fe_2O_3 %	Ext. Al as Al_2O_3 %	Bulk density g/cm³	Silt/ clay ratio
		1:1 KCl	1:1 H_2O				
0- 18	1.42	4.7	5.6	-	-	-	1.91
-50/60	0.20	3.9	5.5	-	-	-	-
-75/80	3.32	4.4	5.2	0.0	2.36	1.43	0.11
- 90	2.82	4.6	5.3	0.05	3.03	1.74	0.80
-200	0.46	4.9	5.2	0.0	2.22	1.72	0.53

Depth (cm)	Extractable bases					Al 1NKCl	Extr. acidity KCl pH 8.2	C.E.C				Base saturation (%)	
	Ca	Mg	K	Na	Sum			NH_4OAc	sum cations	NH_4OAc	E.C.E.C.	NH_4OAc	Sum cations
	meq./100g soil							meq./100g soil		meq./100g clay			
0- 18	1.64	0.56	0.09	0.15	2.44	0.0	2.72	3.2	5.2	141.6	21.2	76.2	47.0
-50/60	0.16	0.04	0.0	0.13	0.33	0.0	0.0	0.4	0.33	7.0	0.33	82.5	1.0
-75/80	0.13	0.07	0.01	0.17	0.38	1.16	10.8	2.4	11.2	64.5	6.2	16.0	3.4
- 90	0.16	0.22	0.0	0.14	0.52	0.9	10.5	3.6	11.0	47.7	4.6	14.6	4.7
-200	0.10	0.07	0.01	0.18	0.36	0.28	5.3	5.7	5.6	20.8	2.1	6.3	6.4

minerals are the most frequent. X-ray analysis showed that the opaque minerals consist of magnetite, ilmanite, hematite and goethite. Zircon is dominant among the transparent minerals of the heavy fraction followed by very low amounts of toumaline and rutile.

Table 61 . Mineralogical composition of the sand fraction (50-250 m) of profile 8

Hor.	Depth (cm)	Light minerals		Heavy minerals			
		Quatrz	Feldspars	Opaques	Zircon	Tourma-line	Rutile
Ap	0- 18	100	0.0	92.6	6.9	tr.	0.0
A2	-50/60	100	"	93.1	6.3	"	"
Bh	-75/80	100	"	91.1	8.3	"	"
B21 h.ir.m.	- 90	100	"	96.4	2.7	"	"
B22 ir.m.	-200	>99	tr.	92.8	6.7	"	"

tr. (traces) = <1%.

3.8.3.2. Clay fraction (<2μm)

The results of the X-ray analysis presented in table indicate kaolinite as the only mineral present in the clay fraction of all horizons. D.T.A. and T.G.A. confirm the results of the X-ray diffractometry and also determine the presence of very low amounts of gibbsite (table 62).

Table 62 . Mineralogical composition of the clay fraction (<2μm) of profile 8

Hor.	Depth (cm)	Clay fraction		
		X-ray	D.T.A.	T.G.A.
B21 h.ir.m.	75/80-90	K	K, G	K5, G1
B22 ir.m.	90-200	K	K, G	K5, G1

Mineral code : K : kaolinite; G : gibbsite.
Approx. weight fractions (T.G.A.) : 5 : more than half; 4 : half to one third; 3 : one third to one fifth; 2 : one fifth to one twentieth; 1 : less than one twentieth.

3.8.4. Sedimentology

The detailed particle size distribution of the fractions between 63 and 2000 microns of the A2, Bh and B22 ir.m. horizons appears in table 63.

Tables 64 and 65 respectively give the cumulative frequencies of the fractions between 63 and 2000 microns and the sedimentological parameters of each soil horizon.

The cumulative frequencies plotted on probability scale are given in fig. 12.

- The A2 horizon shows a perfectly symmetric ($\alpha 3\ \phi = 0.0$), platykurtic ($\alpha 4\ \phi = 0.48$) distribution, with a Mz value of 1.74 ϕ and a standard deviation that indicates moderate sorting (Gl ϕ = 0.92).

- The distribution curve of horizon Bh is asymmetric, positively skewed ($\alpha 3\ \phi = 0.37$), platykurtic ($\alpha 4\ \phi = 0.12$), with a Mz of 1.42 ϕ and having the same type of sorting (Gl ϕ = 0.9) as the horizon above.

- The B22 ir.m. horizon presents a moderate, positively skewed, asymmetry ($\alpha 3\ \phi = 0.18$) and platykurtic ($\alpha 4\ \phi = 0.51$) distribution, a Mz value of 1.62 ϕ and the same sorting as the other horizons ($G1\ \phi = 0.97$).

The mean grain size of particles shows similar values in the top A2 ($Mz\ \phi = 1.74$) and bottom B22 ir.m. ($Mz\ \phi = 1.62$), which are slightly higher with respect to the Bh ($Mz\ \phi = 1.42$) horizon.

The standard deviations present very similar values throughout. The skewness shows significant changes with depth, the distribution is perfectly symmetric in the upper A2 ($\alpha 3\ \phi = 0.0$), clearly asymmetric in the Bh ($\alpha 3\ \phi = 0.37$) and moderately asymmetric in the B22 ir.m. ($\alpha 3\ \phi = 0.18$).

The kurtosis is similar in the uppermost A2 ($\alpha 4\ \phi = 0.48$) and lowest in B22 ir.m. ($\alpha 4\ \phi = 0.5$) horizons, and contrasting with the more peaked distribution of the Bh ($\alpha 4\ \phi = 0.12$) horizon.

From sedimentological viewpoint, the parent materials of the A2 and B22 ir.m. horizons are very similar, and somewhat different for asymmetry, peakedness and mean grain size of particles with respect to the Bh horizon.

Therefore, it is concluded that parent material of the Bh horizon slightly differs from the rest of the profile.

3.8.5. Micromorphology

A. Microstructure and pore pattern

The subsoil B21 h.ir.m. and B22 ir.m. horizons present spongy microstructure comprising vughs and fissures, that grades to weak and strong very fine crumbly with fissured

Table 63 . Particle size distribution of the fractions between 63 and 2000μm

	1400 -2000	1000 -1400	710 -1000	500 -710	355 -500	250 -355	180 -250	125 -180	90 -125	63 -90
A2	0.5	1.6	6.9	13.7	15.8	21.3	17.5	12.7	6.9	2.6
Bh	1.0	3.4	6.9	23.7	21.0	18.6	10.6	8.8	3.7	1.9
B22 irm	1.0	2.0	7.9	18.8	17.8	19.8	11.9	10.9	6.9	3.0

Table 64 . Cumulative frequencies of the fractions between 63 and 2000μm

	>1400	>1000	>710	>500	>355	>250	>180	>125	>90	>63
A2	0.5	2.1	9.0	22.7	38.5	59.8	77.3	90.0	96.9	99.5
Bh	1.0	4.4	11.3	35.0	56.0	74.6	85.2	94.0	97.7	99.6
B22 irm	1.0	3.0	10.9	29.7	47.5	67.3	79.2	90.1	97.0	100.0

Table 65 . Sedimentological parameters of the fractions between 63 and 2000μm

	Mz	1_{σ}	3_{α}	4_{α}
A2	1.74	0.92	-0.0	0.48
Bh	1.42	0.90	0.37	0.12
B22 irm	1.62	0.97	0.18	0.51

intrapedal m.s. Very frequent fissures (less than 10µm ø) and vughs of 20 to 30 µm ø mostly interconnected are the dominant pores. Interpedal compound packing pores of about 100µm ø and channels of 0.45µm ø are occasionally present.

Channel infillings were found in both horizons; they occupy a large soil volume and present strong and moderate very fine granular microstructure. Very frequent interpedal compound packing pores and interconnected vughs are mostly observed; very frequent fissures are subordinated.

B. Matrix

B1. Coarse material (>5µm)

The coarse material is mainly composed of subangular and subrounded quartz grains, ranging from fine to coarse sand size. They generally present strong weathering evidences as fissures, cracks and corroded zones.

B2. Fine material (<5µm)

It is brown in the B21 h.ir.m. and dark brown in the B22 ir.m. horizons, composed of clay, oxihydrates and organic matter. The b-fabric is undifferentiated throuhout. In the B22 ir.m. horizon, some dotted b-fabric are locally very weakly expressed.

B3. Coarse/fine related distribution

In the whole subsoil (B21 h.ir.m. and B22 ir.m.), close to single spaced porphyric to single spaced enaulic related distribution is dominant, and locally double-open porphyric is present. In channel infillings, enaulic, related distribution dominates and locally gefuric is present.

C. Organic matter

Highly decomposed organic matter is coloring the fine material, particularly in the B21 h.ir.m. horizon, where amounts are higher. Other forms of organic matter present are described under the special features.

D. Features

Coatings and infillings of very pale yellow clay are common in the B1 h.ir.m. horizon; the size is about 100µm. They commonly occur in vughs and dessication fissures, have rather strong continuous orientation and sharp boundaries.

Laminated coatings and infillings ranging from 50 to 100µm ø, showing parallel dark and pale yellow layers, are frequently present in the B21 h.ir.m. and B22 ir.m. horizons. They occur mostly in vughs and under cross nichols very weak orientation is observed, probably due to the presence of amorphous material.

Fragments of clay coatings (c), ranging from 50 to 100 microns, are present in the fine mass of the subsoil (B21 h.ir.m. and B22 ir.m.); the colors are pale brown, the boundaries are sharp and the material is weakly to strongly oriented.

Reddish isotropic coatings of few to 40µm ø, mainly composed by iron-rich amorphous sesquioxides, frequently occur in the B21 h.ir.m. and B22 ir.m. horizons. They normally present sharp boundaries.

Highly humified organic (monomorphic) coatings and infillings of few µm ø occur very frequently in vughs, channels and fissures of the subsoil horizons (B21 h.ir.m. and B22 ir.m.). They are smooth and rugose, with sharp boundaries. The fissures are normally filled up by organic accumulations. Most of the quartz grains are partially covered by thin organic coatings. In channels, the organic coatings are lying on top of the illuviated clay.

Channel infillings (VF) are very frequently present in both horizons (B21 h.ir.m. and B22 ir.m.); they are composed of sand-sized microaggregates and grains of quartz.

The clay illuviation in situ in that profile is not operative anymore. The eluvial horizons are exempt of clay and therefore the observed clay coatings can be considered as relict ones.

E. Quantification of illuviation features

The quantification of the clay illuviation features through point counting is presented in table 66. The upper part of the B horizon presents a higher amount of clay coatings, and no fragments of clay coatings were observed throughout. The B21 h.ir.m. and B22 ir.m. horizons respectively show 1.5% and 0.7% illuviation features.

Consequently, the degree of clay illuviation (table 67) is moderate for the B21 h.ir.m. horizon and weak for the underlaying B22 ir.m.. The clay illuviation index for the whole profile is low according to Midema, R. and Slager, S. (1972).

Table 66 . Quantitative micromorphological analysis of soil components (by point counting) expressed in volume per cent of total soil

Depth (cm)	Horizon	Pores	Coarse material	Fine material	Coatings	Fragm.of coatings
75/80-90	B21 h.ir.m.	26.5	30.4	41.6	1.5	0.0
90-200	B22 ir.m.	22.6	31.1	45.6	0.7	0.0

Table 67 . Degree of clay illuviation per horizon and profile clay illuviation index

Horizon	Thickness (cm)	% in situ + translocated illuviation features (on solid phase)	Degree of illuviation
B21 h.ir.m.	15	2.04	moderate
B22 ir.m.	110	0.9	weak
Profile clay illuviation index = 130.0 per cent cm. Low.			

3.8.6. Classification

The profile shows a dark Ap horizon that is not thick enough to be mollic, thus it is an ochric epipedon, underlain by an albic horizon of about 40 cm thick. Below that depth a dark discontinuous Bh horizon is found on top of a clayey indurated subsoil (B21 h.ir.m. and B22 ir.m. horizons) that shows an organic matter accumulation in the B21 h.ir.m. horizon and which looses its hard consistence after heating. The micromorphological study of these horizons indicates the presence of silt size pellets and organic coatings on grains and pores. Thus, fulfilling the requirements of a spodic horizon. Furthermore, thin sections indicate the presence of illuviation cutans in B21 h.ir.m. and B22 ir.m. horizons.

Taking into account the presence of illuviation cutans in the subsoil, the lack of an umbric epipedon, and the presence of almost pure quartz grains in the epipedon, the profile is classified as a member of the skeletal, siliceous, isohyperthermic family of the ULTIC, AERIC TROPAQUODS.

CLASSIFICATION ACCORDING TO OTHER SYSTEMS

FAO/UNESCO	:	Orthic Podzol.
BRAZILIAN SYSTEM	:	Podzol, with duripan, moderate A horizon, sandy texture, semi-evergreen tropical cerrado, level phase.
AMERICAN SYSTEM 1938	:	Ground-Water Podzol.

GEOMORPHOLOGICAL UNIT : PLATEAU D

3.9. Profile 3

I. Information on the site

Date of examination : 8/2/1980.
Author : D. Barrera
Location : Sininbù mill. Fazenda Prata.
Approx. 36°11'W, 9°51'S
Elevation : 85 m
Land form : 1) physiographic position : plateau
(see scheme D)
2) microtopography : slightly undulated.
Slope : class 1 (0-1%)
Land-use : sugarcane.

II. Information of the soil

Parent material : sandy clay sediments
Drainage : class 4-3. Well-drained-moderately well-drained.
Moisture conditions in the profile : dry throughout.
Depth of watertable : perched watertable between 72 and 130 cm depth.
Presence of surface stones, rock outcrops : none.
Human influence : confined to plow layer.
Vegetation : semi-evergreen tropical forest.

3.9.1. Morphological description

The profile is deep, well-drained to moderately well-drained, yellowish brown, becoming reddish yellow in deeper layers. The horizonation between the A and B horizons is rather clear accompained by contrasting red mottling in the top part of the B2. The structure is moderate in the top soil (Ap and A12) and weak in the underlaying horizons. In the upper part of the B the consistence is particularly hard when dry. Roots are concentrated in the upper 20 cm.

Ap - 0-12 cm.	Very dark grayish brown (10 YR 3/2) moist, and grayish brown (10 YR 5/2) dry; sandy clay loam; moderate fine medium angular; many very fine and common medium pores; slightly hard, friable, slightly plastic and sticky; abundant roots; clear smooth boundary.
A12 - 12-28 cm. (A)	Dark brown (10 YR 3/3) moist, and brown-dark brown (10 YR 4/3) dry; sandy clay loam; moderate fine-medium granular and weak fine subangular blocky; slightly hard, friable, slightly plastic and sticky; frequent roots; common medium pores; gradual smooth boundary.
A3 - 28-52 cm. (BA)	Yellowish brown (10 YR 5/4) moist, and very pale brown (10 YR 7/4) dry; sandy clay; moderate fine-medium crumbly, weak fine-medium subangular blocky; slightly hard, friable, plastic and sticky; common medium pores; common roots; clear smooth boundary.
B1 - 52-72 cm. (Bt1)	Brownish yellow (10 YR 6/6) moist, and light yellowish brown (10 YR 6/4) dry; clay; weak moderate, fine-medium subangular blocky; hard, friable, firm; plastic and sticky; common medium pores; common roots; gradual smooth boundary.
B21 - 72-130 cm (Bt2)	Yellowish brown (10 YR 5/8) moist, and brownish yellow (10 YR 6/8) dry; clay; common, medium and coarse, distinct, sharp, light red mottles (2.5 YR 6/8); weak, fine subangular blocky; slightly hard, friable, plastic and sticky; common medium pores; few roots; diffuse smooth boundary.
B22 - 130-200 cm. (Bt3)	Reddish yellow (7.5 YR 6/6) moist, reddish yellow (7.5 YR 7/6) dry; clay; weak fine subangular blocky; hard, friable; plastic and sticky; very few roots; few pores; diffuse smooth boundary.

B3 - 200-250 cm. (BC) Reddish yellow (7.5 YR 6/6) moist, strong brown (7.5 YR 5/6) dry; clay; weak fine angular-subangular blocky; slightly hard, friable, plastic, sticky; very few roots; few pores.

Remarks : ( ) Horizon's nomenclature according to the Soil Survey Manual (1981).

3.9.2. Physico-chemical properties (table 68)

The mechanical analysis (table 68) shows the dominance of the clay and sand fractions. The silt fraction is present in very low amounts (max. 5%). In the uppermost Ap and A12, the clay fraction is about 29.1%, increasing gradually with depth to reach its maximum B22 (67%). Rather strong increase takes place between A12 (29.1%) and A3 (42.5%) and from the latter to the B1 (55.0%).The sand fraction shows identical and opposite trends with depth, having 68.8% in the Ap and 30.3% in the B22. The fine and medium sand make up the greater proportion of the total sand fraction.

Silt/clay ratios are very low ranging from 0.03 (B21) to 0.09 in the Ap and A12 horizons.

Bulk densities are highest in the A12 (1.64 g/cc) and Ap (1.78 g/cc) upper horizons, gradually decreasing with depth to reach 1.52 g/cc in the B23.

The cation exchange capacity per 100 g of soil decreases from Ap (5.3 meq.) to the B1 (2.0 meq.). In B22 and B23, the C.E.C. increases again to about 5.0 meq. Base saturation presents maximum values of 44.0% (A12) in the top soil, and 61.2% in the subsoil. Exchangeable bases which are very low, show similar trend with depth. Exchangeable aluminum increases from the Ap (0.22 meq.) to the B1 (1.02 meq.) horizon, decreasing in the underlaying horizons to reach 0.30 meq. in B23.

The organic carbon content is highest in the Ap (1.44%) and gradually declines with depth, reaching 0.14% in the lowermost B23 horizon.

The pH is very low and uniform throughout, being lowest in the B1 horizon (pH/KCl = 4.2) and highest in the Ap and the B22 (pH/KCl = 4.4).

3.9.3. Mineralogical composition

3.9.3.1. Sand fraction (50-250µm)

In the sand fraction the light minerals are dominant and constitute 94 to 96% (weight %) of the total sample in the different horizons.

The light fraction includes fissured and highly weathered grains of quartz and eventual traces of feldspars (table 69). The heavy fraction is mainly formed by opaques, among which magnetic minerals are dominant. X-ray analysis showed that the opaque minerals include magnetite, ilmenite, hematite and goethite. Zircon is dominant among the transparent minerals of the heavy fraction followed by very low amounts of tourmaline and rutile.

3.9.3.2. Clay fraction (<2µm)

Table 70 shows that X-ray diffractograms, D.T.A. and T.G.A. traces all indicate the exclusive presence of kaolinite throughout this profile,with the exception of the B22 horizon, which, besides kaolinite D.T.A. points out the occurrence of gibbsite.

Table 68. Physico-chemical properties of profile 3

Depth (cm)	Horizon	Size class and particle diameter (mm)								
		TOTAL			SAND					COARSE FRAGM.
		Sand	Silt	Clay	V.C.	C.	M.	F.	V.F.	> 2 mm
		2-0.05	0.05-0.002	< 0.002	2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	
0- 12	Ap	68.8	3.2	28.0	2.3	12.2	22.2	25.8	6.4	0
- 28	A12	68.4	2.8	29.1	1.7	13.0	22.0	25.5	6.2	0
- 52	A3	54.7	2.9	42.5	1.7	10.8	16.8	18.9	6.5	0
- 72	B1	42.3	2.6	55.0	1.4	8.6	13.1	14.3	4.9	0
-130	B21	34.1	2.1	63.8	1.4	7.4	10.3	11.2	3.9	0
-200	B22	30.3	2.7	67.0	1.6	6.6	9.3	9.3	3.5	0
-250	B23	29.1	5.1	65.8	0.9	6.2	8.9	9.9	3.4	0

Depth (cm)	Organic carbon %	pH 1:1 KCl	pH 1:1 H_2O	Ext. Fe as Fe_2O_3 %	Ext. Al as Al_2O_3 %	Bulk density g/cm³	Silt/clay ratio	Coarse clay 2-0.2µ	Fine clay < 0.2µ	Fine clay/Tot. clay
0- 12	1.44	4.4	4.9	0.68	0.35	1.64	0.09	6.0	22.0	0.78
- 28	0.88	4.3	4.7	0.73	0.38	1.78	0.09	6.9	22.2	0.76
- 52	0.54	4.3	4.9	1.11	0.54	1.61	0.06	11.9	30.6	0.72
- 72	0.42	4.2	4.7	1.40	0.65	1.61	0.04	23.6	31.4	0.57
-130	0.38	4.3	5.0	1.72	0.66	1.45	0.03	23.6	40.2	0.63
-200	0.24	4.4	5.2	1.88	0.65	1.53	0.04	15.4	51.6	0.77
-250	0.14	4.3	5.1	2.05	0.65	1.52	0.07	-	-	-

Depth (cm)	Extractable bases					Al 1NKCl	Extr. acidity KCl pH 8.2	C.E.C.				Base saturation (%)	
	Ca	Mg	K	Na	Sum			NH_4OAc	Sum cations	NH_4OAc	E.C.E.C.	NH_4OAc	Sum cations
	meq./100g soil							meq./100g soil		meq./100g clay			
0- 12	2.02	0.30	0.03	0.12	2.47	0.22	3.34	5.6	5.8	16.0	9.3	25.7	42.5
- 28	1.04	0.40	0.01	0.09	1.54	0.46	3.22	3.9	4.8	12.0	6.9	44.0	32.3
- 52	0.43	0.20	0.0	0.08	0.71	0.72	3.2	3.5	3.9	9.3	3.4	18.2	18.2
- 72	0.49	0.10	0.0	0.10	0.69	1.02	3.24	2.0	3.9	3.6	3.1	34.5	17.5
-130	0.92	0.19	0.03	0.13	1.27	0.52	2.64	2.4	3.9	3.8	3.1	61.2	32.5
-200	0.71	0.30	0.04	0.10	1.15	0.30	2.42	5.7	3.6	9.7	2.4	20.1	32.2
-250	0.44	0.11	0.01	0.06	0.62	0.50	2.78	4.7	3.4	7.1	1.7	13.1	18.2

Table 69 .Mineralogical composition of the sand fraction (50-250μm) of profile 3

Hor.	Depth (cm)	Light minerals		Heavy minerals			
		Quartz	Feldspars	Opaques	Zircon	Tourma-line	Rutile
Ap	0- 12	100	-	94.9	4.5	tr.	tr.
A12	- 28	100	-	95.7	3.7	"	"
A3	- 52	>99	tr.	95.0	4.0	"	"
B1	- 72	>99	"	93.2	5.8	"	0.0
B21	-130	100	-	92.2	7.44	"	tr.
B22	-200	100	-	94.4	4.88	"	tr.
B23	-250	>99	tr.	91.9	7.24	"	0.0

tr. (traces) = 1%.

Table 70 . Mineralogical composition of the clay fraction (<2μm) of profile 3

Hor.	Depth (cm)	Clay fraction		
		X-ray	D.T.A.	T.G.A.
A12	12- 28	K	K	K5
A3	- 52	K	-	-
B22	-200	K	K, G	K5
B23	-250	K	K	K5

Mineral code : K : kaolinite; G : gibbsite.
Approx. weight fractions (T.G.A.) : 5 : more than half; 4 : half to one third; 3 : one third to one fifth; 2 : one fifth to one twentieth; 1 : less than one twentieth.

3.9.4. Sedimentology

The detailed particle size distribution of the particles between 63 and 2000 microns for the horizons A12, A3, B1, B21, B22 and B23 is given in table 71.

Tables 72 and 73 respectively give the cumulative frequencies of the fractions between 63 and 2000 microns and the most important sedimentological parameters.

The cumulative curves drawn in probability paper are presented in fig. 13.

The horizon A12 shows an almost symmetric, negatively skewed ($\alpha 3\ \phi = -0.05$), platykurtic ($\alpha 4\ \phi = 0.70$) distribution curve with a Mz ϕ value of 1.79; the standard deviation (G1 ϕ = 1.01) indicates a moderately sorted material.

The horizon A3 has a symmetric ($\alpha 3\ \phi = 0.0$), platykurtic ($\alpha 4\ \phi = 0.70$) distribution, with a Mz value of 1.76% and a standard deviation (G1 ϕ = 1.03) showing a moderately sorted material.

The distribution curve of the B1 horizon is almost symmetric, positively skewed ($\alpha 3\ \phi = 0.05$), platykurtic ($\alpha 4\ \phi = 0.74$) with a Mz value of 1.72 ϕ and having the same sorting as the preceeding horizon (G1 ϕ = 1.05).

The B21 horizon distribution is moderately positive and asymmetric ($\alpha 3\ \phi = 0.15$), platykurtic ($\alpha 4\ \phi = 0.70$), with a Mz ϕ of 1.66 and similar sorting (G1 ϕ = 1.09) as the overlaying horizons.

The distribution of the B22 horizon is moderately negatively skewed ($\alpha 3\ \phi = -0.10$), platykurtic ($\alpha 4\ \phi = 0.62$) with a Mz value of 1.75 ϕ and similar sorting (G1 ϕ = 1.05) as the above horizons.

The B23 horizon presents an almost symmetric negatively skewed ($\alpha 3\ \phi = -0.04$), platykurtic ($\alpha 4\ \phi = 0.59$) distribution, with Mz value of 1.71 ϕ and similar sorting (G1 ϕ = 1.03) as the rest of the soil profile.

The mean grain size of particles is rather similar in all horizons, slightly increasing from the A12 to the B21 horizon, that respectively show Mz ϕ = 1.79 and Mz ϕ = 1.66. In the horizons B22 (Mz ϕ = 1.75) and B23 (Mz ϕ = 1.71) a slight decrease is found.

The standard deviations are practically the same throughout, with figures that range from G1 ϕ = 1.01 in the A1 to G1 ϕ = 1.09 in the B21 horizon.

Most of the horizons show nearly symmetric distributions, where the B21 ($\alpha 3$ ϕ = 0.15) and the B22 ($\alpha 3$ ϕ = -0.10) horizons present the extreme values (see table 73).

The kurtosis is also very similar in the whole profile, presenting figures about $\alpha 4$ ϕ = 0.70 in the A12, A3, B1 and B21 horizons and somewhat lower values ($\alpha 4$ ϕ = 0.60) in the underlaying B22 and B23 horizons.

Thus, from sedimentological point of view, the parent material of the profile under discussion is highly uniform.

3.9.5. Micromorphology

A. Microstructure and pore pattern

Moderate and strong fine crumbly microstructure grading to spongy with fissured and vughy cavited intrapedal m.s. is observed in the A3 horizon. Very frequent compound interpredal and intrapedal packing pores are dominant, followed by very frequent fissures, vughs (smooth and rough) and smooth channels.

The underlaying B1 and B21 present 1) weak crumbly microstructure with fissured and vughy cavited intrapedal m.s. and 2) strong and moderate fine crumbly microstructure with fissured and vughy cavited intrapedal m.s., both types grade to spongy. The total porosity of these horizons is lower with respect to the overlaying and under-

Table 71 . Particle size distribution of the fractions between 63 and 2000μm

	1400 -2000	1000 -1400	710 -1000	500 - 710	355 -500	250 - 355	180 -250	125 - 180	90 -125	63 -90
A12	0.8	2.3	6.8	15.2	13.8	19.1	14.5	12.9	9.9	4.6
A3	0.9	2.8	6.5	16.6	13.9	17.5	14.8	13.0	8.3	5.5
B1	1.1	2.3	9.1	15.8	14.8	17.0	13.6	12.5	7.9	5.7
B21	1.5	3.0	10.4	14.9	14.4	16.4	14.9	8.9	7.4	7.5
B22	1.7	2.6	7.7	13.7	13.8	18.9	13.8	13.7	8.6	5.1
B23	1.8	1.8	9.1	14.5	14.5	16.3	16.3	14.4	5.4	5.4

Table 72 . Cumulative frequencies of the fractions between 63 and 2000μm

	>1400	>1000	>710	>500	>355	>250	>180	>125	>90	>63
A12	0.8	3.1	9.9	25.1	38.9	58.0	72.5	85.4	95.3	99.9
A3	0.9	3.7	10.2	26.8	40.7	58.2	73.0	86.0	94.3	99.8
B1	1.1	3.4	12.5	28.3	43.1	60.1	73.7	86.2	94.1	99.8
B21	1.5	4.5	14.9	29.8	44.2	60.6	75.5	84.4	91.8	99.3
B22	1.7	4.3	12.0	25.7	39.5	58.4	72.2	85.9	94.5	99.6
B23	1.8	3.6	12.7	27.2	41.7	58.0	74.3	88.7	94.1	99.5

Table 73 . Sedimentological parameters of the fractions between 63 and 2000μm

	Mz	1σ	3α	4α
A12	1.79	1.01	-0.05	0.70
A3	1.76	1.03	0.0	0.70
B1	1.72	1.05	0.05	0.74
B21	1.66	1.09	0.15	0.70
B22	1.75	1.05	-0.10	0.62
B23	1.71	1.03	-0.04	0.59

laying layers, where very frequent fissures and vughs dominate, followed by frequent channels and rare compounds packing pores.

In the B22 and B23 horizons the microstructure is dominantly spongy grading to weak and moderately developed crumbly with fissured and vughy cavited intrapedal m.s. The pore pattern is similar to the overlaying horizons dominated by very frequent fissures and vughs (mostly interconnected) and followed by frequent compound packing pores and channels.

Channel infillings are present throughout, showing mostly strong and moderately developed fine crumbly microstructure with fissured intrapedal m.s. Very frequent compound packing pores and fissures are mostly observed and respectively occupy interpedal and intrapedal positions.

B. Matrix

B1. Coarse material (>5µm)

Quartz grains, from coarse to fine sand sized, angular, subangular and subrounded, compose the coarse material in all the horizons. The grains commonly show fissures. Runiquartz are frequently present in the whole profile.

B2. Fine material (<5µm)

The fine material includes mostly kaolinitic clay and very low amounts of oxihydrates. The colors are brownish in the upper A3 and B1, yellowish in the B21 and B22, becoming reddish in the lowermost B23 horizon. The b-fabric is undifferentiated in all horizons; some subordinated types as dotted and circular striated are present in the B1, B21, B22 and B23 horizons.

In channel infillings, undifferentiated b-fabrics are also dominant, with circular striated and poro striated locally present.

B3. Coarse/fine related distribution

Open gefuric, grading to enaulic, dominates in the A3 horizon; locally gefuric and porphyric. In the B1 and B21 mainly porphyric is present, with open gefuric between larger grains. The lowermost B22 and B23 horizons show open and double porphyric.

In channel infillings enaulic is dominant and locally gefuric is observed.

C. Organic matter

In the upper soil horizons the organic matter is present as highly humified roots (f) and as fecal pellets (o).

D. Features

Coatings and infillings, composed of limpid kaolinitic clay, were observed from the A3 to the B22 horizons, ranging from few microns in fissures to 1.2 mm in vughs and channels. They have a yellow color, strong continuous orientation and sharp boundaries, are rare in A3, frequent in the underlaying B21 and B22 horizons and absent in deeper layers.

Clay coatings and infillings of limpid and speckled clay with strong continuous orientation and sharp boundaries are commonly observed only in the B21 horizon. They have around 40µm ∅ and are located in vughs. Fragments of clay coatings (0.1-0.3 mm ∅), with diffuse and sharp boundaries, commonly occur in the fine mass and inside channel infillings.

Channel infillings having smooth and rough walls are very frequent throughout. They range from 1 to 12 mm ∅ and include microaggregates and quartz grains.

E. Quantification of illuviation features

Point counting results are presented in table 74. Clay illuviation percentages are weak in the A3 (0.49%) and moderate in the B1 (2.55%) and B21 (3.68%). The results obtained for the degree of clay illuviation per horizon and the profile clay illuviation index are shown in table 75. The degree of clay illuviation increases from weak in A3 to strong in B21, becoming again weak in underlaying horizons. The clay illuviation index for the whole profile is moderately high (388.5).

3.9.6. Classification

The profile presents a dark surface horizon in the top 28 cm, which has the properties of an umbric epipedon. In the field doubtful thin and patchy clay skins were only observed in the B21 horizon. The thin section study confirmed the presence of illuviation cutans in the B21 horizon (3.68%), and also indicate their existence in the overlaying B1 (2.55%) and A3 (0.5%). The clay increase requirements for an argillic horizon are reached between the A12 and A3 horizons (illuvial/eluvial clay ratio >1.2), and from the A3 to B1 horizons (>8% clay). On the other hand, the subsoil presents throughout the properties of an oxic horizon.

In consequence, the profile is classified as a member of the clayey, kaolinitic, isohyperthermic family of the OXIC PALEUSTULTS.

Table 74 . Quantitative micromorphological analysis of soil components (by point counting) expressed in volume per cent of total soil

Depth (cm)	Horizon	Pores	Coarse material	Fine material	Coatings	Fragm.of coatings	Nodules
28- 52	A3	21.3	36.5	41.7	0.49	-	-
- 72	B1	12.8	26.2	58.0	2.55	0.42	-
-130	B21	14.8	19.7	61.0	3.68	0.81	-
-200	B22	24.2	10.9	64.5	0.0	0.28	-
-250	B23	25.0	11.8	63.3	0.0	0.53	0.2

Table 75 . Degree of clay illuviation per horizon and profile clay illuviation index

Horizon	Thickness (cm)	% in situ + translocated illuviation features (on solid phase)	Degree of illuviation
A3	24	0.62	weak
B1	20	3.40	moderate
B21	48	5.27	strong
B22	70	0.36	weak
B23	50	0.70	weak
Profile clay illuviation index = 388.5 per cent cm. Moderately high.			

CLASSIFICATION ACCORDING TO OTHER SYSTEMS

FAO/UNESCO	:	Ferric Acrisols
BRAZILIAN SYSTEM	:	Red Yellow Podzolic Dystrophic, low clay activity, prominent A horizon, clayey, semi-evergreen tropical forest, level phase
I.N.E.A.C.SYSTEM	:	Hygro-xero Ferrisol.

CHAPTER 4 - DISCUSSION AND CONCLUSIONS

4.1. General attributes of the soils

In the coastal plateaus of Alagoas the dominant soils - Latosols and Red Yellow Podzolic - are very deep and the color of the B horizon is mainly 10 YR (with values and chromas ranging between 5 and 8), that turns to 7.5 in deep layers. The yellow colors are not related to impeded drainage conditions; these soils are normally well and moderately well drained. The clay content in the B horizon varies from 50% to 70% and gradually decreases towards the top of the soil. The structure is normally moderate in the A1 or Ap horizons and weak in the major part of the B. Mottles are commonly observed in the transitional - A3 and B1 - horizons and in the upper part of the B2, where a peculiar great cohesion - hard to very hard consistence - when dry, also occurs. The structure of the A1 or Ap horizons is generally fine and medium crumbly, whereas the B2 mostly shows weak subangular blocky that rather easily breaks down when moist into very fine crumbly. Transitions between horizons are mainly gradual and diffuse; clear transitions are only observed between the Ap and the B21 and their respective underlaying horizons. The horizon differentiation is anyhow always stronger in Red Yellow Podzolic soils than in Latosols.

On the other hand in minor depressed zones with poor drainage the soils - Podzols - present contrasting properties between a structureless sandy epipedon and the clayey indurated subsoil - ortstein - on top of which discontinuous layers of accumulated organic material occurs.

4.2. The soil parent materials

4.2.1. Mineralogy

The mineralogy of the soils formed on the plateaus of Alagoas is simple and uniform throughout. The soils mainly consist of quartz, kaolinite and low amounts of sesquioxides of iron and aluminum.

4.2.1.1. Sand fraction

In the sand fraction (between 50 and 250µm) the light minerals are dominant, making 91% to 98% of the total sample. Everywhere the light fraction is almost entirely composed of fissured and highly weathered grains of quartz and no more than traces of feldspars. The examination of soil thin sections led to the same conclusion.

The heavy fraction includes mainly opaques that within profiles range from 84 to 92%, where magnetic minerals are the most frequent. X-ray analysis showed that the magnetic minerals consist of magnetite, ilmenite, hematite and goethite. Among the transparent minerals zircon is dominant, ranging from 2.5% to 11.8%, followed by very low contents of tourmaline - <1% - and the occasional presence of rutile.

The almost complete absence of weatherable minerals in the sand fraction confirms the extreme age and pre-weathered nature of the soil forming materials.

4.2.1.2. Clay fraction

The X-ray diffractograms showed that kaolinite is almost the unique mineral composing the clay fraction, throughout the studied area. Occasionally, some soil horizons show besides the kaolinite, the presence of gibbsite and titanium oxides.

The presence of kaolinite is evidenced by well defined peaks at 7.15 Å and 3.58 Å, which completely disappear after heating at 550°C (see fig. 2). Occasionally, rather faint peaks at 4.85 Å that vanish on heating at 330°C due to dehydroxilation indicate the presence of gibbsite. The occurrence of titanium oxides is sometimes indicated by poorly defined peaks at 2.9 Å and 3.5 Å, that respectively correspond to rutile and anatase (fig. 3).

Differential thermal analysis (D.T.A.)

The differential thermal analysis always show major endothermic reactions at temperatures of about 550°C due to the destruction of OH-groups (dehydroxilation) of kaolinite. When gibbsite is present, minor but well defined peaks at about 280°C point out the dehydroxilation of this mineral (see fig. 4).

Thermo-gravimetric analysis (T.G.A.)

In agreement with the X-ray diffractometry and the D.T.A. analysis, the thermogravimetrical curves of fig. 4 show :

1) a slight slope at temperatures of about 70-80°C, where the loss of weight is 1.5%,
2) a plateau between 90 and 230°C, showing a weak decrease of 1%,
3) from 240°C to 400°C a gradual loss of weight of about 3%,
4) a steep slope between 400°C and 550°C, where the loss of weight reaches 9%, and
5) above 550°C the curve flattens, giving a weight loss that ranges from 1% to 1.5% up to 900°C.

The very weak loss in weight at less than 80°C is probably due to low amounts of loosely bound water, and the main endothermic (dehydroxilation) peaks observed between 240°C and 260°C, and between 400°C and 550°C, respectively confirm the presence of gibbsite and kaolinite, as already pointed out by X-ray and D.T.A. analysis.

Fig. 2 - X-ray patterns indicating the presence of kaolinite.

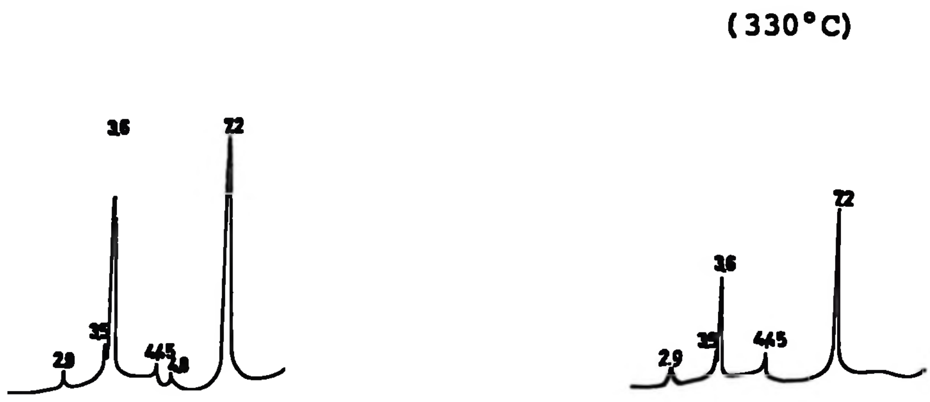


Fig. 3 - X-ray patterns indicating the presence of kaolinite, gibbsite, rutile and anatase.

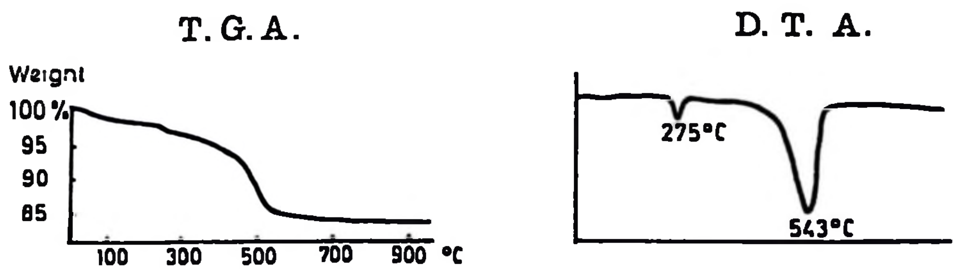


Fig. 4 - T.G.A. and D.T.A. patterns showing the presence of gibbsite and kaolinite.

4.2.2. Uniformity of the soil parent materials

In the study of soil forming processes the uniformity within a soil parent material is a basic prerequisite in differentiating pedological features from those which are geological in origin. Uniformity is therefore essential for any interpretation of soil forming processes and their rates.

Uniformities are frequently estimated through field evidences and/or based on trends of soil components with depth, such as resistant minerals. But due to the great variety of soil parent materials, a large amount of criteria have been applied by different workers. Based on the proposals of several authors, Barshad (1964) has suggested total mineralogical analysis, particle size distributions of resistant minerals, ratio of two resistant minerals in one fraction, size distribution of non-clay fractions, the nature of clay distribution with depth and changes in the chemical composition of the non-clay fraction as useful properties to determine the uniformity of soil materials. Marshal and Haseman (1943), cited by Chang Wang and Arnold (1973), used particle size distributions and mineral analysis to establish the uniformity of the soil system. Arnold (1979) stated that uniformity should be based on appropriate parameters and that several lines of evidence - when possible - are preferred to a depth function of a single parameter.

Particle size distributions are not often analyzed in residual soils because of the heterogeneous composition of the grains and the frequent changes in sizes of the particles as a consequence of weathering. A progressive reduction in grain size from the lower to the upper soil horizons is commonly observed in all the mineral species forming the parent material (Brewer, 1955).

But, the sand fraction of the materials under discussion is almost entirely composed of a similar suite of highly resistant minerals, where the quartz represents more than 95%; thus excluding the possibility of using a specific 'marker' mineral, in which case only presence or absence is usually diagnostic. On the other hand, the mean size of the grains within profiles is in most cases highly uniform throughout (see sedimentological parameters), suggesting that no significant changes in the size of the minerals occurred after the deposition of the sediment, as a result of weathering.

In consequence, the particle size distributions of the total sand fraction - which appear to be insignificantly affected by pedogenesis - were considered a reliable base of comparison between the parent materials of the studied soils.

A preliminar approach to the uniformity of the parent materials within profiles was already given by the sedimentological parameters of the fractions between 63 and 2000 µm as discussed in chapter 3.

In the following paragraphs, the comparative particle size distribution indices (C.P.S.D. index) for the fractions between 63 and 2000µm, will be calculated. This in order to verify the results obtained through the sedimentological parameters, and to provide a quantitative estimation about the degree of similarity of the parent material within individual profiles.

At the same time the C.P.S.D. index method allows the comparison of the particle size distributions between different profiles. In this way not only the similarity of the soil forming materials between profiles that belong to the same geomorphological unit (plateau), but also the degree of similarity among the materials present in different plateaux will be established.

4.2.2.1. Uniformity of the soil parent materials within individual profiles

4.2.2.1.1. PLATEAU A

Profile 1. The sedimentological study carried out in 3.1.4. pointed out that the parent materials composing the different soil horizons of this profile, are highly similar, as illustrated by the cumulative curves (fig. 5). The almost identical figures of the mean (Mz) and the standard deviation (Gl) in the different soil horizons (table 10) is remarkable.

The results of the C.P.S.D. index method (table 76) show indices ranging from 90 to 96 within the profile, suggesting very high and extremely high similarities among horizons.

As a consequence it may be concluded that the soil parent material of this profile is highly uniform throughout.

Profile 2. The sedimentological study developed in 3.2.4. indicates that the sand size distribution of B21 is somewhat different, as compared with the underlaying and overlaying horizons. These differences, which are more pronounced with respect to the deeper layers, are indicated by most sedimentological parameters (table 18), and are illustrated by the cumulative frequencies of the sand fraction (fig. 6).

The comparison between the sand distributions of the horizons forming this profile (through the C.P.S.D. index) (table 76) show rather low similarities when comparing the horizon B21 with the underlaying layers (indices from 75 to 78), and somewhat higher similarities with respect to the overlaying horizons (indices from 80 to 83).

On the other hand, the similarity within the sand size distribution of the layers, on top and below B21, are very high (indices from 91 to 94).

Finally, the sedimentological parameters and the results of the C.P.S.D. index method show that B21 differs with respect to the other soil horizons. Therefore, the parent material of profile 2 is not considered as uniform from a sedimentological point of view.

Table 76. C.P.S.D. index based on 10 fractions between 63 and 2000μ. Plateau A

	2	3	4	5	6	7	8	9	10	11
1	96	91	95	89	91	77	97	93	92	95
2		92	94	87	91	76	96	95	91	93
3			90	82	87	71	91	90	85	88
4				84	88	75	93	95	95	96
5					91	80	88	85	85	84
6						83	93	91	89	88
7							78	77	76	75
8								94	91	93
9									94	93
10										93

<u>Reference numbers</u>

Profile 1 : A3 (1), B1 (2), B21 (3), B22 (4).
Profile 2 : A1 (5), A3 (6), B21 (7), B22 (8), B23 (9), B24 (10), B3 (11).

The C.P.S.D. indices presented in table 76 also show the comparison between the particle size distributions of the horizons forming the profiles samples in Plateau A. The similarities among profiles are in general high to extremely high (indices from 82 to 96), with the exception of the horizon B21 of profile 2.

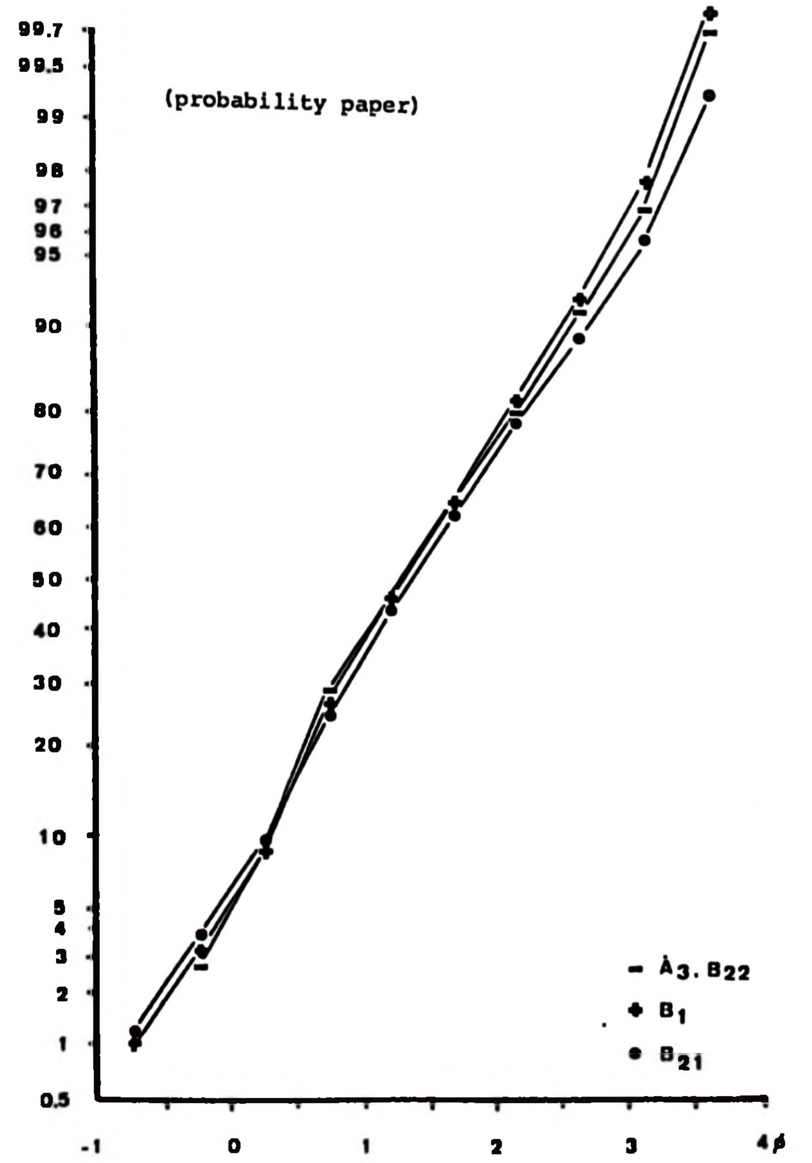


Fig. 5 - Cumulative curves of profile 1

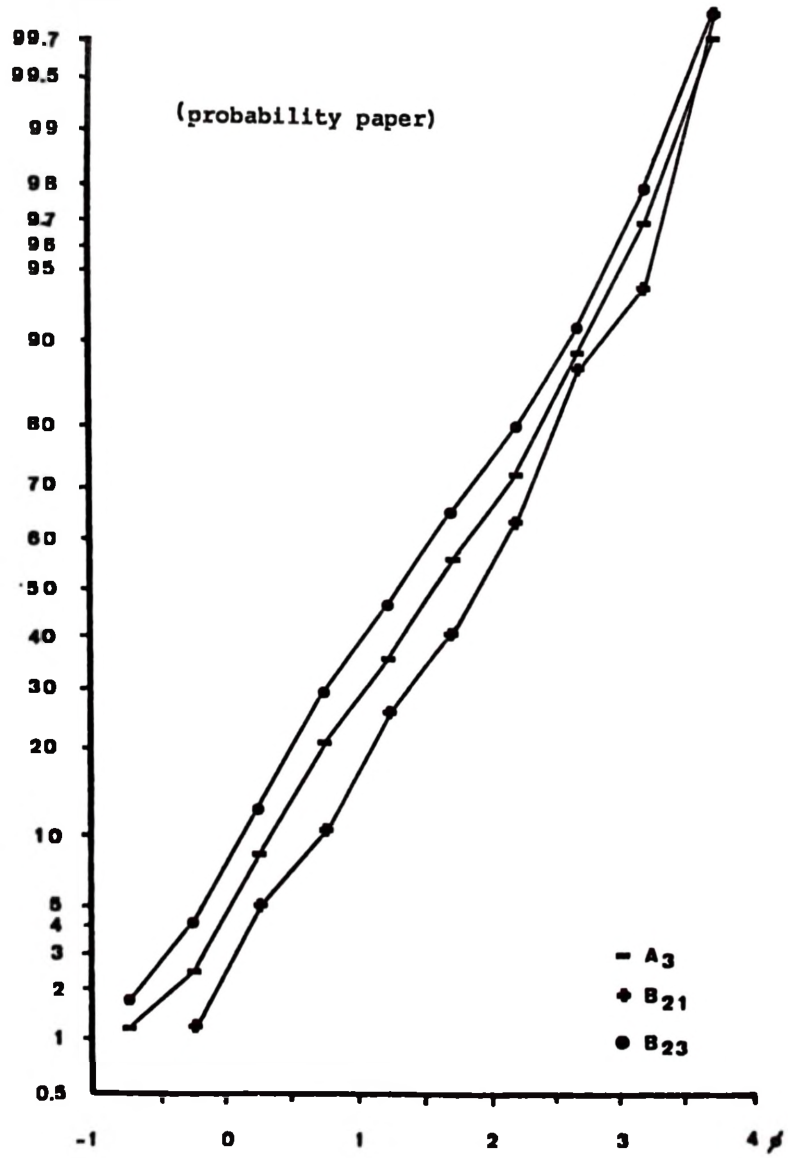


Fig. 6 - Cumulative curves of profile 2

4.2.2.1.2. PLATEAU B

Profile 4. The conclusions of the sedimentological characterization carried out in 3.3.4. indicate that the parent material, forming the horizons of this profile, are very similar. The sedimentological parameters presented in table 26 and the cumulative frequencies of the fractions between 63 and 2000µm, for each soil horizon (fig. 7) clearly show a very high granulometrical similarity among horizons.

The results obtained when using the C.P.S.D. index method are presented in table 77. Similarity indices that range from 89 to 95 within this profile point to samples having very similar distributions.

Consequently, both methods confirm the very high uniformity of the soil parent material of profile 4.

Profile 5. The sedimentological study elaborated in 3.4.4. shows a very high granulometrical uniformity among the soil horizons of this profile. This, with the exception of the lowermost B32 which appears somewhat different from a sedimentological point of view with respect to the other horizons. That slight sedimentological difference indicated by the mean (Mz) and the skewness ($\alpha 3$) (table 34) is graphically illustrated by the cumulative frequencies of the sand fraction (fig. 8).

The C.P.S.D. index method (table 77) confirms the results obtained through the sedimentological study. In this way the horizons A1, A3, B21, B22, B23 and B31, present very high and extremely high similarities, as suggested by indices ranging from 91 to 99. The B32, when compared with the other soil horizons, showed the lowest indices for the whole profile (from 84 to 89); anyhow, indices in that range still point to highly similar distributions.

We therefore conclude that profile 5 is developed on a highly uniform parent material. Moreover, it is possible to add that both profiles sampled on plateau B are not only individually highly homogeneous, but also developed in extremely similar materials as indicated by the sedimentological parameters (tables 26 and 34) and by C.P.S.D. indices that range from 86 to 98 (table 77).

Table 77. C.P.S.D. index based on 10 fractions between 63 and 2000µ. Plateau B

	2	3	4	5	6	7	8	9	10	11	12	13
1	95	95	93	89	91	98	95	95	92	91	90	86
2		95	93	90	92	96	96	97	94	92	91	88
3			94	92	94	95	94	95	95	93	92	87
4				92	95	93	95	93	96	90	89	89
5					91	89	90	89	93	88	87	87
6						91	94	90	95	92	91	87
7							95	96	92	90	90	87
8								96	95	92	91	89
9									93	91	91	86
10										92	91	89
11											99	85
12												84

Reference numbers

Profile 4 : A12 (1), A3 (2), B1 (3), B21 (4), B22 (5), B23 (6).

Profile 5 : A12 (7), A3 (8), B21 (9), B22 (10), B23 (11), B31 (12), B32 (13).

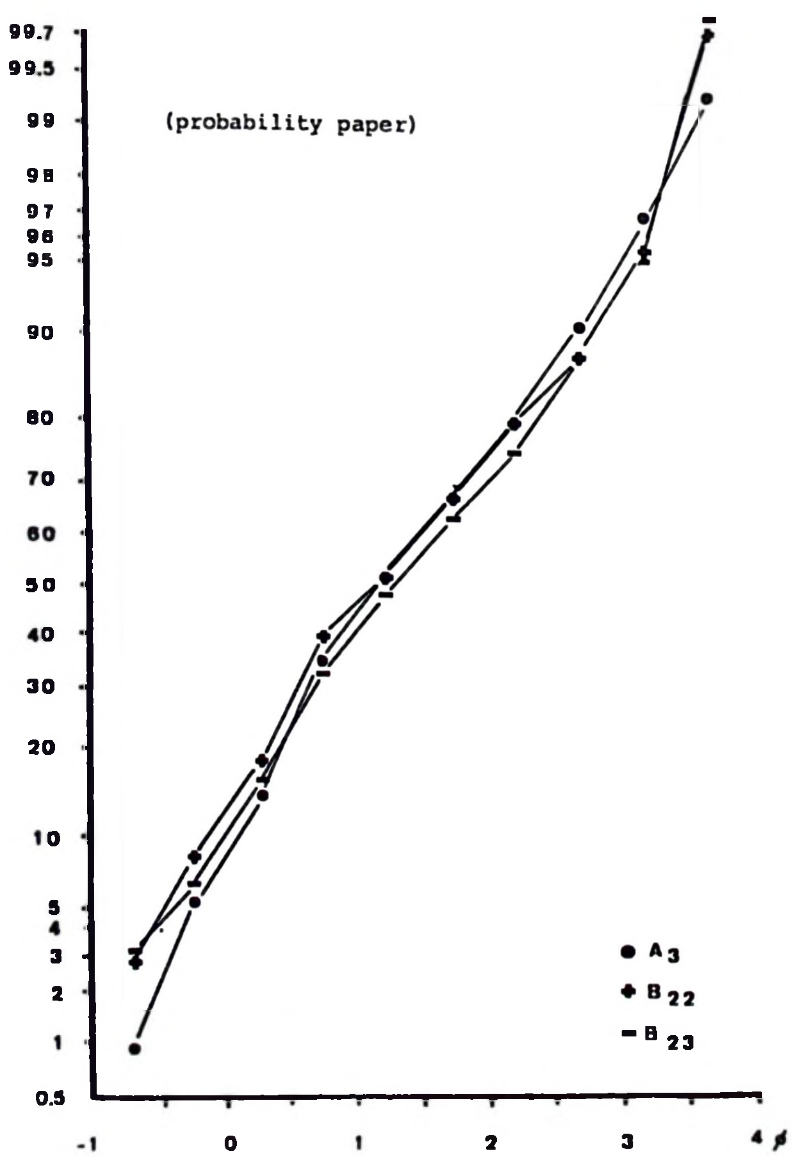


Fig. 7 - Cumulative curves of profile 4

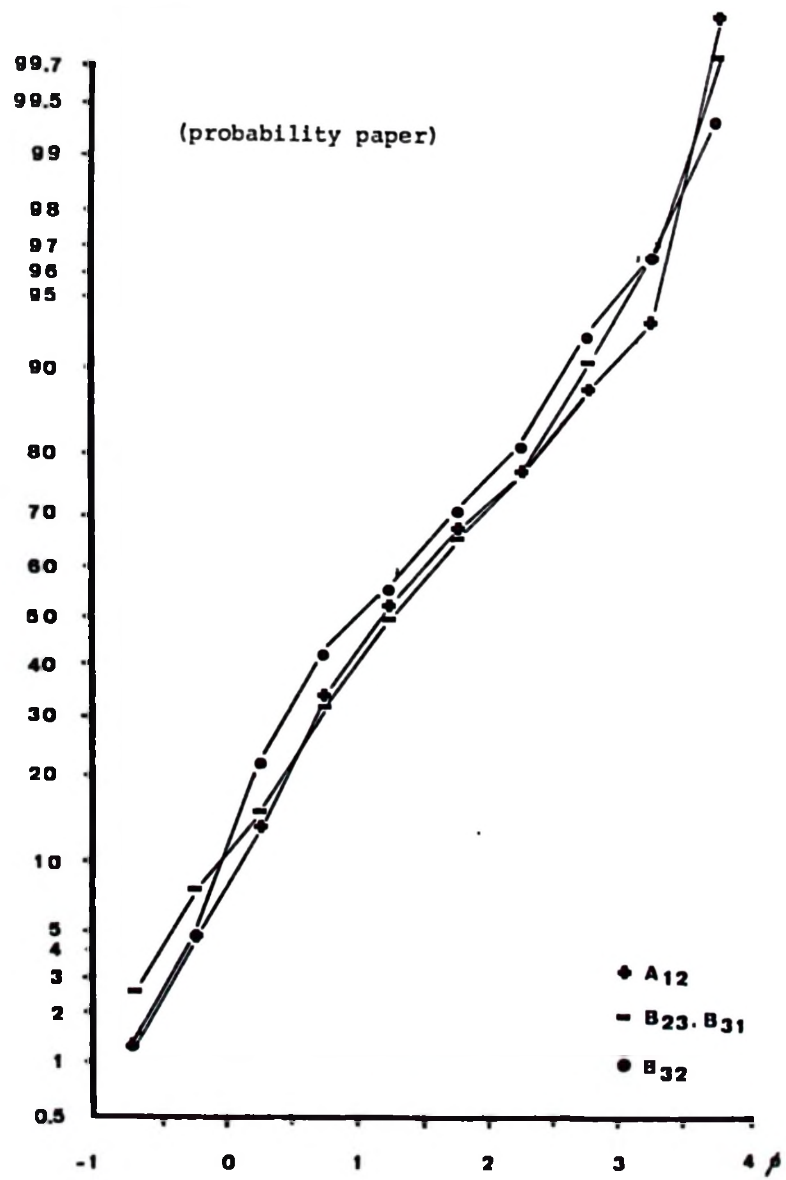


Fig. 8 - Cumulative curves of profile 5

4.2.2.1.3. PLATEAU C

Profile 6. The sedimentological study, developed in 3.5.4. points out that the parent materials forming the different soil horizons in that profile, are very similar. A very high sedimentological likeness is indicated by the parameters of table 42 and illustrated by the cumulative frequencies of the sand fraction (fig. 9).

In agreement with the conclusions of the sedimentological study, the C.P.S.D. index method, presented in table 78 also confirms a very high similarity of the sand fraction distributions among the soil horizons. Indices between 88 and 96 indicate that the resemblance within the profile varies from high to extremely high.

Profile 9. The sedimentological study elaborated in 3.6.4. suggests a very high similarity between the sand size distribution of the upper A12 and B/A horizons (table 50). The subsoil horizons B21x and B22x, which are also highly similar, appear somewhat different from the sedimentological point of view, when compared with the upper horizons (A12 and B/A), as illustrated in fig. 10. The sedimentological difference among the upper and lower horizons is highest between A12 and B22x,which is indicated by a gradual change in the values of all sedimentological parameters with depth (table 50).

The C.P.S.D. index method seen in table 78 confirms the results of the sedimentological study. The lowest similarities within the profile were observed when comparing the upper A12 and B/A horizons against the lowermost B22x. Their respective indices of 80 and 83 anyway attest for highly similar distributions. The highest similarity was observed between the A12 and B/A horizons (index 94). High similarities among contiguous horizons are also indicated by indices ranging from 85 to 94.

Profile 7. The sedimentological study carried out in 3.7.4. designates that a sedimentological difference exists between the upper layers (A12 and A2, and the subsoil B21hirm and B22hirm, as illustrated in fig. 11, characterized by the gradation of most sedimentological parameters with depth (table 57).

The results of the sedimentological characterization are supported by the results of the C.P.S.D. index method presented in table 78. The lowest similarities among the sand size distributions of the different soil horizons are observed, when comparing the top A12 and A2 versus the lowermost B22hirm, where indices of 80 in any case suggest a rather high similarity. The gradual change followed by the sedimentological parameters with depth is corroborated by the high to extremely high indices (ranging from 89 to 95), found between contiguous horizons.

Profile 8. The sedimentological characterization elaborated in 3.8.4. determines that the parent material of the horizon Bh appears somewhat different from a sedimentological viewpoint with respect to the very similar overlaying (A2) and underlaying (B22irm) horizons, as shown by most of the parameters presented in table 65 and illustrated in fig. 12.

The C.P.S.D. index method shown in table 78 confirms the conclusions of sedimentology. The lowest similarities among the sand size distributions in that profile result from the comparison of the horizon Bh with the overlaying A2, having an index of 82 which anyway indicates rather similar distributions. The highest similarities for the whole profile (index = 91) were observed when womparing the horizon A2 versus B22irm.

Table 78. C.P.S.D. index based on 10 fractions between 63 and 2000μ. Plateau C

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	95	94	92	89	88	91	93	82	82	79	81	91	94	95	88	91	94
2		96	94	90	89	91	94	84	83	77	78	88	91	93	86	89	92
3			94	90	91	88	91	83	86	78	80	89	93	93	88	86	92
4				92	89	88	91	88	87	79	79	89	91	92	87	85	92
5					91	86	86	86	85	77	78	87	87	86	86	83	90
6						87	85	87	88	77	79	86	86	84	87	82	88
7							94	86	80	72	72	82	86	90	79	91	88
8								85	83	73	74	84	88	92	81	90	90
9									85	74	73	79	81	82	79	78	83
10										70	70	78	81	80	78	76	82
11											94	88	85	80	90	74	83
12												89	85	80	92	75	83
13													95	90	94	85	93
14														94	91	88	94
15															87	90	94
16																82	91
17																	90

<u>Reference numbers</u> : Prof. 6 - A12 (1), A3 (2), B1 (3), B21 (4), B22 (5), B23 (6).
Prof. 9 - A12 (7), B/A (8), B21x (9), B22x (10).
Prof. 7 - A12 (11), A2 (12), Bh (13), B21hirm (14), B22hirm (15)
Prof. 8 - A2 (16), Bh (17), B22irm (18).

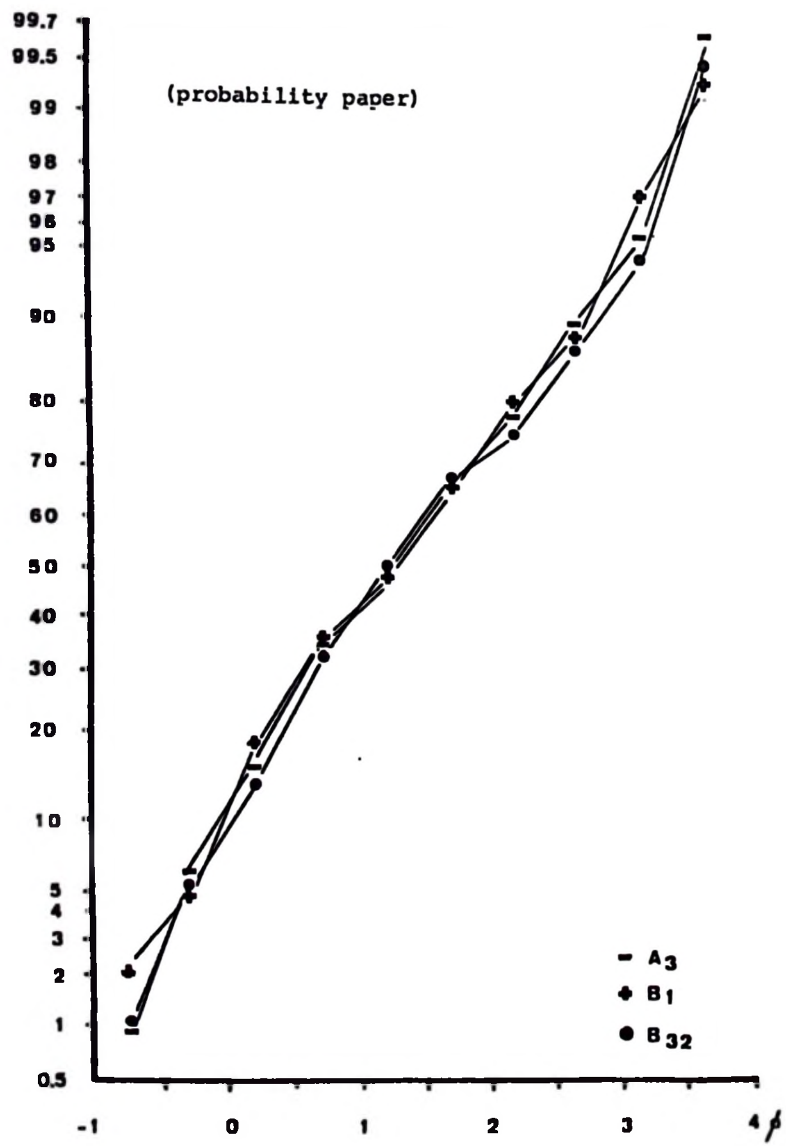


Fig. 9 - Cumulative curves of profile 6

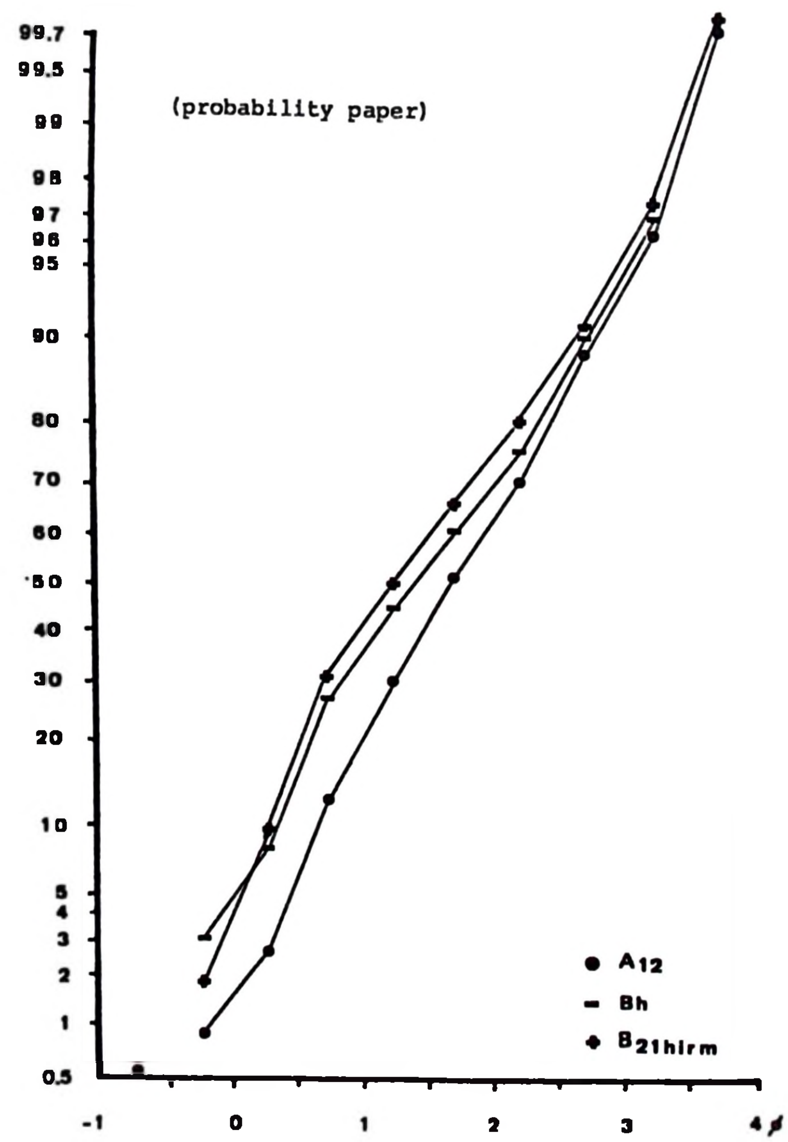


Fig. 10 - Cumulative curves of profile 9

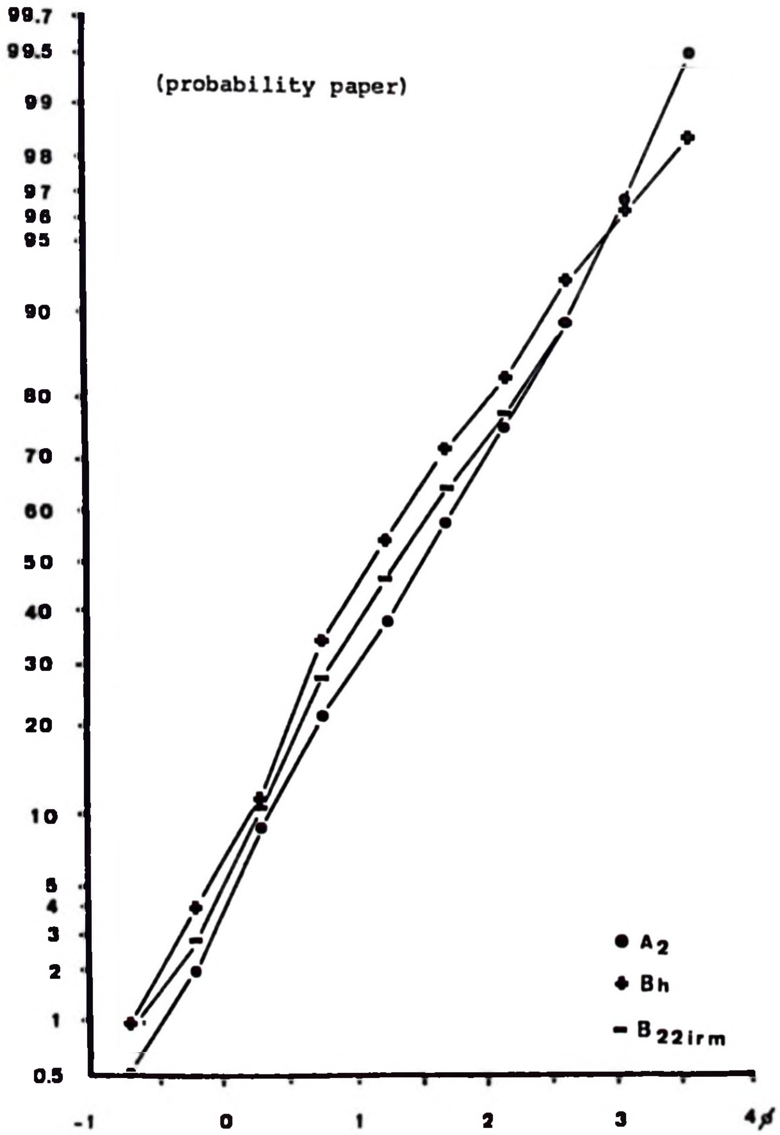


Fig. 11 - Cumulative curves of profile 7

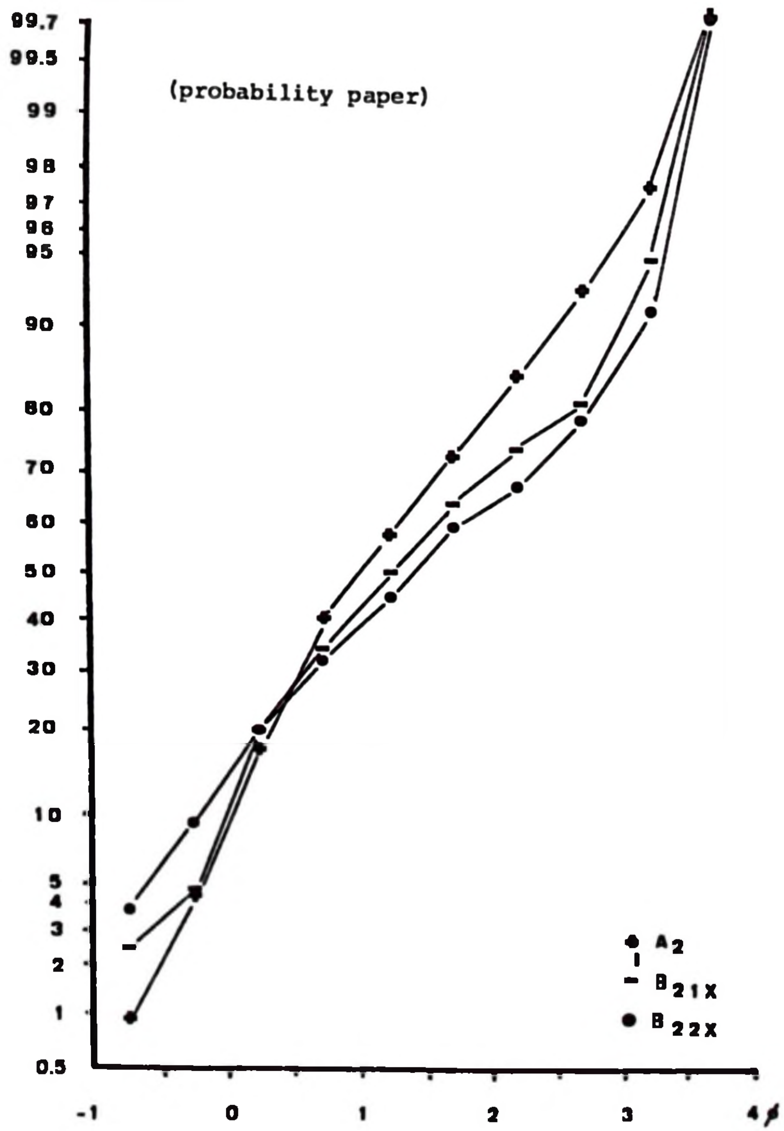


Fig. 12 - Cumulative curves of profile 8

4.2.2.1.4. PLATEAU D

Profile 3. The sedimentological parameters (table 73) and the cumulative frequencies of the fractions between 63 and 2000µ for each soil horizon (fig. 13) illustrate a very extremely high uniformity throughout.

Moreover, the C.P.S.D. index (table 79) show indices of similarity ranging from 91 to 96, thus indicating that the compared distributions are very to extremely similar, and confirming the results of the sedimentological characterization.

Table 79. C.P.S.D. index based in 10 fractions between 63 and 2000µ. Plateau D

	2	3	4	5	6
1	96	95	90	96	91
2		96	92	95	92
3			94	95	94
4				91	92
5					93

Reference numbers

Profile 3 : A12 (1), A3 (2), B1 (3), B21 (4), B22 (5), B23 (6).

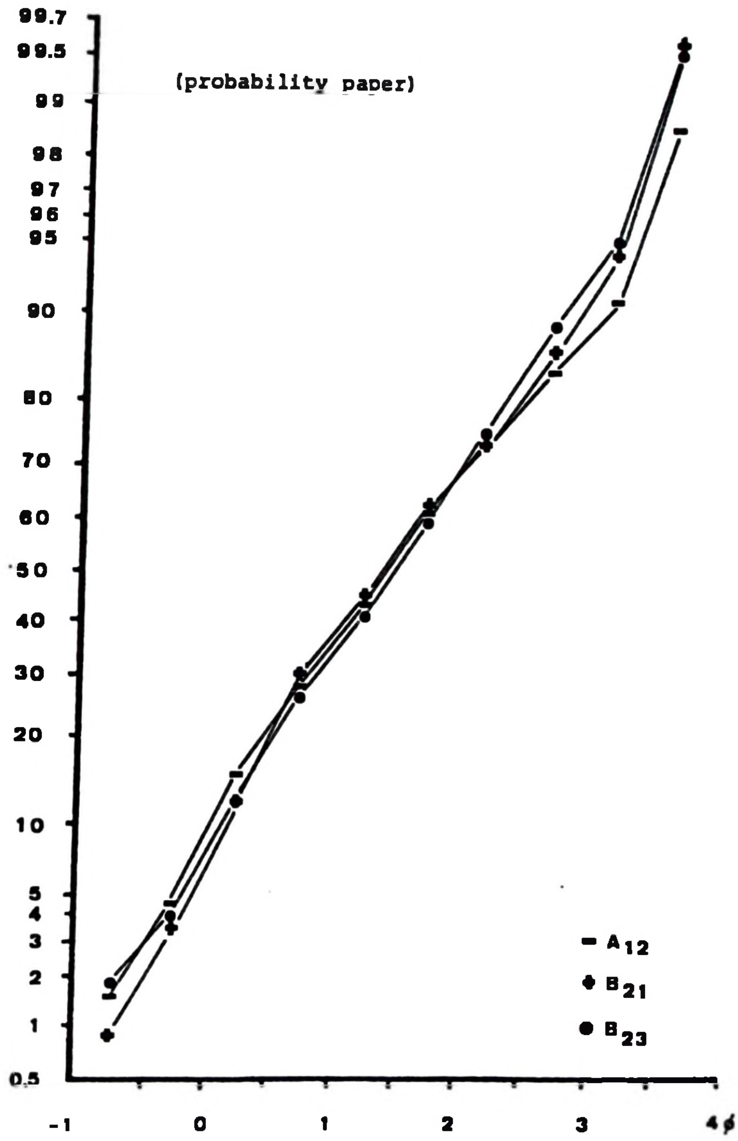


Fig. 13 - Cumulative curves of profile 3.

4.2.2.2. Similarity of the soil parent materials between geomorphological units

In order to estimate the degree of similarity among the soil parent materials present in the different geomorphological units included in this work, the particle size distribution of the fractions from 63 to 2000μ corresponding to the soil horizons comprised in the upper 50 cm, between 50 and 150 cm, and from 150 to 250 cm depth, were compared with the aid of the C.P.S.D.index method. The calculated indices for the chosen depth intervals are presented in tables 80, 81 and 82.

Table 80 shows that in the upper 50 cm the similarity of the materials is in general high to extremely high throughout the region. A somewhat lower index of similarity - 71 - is only observed when comparing the A1 horizon of profile 2 against the A12 horizon of profile 9, respectively located in plateaux A and C.

Table 80. C.P.S.D. index based on 10 fractions between 63 and 2000μ of the horizons between 0 and 50 cm

	2	3	4	5	6	7	8	9	10	11	12	13	14
1	89	91	91	91	93	91	93	93	92	89	88	94	84
2		91	87	86	80	79	81	82	80	78	93	91	71
3			92	91	84	84	85	87	84	84	92	95	77
4				96	88	88	88	90	88	88	84	92	80
5					90	90	90	92	90	89	83	91	82
6						95	98	95	95	85	79	87	90
7							96	96	97	96	79	87	91
8								95	95	95	80	88	90
9									96	94	81	90	89
10										95	79	88	91
11											77	86	91
12												90	72
13													79

Reference numbers

Plateau A -	Prof. 1 :	A3 (1),
	Prof. 2 :	A1 (2), A3 (3).
Plateau D -	Prof. 3 :	A12 (4), A3 (5).
Plateau B -	Prof. 4 :	A12 (6), A3 (7),
	Prof. 5 :	A12 (8), A3 (9).
Plateau C -	Prof. 6 :	A12 (10), A3 (11),
	Prof. 7 :	A12 (12),
	Prof. 8 :	A2 (13),
	Prof. 9 :	A12 (14).

Between 50 and 150 cm depth, the similarity of the particle size distributions among the studied geomorphological units is also high to extremely high, as shown in table with the sole exception of horizon B21 in profile 2, which normally shows rather low indices throughout.

Table 81. C.P.S.D. index based on 10 fractions between 63 and 2000μ of the horizons between 50 and 150 cm depth

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	92	76	96	95	90	87	89	88	92	87	90	88	87	95	88	86	80
2		71	91	90	86	83	86	85	89	84	86	86	86	88	86	83	81
3			78	77	79	76	74	75	74	74	76	76	82	80	67	69	70
4				94	90	86	90	89	92	88	90	89	89	96	85	84	79
5					93	92	93	92	94	90	92	93	85	94	87	88	84
6						94	93	94	91	92	95	94	82	91	83	86	85
7							91	92	88	90	92	93	79	86	82	87	86
8								94	95	95	96	94	80	89	86	91	84
9									93	96	95	95	79	88	85	91	85
10										93	94	93	82	92	91	92	82
11											96	93	78	87	85	92	83
12												94	80	89	86	91	83
13													79	89	85	91	88
14														89	75	74	73
15															85	84	79
16																90	78
17																	85

<u>Reference numbers</u> : Plateau A : Prof. 1 : B1 (1), B21 (2); Prof. 2 : B21 (3), B22 (4), B23 (5).
Plateau D : Prof. 3 : B1 (6), B21 (7).
Plateau B : Prof. 4 : B1 (8), B21 (9); Prof. 5 : B21 (10), B22 (11).
Plateau C : Prof. 6 : B1 (12), B21 (13); Prof. 7 : A2 (14), Bh (15);
Prof. 8 : Bh (16); Prof. 9 : B/A (17), B21 h.ir.m. (18).

Table 81 suggests a high and extremely hign similarity of the soil parent materials between 150 and 250 cm depth for the four plateaux included in this work.

Table 82. C.P.S.D. index based on 10 fractions between 63 and 2000μ of the horizons between 150 and 250 cm depth

	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	96	90	87	86	90	90	89	84	89	87	96	95	97	80
2		90	87	87	91	89	88	86	90	88	95	93	96	81
3			93	87	92	89	88	83	90	91	90	87	90	85
4				85	92	90	89	84	86	88	89	88	87	84
5					91	88	87	87	90	87	85	88	87	87
6						92	91	87	91	90	91	90	91	89
7							99	85	86	89	91	90	91	88
8								84	85	89	90	89	90	88
9									89	88	85	87	86	82
10										91	87	86	90	85
11											86	84	88	88
12												94	94	81
13													94	80
14														82

<u>Reference numbers</u>

Plateau A - Prof. 1 : B22 (1), Prof. 2 : B3 (2).
Plateau D - Prof. 3 : B22 (3), B23 (4).
Plateau B - Prof. 4 : B22 (5), B23 (6),
Prof. 5 : B23 (7), B31 (8), B32 (9).
Plateau C - Prof. 6 : B22 (10), B23 (11),
Prof. 7 : B21 h.ir.m.(12), B22 h.ir.m. (13)
Prof. 8 : B22 ir.m. (14)
Prof. 9 : B22x (15).

4.2.2.3. Conclusions

1. In the plateaux of Alagoas, the mineralogical composition of the soil parent materials is uniform throughout, composed mainly by quartz, ubiquists, kaolinite and low amounts of iron and aluminum oxides.

2. The almost complete absence of weatherable minerals confirms the ultimate stage of weathering of the soil parent materials.

3. Quartz and kaolinite, major mineral components of the discussed soils, are stable end-components of the weathering sequence, and therefore as a result of pedogenesis, changes in the mineralogical composition from the actual mineral assemblage are unlikely to occur.

4. Besides the identical mineralogical composition and with the sole exception of profile 2, all the pedons selected for this study may be considered as developed on highly uniform sediments. And also the different geomorphological units included in the studied region present throughout a very high sedimentological similarity.

Therefore, the observed differences in soil features, processes or rates within and between the studied soils are related to other factors than the materials of departure.

4.3. Particle size distribution

The particle size distributions of the dominant soils - Latosols and Red Yellow Podzolic soils - illustrated in fig. 15 shows that the clay content gradually increases from the topsoil to about one meter depth, remaining constant in the subsoil. They also show that the sand fraction follows a similar but opposite trend. The amounts of silt are very low and similar throughout, and present somewhat higher figures with depth.

Podzols are characterized by contrasting textures between the upper and the lower sola, as shown in fig. 15. The upper horizons are almost entirely composed of sand up to one meter depth. The subsoils are heavy textured, show uniform clay contents and significant higher amounts of silt are generally observed in horizons where organic matter and sesquioxides of Al accumulate.

In Red Yellow Podzolic-Podzol intergrades the depth distributions of clay and sand are similar to the ones observed in Latosols and Red Yellow Podzolic soils, whereas the silt distribution with depth resembles that of Podzols.

Clay increases from the topsoil to the subsoil are common in soils of intertropical regions and have often been interpreted as the result of clay migration, like in certain groups of temperate soils.

Anyhow, many times pedologists pointed out the influence of erosion itself or associated with other processes as the cause of textural gradients. Thus, De Leenheer, D'Hoore and Sys (1952) verified for the catena of Yangambi (Central Africa), the relationship between textural differentiations and run-off intensities. Also Sys (1960) explained the clay peak frequently found in Kaolisols of

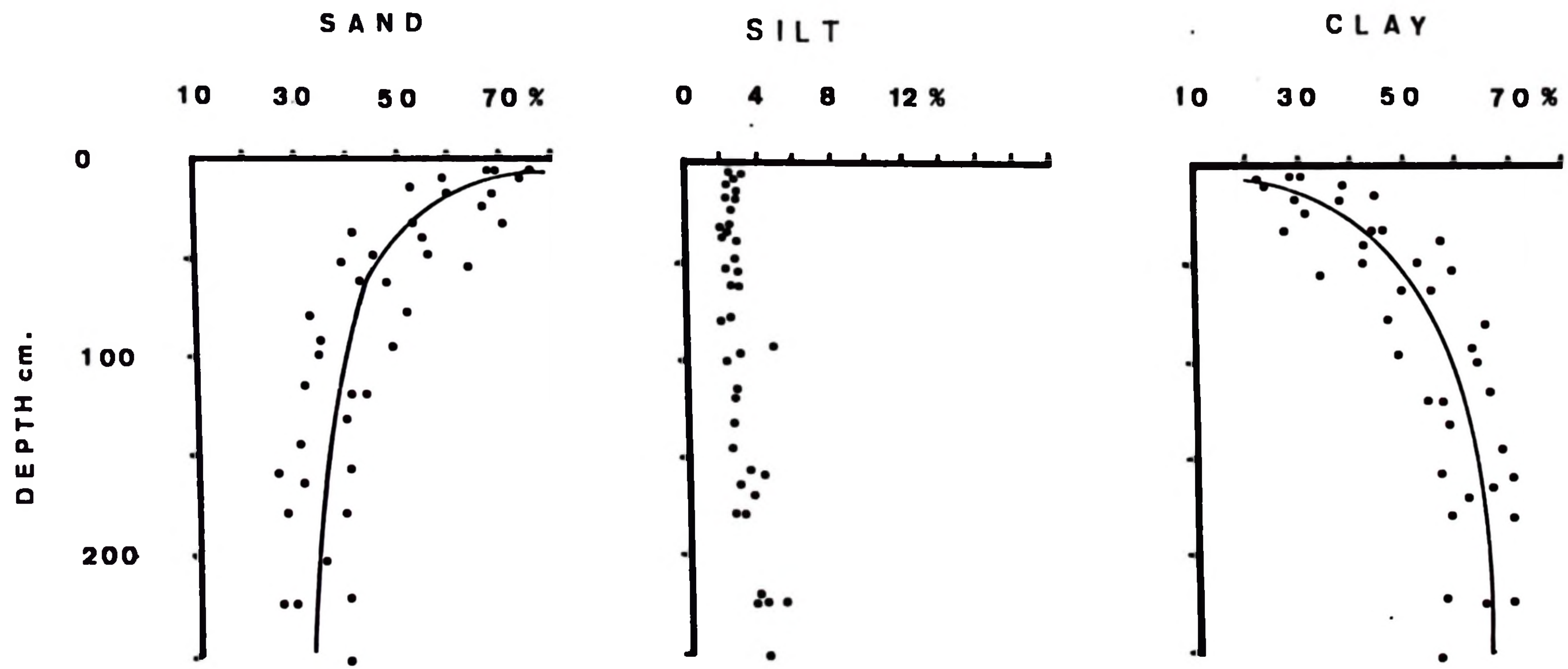


Figure 14. - Sand,silt and clay distributions with depth in Latosols and Red Yellow Podzolic soils.

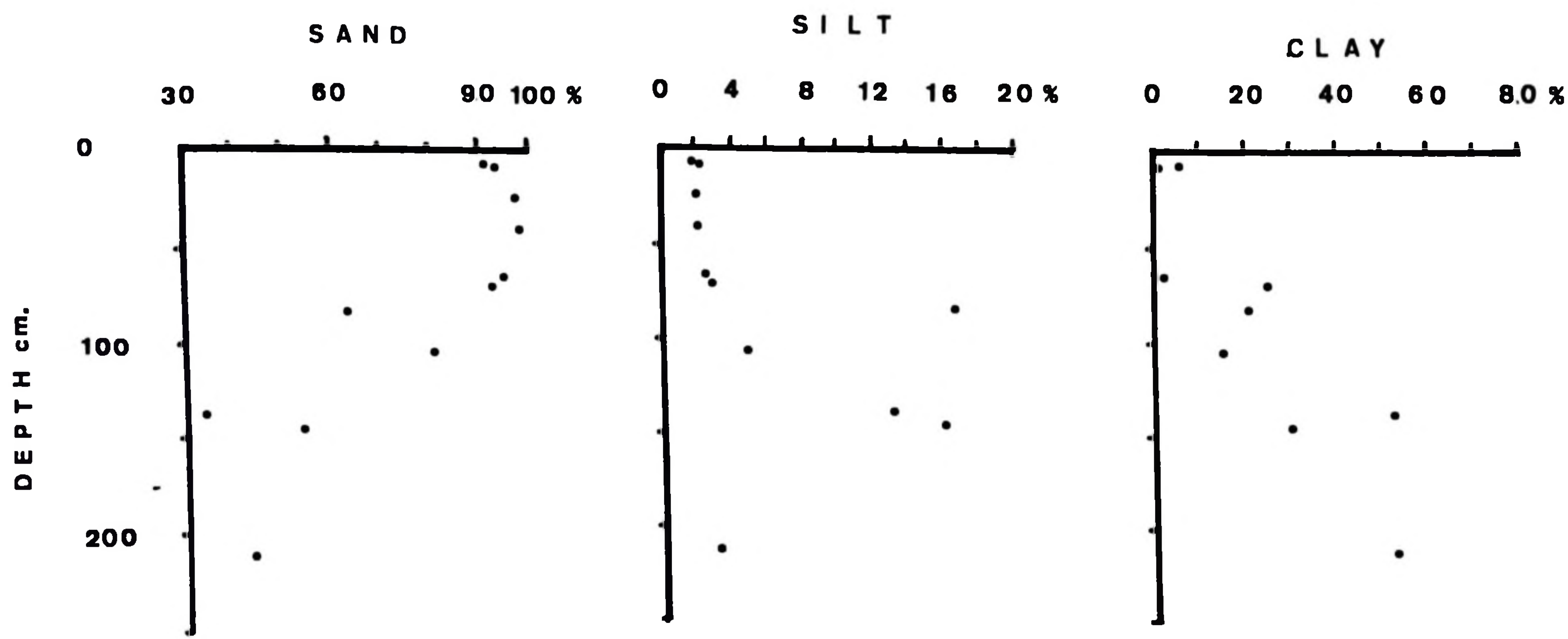


Figure 15.- Sand,silt and clay distributions with depth in Podzols.

Zaire by maximum weathering, and suggested surficial erosion as a factor contributing to the generally sandier texture of the A horizon. On the other hand, U.S.D.A. (1960), Folster (1964), Folster and Ladeinde (1967), indicated the influence of surface erosion associated with termite and earthworm activities contributing to the coarser texture of the A horizon in soils of Western Nigeria. Also primary differences of clay content in stratified parent materials were evoqued by Folster and Ladeinde (1967), as the causes of textural differentiations.

Most probably based in similar findings and in agreement with Soil Taxonomy (1975), Moormann (1979) concludes that the textural differentiation in L.A.C. (low activity clay) soils may result from one or more processes acting simultaneously or sequentially, affecting surface horizons, subsurface horizons or both.

Among the most important ones the author considers : sedimentation of coarse textured surface materials, clay destruction in the epipedon, clay eluviation and illuviation and lateral selective erosion.

In the studied soils some of these processes actively participate in the present pedogenesis and are in consequence related with the classification and the distribution of the soils in the landscape.

4.3.1. Sedimentation of coarse textured surface material

The evaluation of the uniformity of the soil forming materials carried out in 4.2.2. shows that the soil profiles included in this work - with the exception of profile 2 - are all developed in homogeneous parent materials. And also that the materials forming the different soil profiles are in turn highly similar throughout.

Therefore, it is possible to state that the clay increases within individual profiles and the different clay gradients observed between profiles, result from other factors than the material of departure.

4.3.2. Clay destruction in the epipedon

The relative loss of clay in the upper horizons of tropical soils may result from the weathering of layer-lattice silicates (Moormann, 1979). In the upper soil horizons, where weathering is more intense, slow clay destruction, elimination of bases and silica (ferralitization) is a particularly intense process in the high surface temperatures of well-drained soils. Because this process affects surface horizons more than subsurface horizons, a vertical textural differentiation usually results.

4.3.3. Clay eluviation and illuviation

Apart from the clay distribution itself in the L.A.C.clay soils under discussion, the presence of clay skins in the field is the main diagnostic criterion for the recognition of illuvial horizons; the textural B horizon after Lemos, Bennema, Santos et al. (1960), or the Argillic horizon according to Soil Taxonomy (1975) and FAO-UNESCO (1975) systems. In these soils clay skins were not observed during the field work (examined without magnifying glasses). Anyhow, the micromorphological study showed moderately high and very high illuviation indices (Midema and Slager, 1972) throughout the area; and in spite of the intense biological activity all soils - Latosols, Red Yellow Podzolic, Podzols, and their respective intergrades - present in the subsoil required illuvial rates for the Argillic horizon. In those materials the discrepancy between tne appreciation of illuvial clay in the field and the microscopic evidences of this process is discussed in 4.5.5.1.

In principle, the micromorphological study points out that the clay illuviation processes appreciated throughout the area, could at least to some extent contribute to the clay increases with depth generally observed.

But in most cases the main soils of the region - Latosols and Red Yellow Podzolic - not only show the presence of clay coatings in the subsoil, but also in the eluvial horizons, suggesting that the occurrence of illuvial features and the textural differentiations with depth are not controlled by the same factors.

4.3.4. Selective erosion

Precipitation on the land surface can follow three major pathways : overland flow, throughflow (interflow) and deep percolation (Seyhan, E., 1975). The amount of water following these various pathways is controlled by a complex set of interrelated factors among which duration of the rainfall, topographic characteristics, permeability of the soil, vegetative cover, and physical condition of the surface of the soil are the most relevant (Hall, 1983).

Aubert (1966) and Duchaufour (1965) stated that the permeability of each soil horizon is frequently higher than the permeability of underlaying layers. Therefore, a very slight slope may induce the lateral movement of the drainage waters that momentaneously saturate the upper part of these horizons. The importance of shallow throughflow to overland flow in forested watersheds in humid regions has also been pointed out by many hydrologists (Harr, 1977; Whipkey, 1969; Hewlett and Hibbert, 1967; cited by Moniz and Buol, 1982). Miller et al. (1971) found out that 50% of the January-June precipitation ended up as throughflow above a fragipan and that in a single month with low transpiration, 80% of the precipitation moved downslopes as subsurface run-off. Anyhow, Roose (1968) points out that although the lateral movement of flowing water is mostly observed when an impermeable horizon is below a thin and very permeable layer, the same phenomenon is likely to occur when the differences in permeability are not so contrastive. According to Miller (1971), deep percolation is a significant pattern only in depressed landscape positions, or in coarse and very permeable materials such as gravel, sand or coarse volcanic deposits. In agreement to this Roose (1970) found that in Ferralitic soils of Ivory Coast, only 500 to 600 mm out of an average annual precipitation of 1750 mm were vertically drained through the soil. Therefore, in function of the rainfall rates, duration and the hydraulic properties of the soil, a significant part of the precipitation is evacuated from the landscape as throughflow along the surface of less permeable subsurface horizons.

In 1970 Roose evaluated the impact of flowing waters on soil properties under tropical conditions. The author points out that under semi-deciduous forest, the impoverishment through selective erosion (throughflow) and vertical leaching without localized accumulation in fine particles from the upper horizons, prevails in the actual pedogenesis. Besides that, horizontal migration of rion and aluminum oxides associated with the solid eroded particles, leaching of nitrogen and bases, and the migration of Si and organic matter mostly in solution or linked with the removed clay and silt, were also observed. Similar conclusions were reached by Hugget (1976) who, through field studies, evaluated the effects of flow in temperate soils. This author concludes that : 1) silt and clay, as well as iron, aluminum, silicon and manganese, were translocated laterally and contributed significantly to soil development; 2) convergent throughflow in the cove positions resulted in a greater movement of soil plasma than in the nose positions were the throughflow was divergent; 3) throughflow of soil plasma and amorphous colloids decreased with depth in the soil and 4) the process of lateral translocation might be wave-like.

Within the studied area geomorphological and pedological evidences indicate that the clay surficial impoverishment of the soils is strongly dependent on selective erosion processes.

1) This way Wanderley Leite (1974) defines the selective erosion of silt and clay from the upper soil layers as the main morphogenetical process everywhere occurring in similar plateaux surfaces and no matter the vegetative cover present. Accordingly, during the rainy season, the rivers draining the plateaux transport a considerable mud load which is removed out of the area, and mainly deposited in the littoral depression.

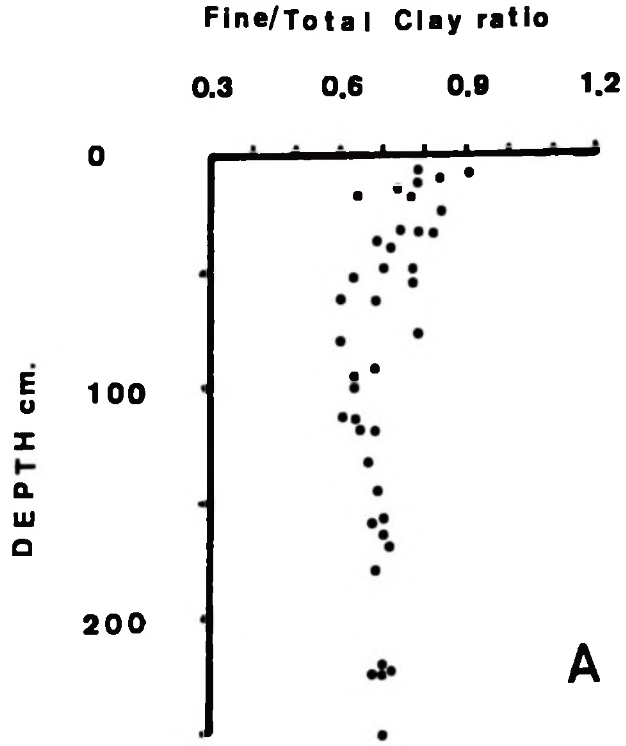
2) On the other hand, the type of clay distribution of the soils is everywhere that of a constant clay level below a clay impoverished surface horizon, but witnout any sign of an equivalent ~~an~~ accumulation peak in the subsoil as in the typical leached soils of temperate areas.

3) Moreover, Argillic horizons as defined in Soil Taxonomy (1975) contain more total clay and more fine clay than the eluvial horizons. In consequence, the illuviation of fine clay from the topsoil to the subsoil results in a relative increase of other fractions in the topsoil and a decrease in the B horizon, while the fine clay/total clay ratio is highest in the B. On the other hand, the removal of fine material from the topsoil by selective erosion causes no changes in the fine clay/total clay ratio of the subsoil but results in a relative increase of the coarse fractions in the topsoil.

Based on these assumptions and considering that the main soils of the area - Latosols and Red Yellow Podzolic soils as show in fig. 16 - present a rather constant fine clay/tot. clay ratio throughout with highest values in the topsoil, where the coarse fractions relatively increase, we may conclude that the fine material appears to be removed from the topsoil by selective erosion. But, within the studied area run-off intensities, which are mainly controlled by topographic characteristics, drainage and vegetative cover, are not uniform throughout and exert a remarkable impact in the textural gradients of the soils.

In the dominant well-drained segments of the landscape - where Latosols and Red Yellow Podzolic soils occur - no matter the vegetation type (forest or cerrado), the resulting textural gradients are gradual and rather similar throughout, as previously shown in fig. 14.

Anyhow, the profiles sampled under forest - Red Yellow Podzolic soils (profiles 3, 4, 5, 6) - present clay increases that satisfy the requirements of the argillic horizon and are thus classified as Ultisols (Soil Taxonomy, 1975) or Acrisols (FAO/UNESCO, 1974), whereas identical soils under cerrado (Latosols, prof. 1 and 2) not having the increase of clay required for the argillic horizon, are classified as Oxisols (Soil Taxonomy, 1975) or Ferralsols (FAO/UNESCO, 1974). But, it is also important to stress that in areas having the same type of vegetative cover - forest or cerrado -, Latosols (Oxisols) and Red Yellow Podzolic soils (Ultisols) currently occur in close proximity. Therefore, based on these evidences and considering that all the studied profiles are developed in uniform and highly similar parent materials (see 4.2.2.) and show the same mineralogical (see (4.2.1.), physico-chemical (see 4.4.) and micromorphological (see 4.5.) properties, we may conclude that the soils here classified as Latosols (Oxisols) and Red Yellow Podzolic soils (Ultisols)



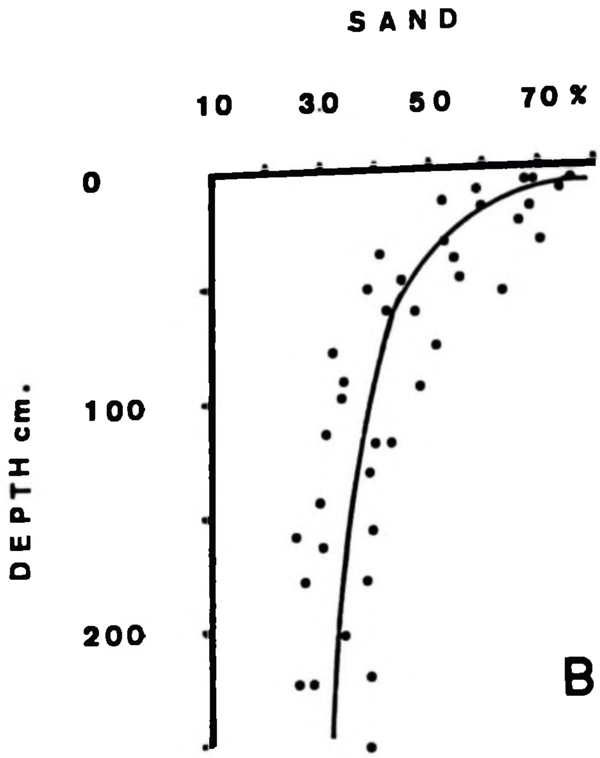


Figure 16 - A) Fine clay/total clay ratios, and B) Sand distributions with depth in Latosols and Red Yellow Podzolic soils.

are not more than differently eroded phases of the same soil type, either influenced by the vegetation or the topographical position.

In close depressed zones within the dominant well-drained sectors of the landscape, the convergent run-off waters - transporting fine elements - there accumulated are mainly removed through deep percolation. Therefore, the profiles in those positions present in the subsoil the highest amounts of fine material (silt plus clay) for the whole area (see prof. 9).

In contrast with the main well-drained sectors of the landscape, in collection areas for seepage waters under cerrado with free lateral drainage and restricted percolation, intense run-off totally removes the fine fractions silt and clay from the upper meter of the soil (x). The resulting coarse porous material leads to the formation of Podzols (Spodosols) in the upper eroded layers of a Latosol or a Red Yellow Podzolic soil. In consequence, the non-eroded clay-rich horizons below show under the microscope overlapped pedological features which correspond to pre-existing and actual pedogenetic processes (see micromorphology prof. 7 and 8). The simultaneous expression in the subsoil of typical diagnostic features for argillic and spodic horizons in profiles having a uniform soil parent material, confirms that Podzols are developed in the upper clay impoverished layers of Latosols or Red Yellow Podzolic soils, in agreement with Soil Taxonomy (1975) and Bennema (1979).

Finally, the presence of Podzols in landscape positions of maximal run-off and that of Latosols and/or Red Yellow

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(x) See location of prof. 7 and 8 in scheme C.

Podzolic soils in less eroded zones, clearly points out ~~a~~ the significance of run-off intensities in the regional distribution of the soils and shows the marked interdependence between geomorphological and pedological processes.

4.3.5. Conclusion

No matter that in the discussed soils the textural differentiation may be due to pedological or geomorphological processes acting simultaneously or sequentially, and in spite of the micromorphological evidences of clay illuviation present in all the selected profiles, along the studied region the soil textural gradients mainly result from processes of selective erosion and their rates are determined by factors which control run-off intensities.

Therefore, the lateral translocation of fine soil components must be considered in the plateaux of Alagoas as a significant contributor to soil development.

4.4. Chemical properties

4.4.1. Organic matter

The analytical results of the dominant well-drained soils - Latosols and Red Yellow Podzolic soils - show that the readily available plant nutrients are concentrated in the surficial ochric and umbric epipedons, where the bulk of the organic matter is normally present.

The organic matter contents are low, they range from 0.14 to 1.5%, and show an exponential decreasing trend with depth (fig. 17).

In the topsoil of the profiles under cerrado, organic matter contents are low (<1%), whereas in the soils under forest, medium contents (1-1.5%) are observed. In the subsoils the amounts of organic carbon are similar throughout. Table 83 shows the average O.C % in surficial, transitional and subsoil horizons.

The low levels of organic matter everywhere present can be attributed to the warm climate and to the favourable soil drainage conditions, which provide suitable temperatures for high decomposition rates by aerobic micro-organisms.

In depressed zones and independently of the vegetative cover type (forest or cerrado), the profiles have an irregular distribution of the organic matter with depth (see fig. 18) and the highest amounts for the whole area. Maximal organic accumulations occur in the subsoil horizons of imperfectly drained Podzols under cerrado, where the presence of a high watertable during rather long periods inhibits the organic matter decomposition by lack of oxygen. Moreover, those particular segments of the landscape not only receive the organic material supplied by the

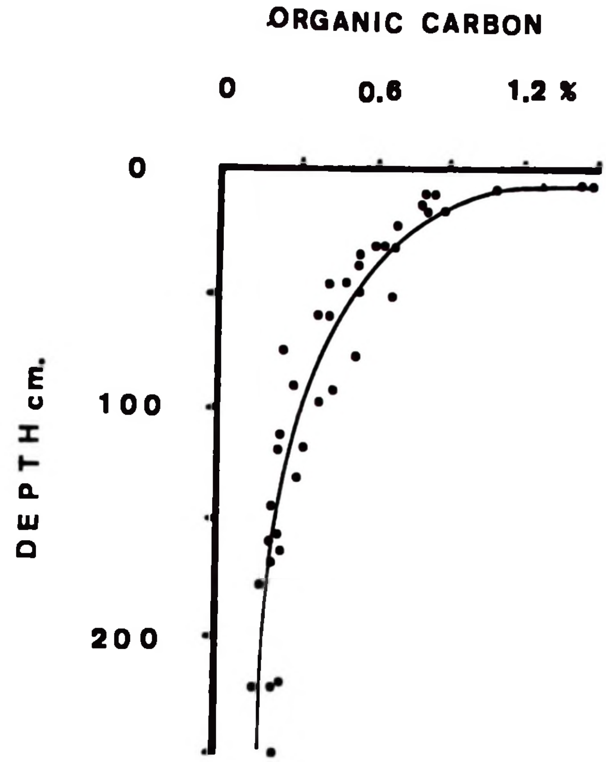


Figure 17 - Organic carbon distribution with depth in Latosols and Red Yellow Podzolic soils.

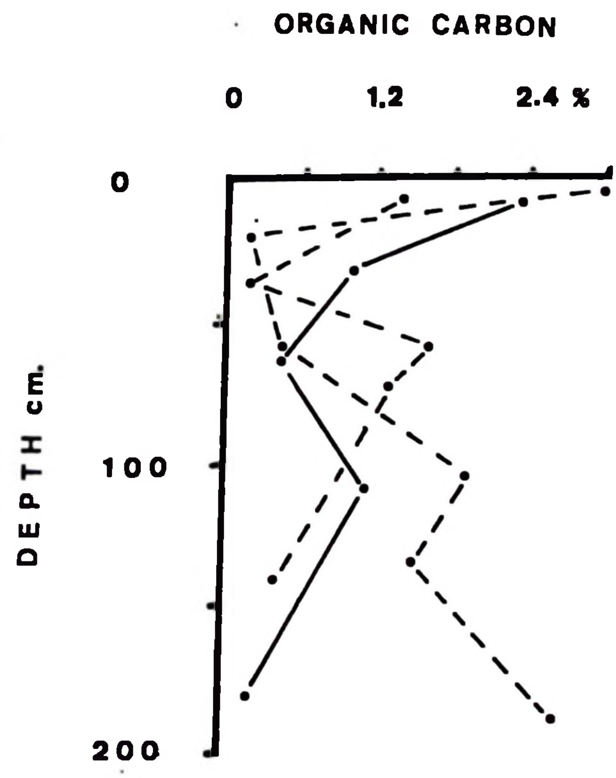


Figure 18 - Organic carbon distribution with depth in Podzols (cutted line) and Red Yelow Podzolic-Podzol intergrades (full line).

local vegetation, but also organic matter solubilized in the laterally flowing water as established by Roose (1968, 1970).

The rather high organic matter present in the surficial horizons of Podzols and Red Yellow Podzolic-Podzol intergrades included in this work, are due to the incorporation of sugar mill organic residues enriched in Ca and Mg (filter cake).

The average and extreme organic carbon values of surficial (Ap, A2) and subsoil horizons (Bh, Bh.ir.m., Bir.m.) are presented in table 84.

Table 83. Organic carbon contents in Latosols and Red Yellow Podzolic soils

Horizons	Average (%)	Extr. values
Ap, A1	0.95	(0.66-1.48)
A3, B1	0.49	(0.38-0.77)
B2, B3	0.26	(0.11-0.54)

Table 84. Organic carbon content in Podzols

Horizons	Average (%)	Extr. values
Ap, A2	1.04	(0.20-2.98)
Bh	1.75	(1.60-1.90)
B2h.ir.m. Bir.m.	1.50	(0.46-2.82)

4.4.2. Exchangeable bases

In Latosols and Red Yellow Podzolic soils the sum of exchangeable bases (S value) represents a rather small part of the exchange complex. In the topsoil (Ap and A1 horizons) the variation of V ranges between 20% and 69.7% with an average of 43.6%. In transitional horizons (A3 and B1), the variation is between 12.3% and 47.4%, with an average of 25.9%. In the subsoil (B2 and B3 horizons), it ranges from 11.6 to 61.2%, with an average of 28.3% (table 85).
The absolute amount of Ca, Mg and K is extremely low throughout and shows the highest percentage in the topsoil. The percentage if Ca is always higher than that of Mg and both cations are dominant among the bases.

The total amount of bases is rather similar within profiles, and the lowest S values are normally observed in the transitional A3 and B1 horizons (see table 85).

The distribution or exchangeable bases approximately parallels the base saturation trends with depth (table 85).

The decrease of bases with depth in the upper sola is largely due to biocycling of nutrients by the native vegetation. But biocycling, which constitutes - in the absence of weatherable minerals - the sole source of replenishment of bases, is not totally efficient and continued losses through leaching and erosion result in a progressive impoverishment of bases. On the other hand, in agreement with Miller (1983), who stated that decreases in base saturation frequently occur in saturated parts of the profile, the transitional A3 and B1 horizons, where a perched watertable periodically oscillates, always show the lowest S values (see table 85).

Table 85. Sum of bases and base saturations of Latosols and Red Yellow Podzolic soils

Horizons	Sum of bases (meq./100 g)		Base saturation (%)	
	Average	Extr. values	Average	Extr. values
Ap, A1	1.92	(0.86-2.89)	43.6	(20.0-69.7)
A3, B1	1.00	(0.57-2.04)	25.9	(12.3-47.4)
B2, B3	1.48	(0.62-2.54)	28.3	(11.6-61.2)

In depressions where Podzols and Red Yellow Podzolic-Podzol intergrades occur, more intense leaching results from the concentration of rainfall and laterally flowing waters. In these sites the soil profiles normally show a significantly lower base status than in Latosols and Red Yellow Podzolic soils (see table 86).

Abnormally high levels of the S value and base saturation in the upper horizons (Ap, A1, A2) of Podzols and Red Yellow Podzolic-Podzol intergrades result from the massive application of organic sugar mill subproducts (filter cake) rich in Ca and Mg.

Table 86. Sum of bases and base saturations of Podzols and Red Yellow Podzolic-Podzol intergrade

Horizons	Sum of bases (meq./100 g)		Base saturation (%)	
	Average	Extr. values	Average	Extr. values
Ap, A1, A2	1.16	(0.33-16.9)	54.8	(30.2-82.5)
Bh	0.36	(0.35-0.38)	4.8	(4.26-5.3)
B2	0.38	(0.32-0.93)	5.3	(3.1-9.1)

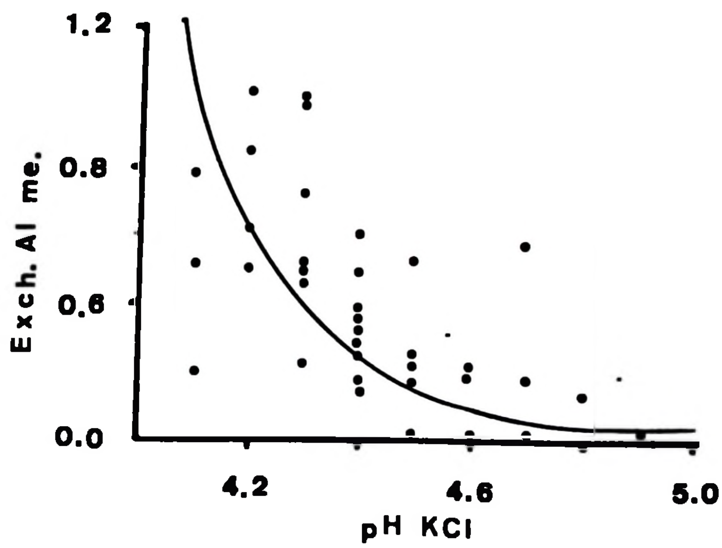
4.4.3. Exchangeable aluminum

The contents of exchangeable aluminum are low throughout the studied area. The absolute amounts of Al^{+} range from 0.0 to 2.4 meq./100 g of soil.

In all profiles the trends with depth followed by KCl exchangeable aluminum are strongly dependent on pH. The polymerization of $Al(OH)_3$ increases with pH, and exchangeable amounts decrease as a result although the total amount of Al in the soil does not necessarily change. Consequently, lower pH values correspond to higher amounts of monomeric Al^{+++}, which in turn generates acidity by hydrolysis when there are not enough hydroxyl anions to neutralize it.

The negative correlation between exchangeable aluminum and pH/KCl in the dominant soils of the area is graphically illustrated in fig. 19.

Fig. 19. Relation between pH/KCl and exchangeable aluminum in Latosols and Red Yellow Podzolic soils



It is generally agreed that high levels of exchangeable aluminum in the soil have a detrimental effect on crop production.

Table 87 shows that in Latosols and Red Yellow Podzolic soils the aluminum saturations of the effective C.E.C. (E.C.E.C.)are highest (average = 37.8%) in transitional horizons (A3 and/or B1), where pH values are normally lowest (see table 89). At the same time saturations higher than 50% are occasionally present in either of these two soil horizons.

Anyhow, the highest aluminum saturations for the whole area occur in the organic matter enriched Bh, Bh.ir.m. and Bir.m. subsoil horizons of Podzols. The average rates there observed range from 68.1% to 80.8% (see table 88) in agreement with the measured pH values.

4.4.4. pH

In agreement with the low base saturations generally observed, all the sampled profiles show "very strong" and "strong" acid reaction (terminology of the Soil Survey Manual, 1950).

The pH/H_2O values are rather uniform within profiles, not showing in Latosols and Red Yellow Podzolic soils any clearly defined trend with depth, as seen in fig. 20. Anyhow, table 89 shows that the variation of this value in the topsoil (Ap and A1 horizons) is from 4.4 to 5.6, with an average of 4.9; in transitional horizons (A3 and A1) it ranges from 4.3 to 5.3, with an average of 4.7, and in the subsoil (B2 and B3 horizons) the variation is between 4.6 to 5.5, with an average of 5.07. Therefore, the transitional A3 and B1 horizons generally show somewhat lower figures than the overlaying and underlaying layers; that

Table 87. Average and extreme values of KCl extractable Al, E.C.E.C. and Al saturations in Latosols and Red Yellow Podzolic soils

Horizons	Al(KCl)/100 g clay		E.C.E.C./100 g clay		Al saturation	
	Average	Extr.val.	Average	Extr. val.	Average	Extr. val.
Ap, A1	1.14	(0.56-2.20)	8.0	(3.57-17.0)	18.8	(4.44-49.5)
A3, B1	2.37	(0.61-1.85)	3.16	(2.04-5.42)	37.8	(12.0-59.6)
B2, B3	0.40	(0.0-0.81)	2.88	(1.70-4.06)	14.5	(0.00-44.1)

Table 88. Average and extreme values of KCl extractable Al, E.C.E.C. and Al saturations in Podzols

Horizons	Al(KCl)/100 g clay		E.C.E.C./100 g clay		Al saturation	
	Average	Extr. val.	Average	Extr. val.	Average	Extr. val.
Ap, A2	2.03	(0.0-7.82)	17.5	(0.4-39.7)	7.2	(0.0-30.1)
Bh	9.60	(6.2-16.8)	11.52	(6.2-16.8)	80.8	(7.54-86.2)
B2h.ir.m., B2.ir.m.	2.66	(0.0-4.47)	3.44	(1.96-5.06)	68.1	(46.3-94.15)

in agreement with the base and aluminum saturations which are respectively lowest and highest in these layers (see tables 85 and 87).

On the other hand, the pH/KCl values, which are always lower - less than one unit - than the pH/H_2O values, indicate that the overall charges of the soil colloids have a negative sign (Mekaru and Uehara, 1972).

Table 90 shows that in Podzols the pH values are highest in the topsoil (Ap, A1 and A2 horizons) where base saturations are highest and aluminum saturations lowest (see tables 86 and 88). A reversed situation is observed in the Bh horizons. The pH/KCl values are everywhere lower than the pH/H_2O values, and here also the soil colloid charge is negative.

Fig. 20. Distribution of pH/H_2O with depth in Latosols and Red Yellow Podzolic soils

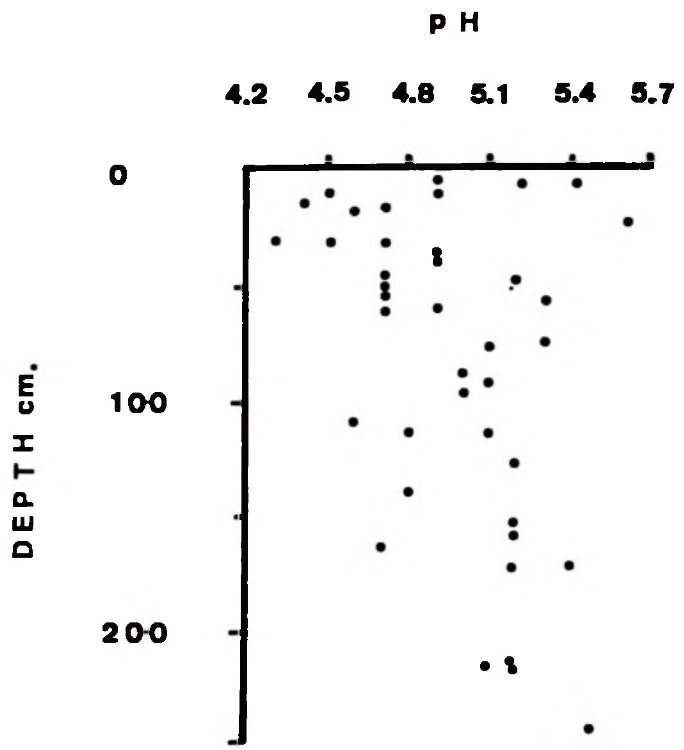


Table 89. Average pH/H_2O and pH/KCl values in Latosols and Red Yellow Podzolic soils

Horizons	pH/H_2O		pH/KCl	
	Average	Extr. val.	Average	Extr. val.
Ap, A1	4.90	(4.4-5.6)	4.78	(4.0-4.8)
A3, B1	4.70	(4.3-5.3)	4.30	(4.1-4.6)
B2, B3	5.07	(4.6-5.5)	4.47	(4.3-4.9)

Table 90. Average pH/H_2O and pH/KCl values in Podzols

Horizons	pH/H_2O		pH/KCl	
	Average	Extr. val.	Average	Extr. val.
Ap, A1, A2	5.42	(5.2-5.6)	5.00	(4.9-5.2)
Bh	4.85	(4.5-5.2)	4.15	(3.9-4.4)
B2h.ir.m., Bx	4.97	(4.6-5.3)	4.42	(4.0-4.9)

4.4.5. Cation exchange capacity

The apparent C.E.C. by ammonium acetate in the B horizons is normally less than 16 meq./100 g clay throughout the studied area. The apparent C.E.C. values denote the dominance of kaolinite in the clay fraction, and the soils have therefore reached the so-called oxic stage of pedogenesis (Tavernier and Eswaran, 1973). The occasional higher C.E.C. values observed in some topsoils and in the subsoils of profiles, located in depressions - Podzols and Red Yellow Podzolic-Podzol intergrades -, are exclusively due to significant accumulations of organic matter.

Using the data of all horizons of the nine soil profiles selected for this work, the apparent C.E.C. by ammonium acetate at pH 7.0 was compared with the organic matter content. Fig. 21 shows a very clear trend, as calculated from

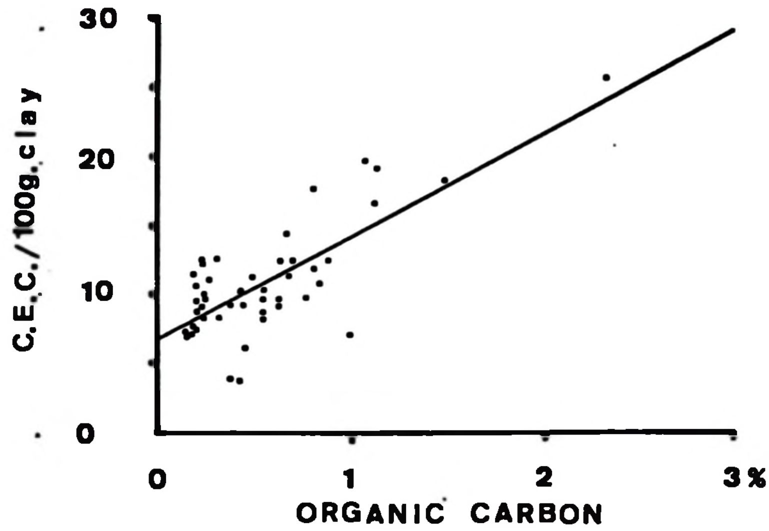


Figure 21 - Relationship between percentage of organic carbon and C.E.C.(NH4OAc)/100g. clay in Latosols and Red Yellow Podzolic soils.

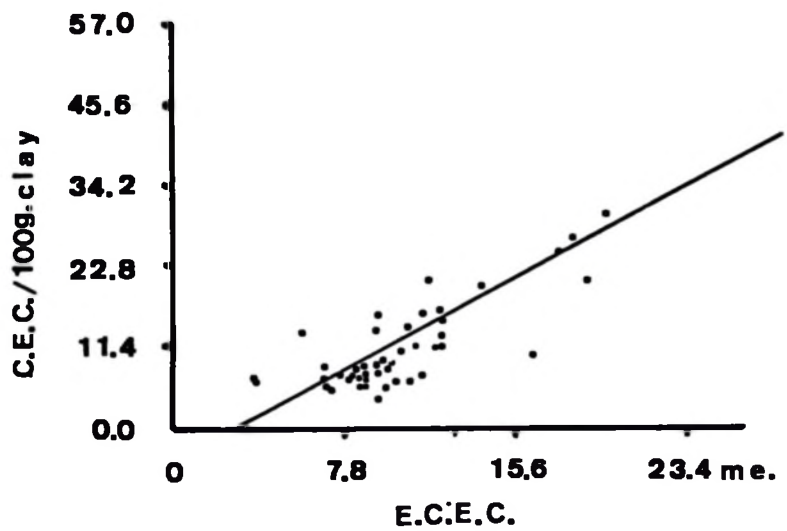


Figure 22 - Relationship between C.E.C.(NH4OAc)/100g. clay and E.C.E.C. expressed on clay basis.

the following equation : apparent C.E.C. (NH_4OAc) = 7.363 e 0.554. 0.6 %.
The C.E.C. of the clay fraction always shows a positive high correlation (coef. corr. = 0.76) with the organic matter content.

Moormann and Buol (1981) proposed the use of apparent C.E.C. per 100 g clay (<16 meq.), or E.C.E.C. (<12 meq.) expressed on clay basis, as alternative criteria for the recognition of the Kandic horizon. The studied Latosols and Red Yellow Podzolic soils showed a high (coef. corr.= 0.99) linear relationship between C.E.C. by NH_4OAc and E.C.E.C., which is given by the following equation : C.E.C. (NH_4OAc) = E.C.E.C. (0.845 + 0.295 E.C.E.C.), and illustrated in fig. 22.

4.4.6. Free iron and aluminum oxides

Due to the nature of the soil parent material, the amount of free Fe and Al oxides, as extracted by dithionite-citrate-bicarbonate, is very low throughout the region.

In the B2 horizons of the dominant well-drained Latosols and Red Yellow Podzolic soils, the free Fe oxides range from 1.05% to 2.21%, with an average value of 1.56%; and the free Al oxides vary between 0.38% and 0.93%, with an average of 0.67%.

The low content of sesquioxides which makes the structure of these soils rather unstable, is related with important management properties, as pointed out by Bennema (1979). In these soils, dense layers are easily formed in the upper sola (from 20 to 80 cm) as discussed by Oliveira et al. (1968) and Janssen and Van Der Wert (1976). Density is easily increased by the use of agricultural machinery or when clearing the forests. On the other hand, under agricultural use the topsoils can easily loose clay and organic matter by differential erosion and by vertical migration, as stated by Bennema (1979).

In these soils the free oxides (Fe and Al) distributions are very similar and follow a smooth increasing trend with depth, which parallels the distribution of the clay. The relationship between the distributions of free Fe oxides and clay, and between Al oxides and clay are respectively illustrated in fig. 23 and 24.

In consequence, the free Fe/clay ratios and the free Al/clay ratios are constant within individual profiles, indicating that the comigration of clay and free oxides is a generalized process in the upper sola. This in agreement with Roose (1968 and 1970), who stated that in the upper horizons of Ferralitic soils of Ivory Coast, iron and aluminum oxides migrate in association with solid fine particles (from 0 to 20μ), mainly by a selective subsurface erosion - throughflow -.

At the same time in depressed zones of the landscape, where surface and subsurface run-off waters are collected, the watertable normally remains on top of the soil for rather long periods during the rainy season. Consequently, iron is there solubilized and removed from the soil in significant amounts. Anyhow, in some places part of the soluble Fe^{++} is oxidized and precipitates to form mottles. Under tne microscope, these iron-rich zones are observed along pores, indicating either a more oxidizing environment or one in which oxidation prevails for longer periods than in the associated iron depleted soil mass.

In open depressions along the edges of the plateaus, when the drainage is imperfect (see prof. 7 and 8 in scheme C), and in contrast with the associated well-drained profiles of the same landscape, free iron oxides are totally absent in the upper (ochric or albic) horizons, and range from

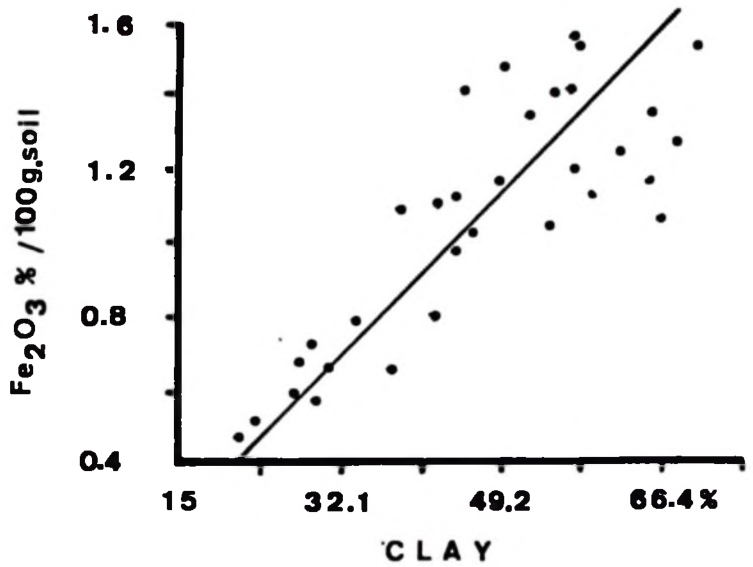


Figure 23 - Relationship between clay and free iron distributions in Latosols and Red Yellow Podzolic soils.

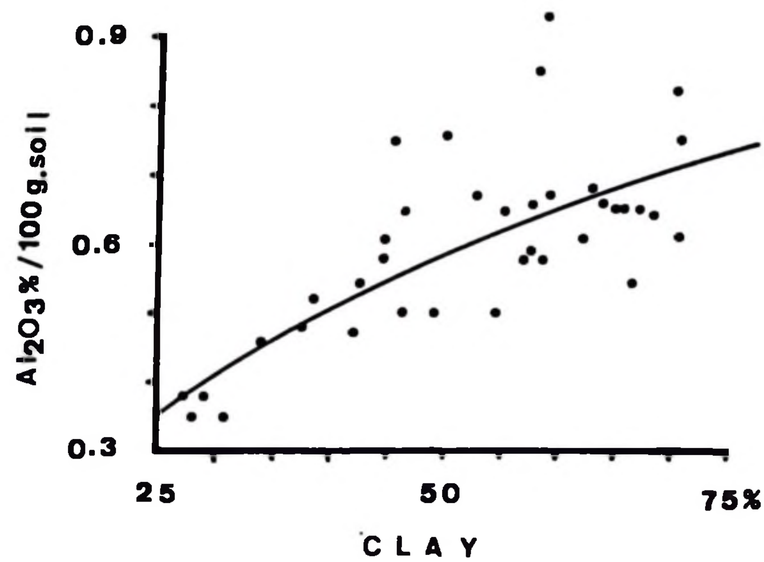


Figure 24 - Relationship between clay and free aluminium distributions in Latosols and Red Yellow Podzolic soils.

0.0% to 0.96%, with an average of 0.17% in the subsoil. In those areas the solubilized Fe^{++} may be vertically leached and also laterally removed by throughflowing and overflowing water.

In close depressed zones - in the central part of the plateaux - with moderate drainage conditions (see location of profile 9 in scheme C), free iron oxides, even in extremely low amounts, are present throughout the soil. The contents are highest in the subsoil ranging from 0.13% to 0.40%, with an average of 0.26%. The somewhat higher contents of free iron oxides, observed in this type of depression, are probably related to the amounts of collected water, and to the fact that the losses of soluble Fe^{++} are only restricted to vertical leaching.

Finally, in these surfaces the macro- and microrelief are both related to the soil drainage. The influence of the watertable and the related oxido-reduction regimes in turn determine the amounts of free iron oxides in each soil (Daniels et al., 1975). This way, the profiles located in depressions - Podzols and Red Yellow Podzolic-Podzol intergrades - have significantly lower levels of free iron oxides than the well-drained soils - Latosols and Red Yellow Podzolic soils -.

In contrast to Fe, the free Al oxides, which are not reducible to a more soluble oxidation state, always accumulate in the subsoil horizons of profiles located in depressions - Podzols and Red Yellow Podzolic-Podzol intergrades -, and there form organic matter-sesquioxide complexes which give raise to characteristic indurated subsoils (see prof. 7, 8 and 9).

4.4.7. Conclusions

1. The low organic matter contents shown by the main soils of the region - Latosols and Red Yellow Podzolic soils - are due to high decomposition rates resulting from high temperatures and favourable drainage conditions. The non-mineralized organic material is anyhow partly removed through vertical leaching and probably also by laterally flowing waters.

Accumulations of organic matter are normally observed in depressed sectors of the landscape, where its decomposition is periodically inhibited by high watertable levels.

2. The amount of bases and the base saturation rates are generally low, with highest figures in the upper soil horizons of the dominant soils of the area - Latosols and Red Yellow Podzolic soils -.

In depressed zones more intense leaching results from the concentration of rainfall and laterally flowing water, and thus in those sites both parameters present significantly lower values.

3. The absolute amounts of exchangeable aluminum in the main well-drained soils of the area - Latosols and Red Yellow Podzolic soils - are rather low and negatively correlated with pH values. Aluminum saturations are also rather low and follow similar trends.

Significantly higher contents and saturations of exchangeable aluminum are observed in the subsoil horizons of profiles located in depressions, where pH values are lowest for the whole discussed area.

4. In agreement with the mineralogy of the materials of departure, the diagnostic horizons of the major soils - Latosols and Red Yellow Podzolic soils - always show apparent C.E.C. values which correspond to that of oxic materials.

Higher C.E.C. values are only observed in epipedons and in subsurface horizons of profiles located in depressions where significant organic matter accumulations occur.

5. Iron and aluminum oxides migrate from the upper soil layers of Latosols and Red Yellow Podzolic soils in association with the removed fine material - silt and clay - through selective erosion.

In depressed zones under the influence of periodically high watertables, the iron is solubilized and significantly removed with the flowing water, whereas the insoluble aluminum accumulates in the subsoils.

When depressions present free lateral drainage, iron and aluminum oxides are totally removed from the upper soil layers.

6. From chemical point of view, the main soils of the studied region - Latosols, Red Yellow Podzolic soils and their respective intergrades - constitute a highly homogeneous group of soils.

4.5. Micromorphology

4.5.1. Coarse material (>5µm)

Quartz is the predominant mineral of the coarse material. It is mainly composed by subangular and subrounded grains, giving evidence of transport. Other primary or weatherable minerals were not observed. Mostly in the medium and coarse sand fractions, a lot of fissured and corroded grains are present in all horizons, suggesting that the sediment was already highly weathered before deposition (photo 2). Iron oxides and/or fine material often fills the fissures present in quartz grains. That particular feature called Runiquartz, according to Eswaran (1975) results from plasma infusion processes. Runiquartz have among others been observed by Stoops (1968) in Ferralsols of Zaïre, by Beaudou (1972) in Ferralitic soils of Senegal, by Benayas, J. and Refega, A. (1974) in Oxisols of Angola, and according to Buol et al. (1978) and Stoops (1979) it is a feature currently present in highly weathered tropical soils.

4.5.2. Fine material (<5µm)

The fine material is the major soil component in most of the studied soils. It is composed of kaolinitic clay stained with organic matter and iron oxihydrates, mostly showing yellowish colors, or brown and dark brown colors in horizons where organic matter accumulates.

Undifferentiated b-fabrics (magnification 100 X) are dominant in all the studied profiles. In the top layers, where organic matter concentrates, it is the only type observed. In the subsoils dotted, circular striated, also called ooidisepic (Verheye and Stoops, 1975), parallel striated and poro striated b-fabrics are present as subordinated types, which are generally weakly expressed and mostly observed under maximum light intensities. Therefore, the fine material is only oriented to some extent in the subsurface soil horizons. The lack of orientation in the upper horizons is most probably due to the masking effect of humified organic matter. The orientation of the fine material depends on the mineralogical properties, and its morphological expression results from pressures taking place in the soil mass. Kaolinite and sesquioxides - major components of the fine material of these soils - have low COLE values. On the other hand, free iron coatings mask optical properties. Consequently, undifferentiated b-fabrics are mostly observed.

The tendency to form microaggregates constitutes a particular property of the fine material. These microaggregates are more or less rounded, ranging from silt to medium sand size, are better developed in the subsoil horizons and show different degrees of separation. They are frequently not detached from the fine mass and the external boundary is defined by an halo of more limpid clay. In cases of stronger separation, very fine streaks of oriented clay (which often may give raise to circular striated b-fabrics) are observed sometimes together with the presence of curved fissures that partially isolate the microaggregates from the groundmass (see photo 1).

4.5.3. Microstructure and pore pattern

With the exception of the eluvial horizons of the Spodosols, the microstructure and pore pattern of the area's dominant soils are very similar, and show the following general characteristics.

4.5.3.1. Microstructure

In the uppermost centimeters, fine crumbs and pellets - both uncomplete and mostly complete -, which result from high biological activity, are normally present.

The transitional A3 and B1 horizons are also extremely reworked and in most cases show a spongy microstructure.

Crumbs are dominant in the subsoil (B2 and B3 horizons). They normally appear partially separated from the groundmass by channel infillings (see 4.5.5.4.) or by zones of highly reworked material, that respectively display pellety and spongy microstructures. It is important to stress that the soil volume occupied by channel infillings and reworked material is very high in all horizons. Thus, biotic factors exert a very important influence in the general soil microstructure.

In thin sections, uncomplete microstructures are most commonly observed. They are characterized by intergrades between apedal and pedal types (spongy to crumbly and spongy to pellety). Accordingly, the structures observed in the field are normally weak or moderate, and ped surfaces are not well defined. Only in the uppermost centimeters, under the influence of a denser root system and due to the cementing effect of the organic matter, peds are better defined.

4.5.3.2. Pore pattern

Very fine (less than 10µm) smooth fissures, formed by shrinkage of the fine mass, are very frequently observed throughout the profiles (except in the upper horizons of the Spodosols). In the upper horizons usually appear interconnecting large pores (vughs), whereas in the subsoil, curved types associated with partially separated microaggregates are largely dominant.

Vughs are very frequent, and mostly appear interconnected in the upper and transitional (A3 and B1) horizons.

Compound packing pores, mainly resulting from a random arrangement of fine material aggregates and quartz grains, are dominant in channel infillings, reworked zones and in the upper horizons. They normally constitute the largest observed pores and appear to be formed under the influence of intense biological activity. The total porosity of the different soil horizons largely depends on the frequency of this pore type.

Channels which are generally built up through the effect of the root system are also more frequent in the top horizons.

4.5.4. Coarse/fine related distribution (c/f)

The coarse/fine related distribution indicates the distribution of individual fabric units in relation to smaller fabric units and associated pores, not included in the fabric units (Stoops, 1978).

In all profiles the subsoils are rich in clay, thus the R.D.P. is always porphyric, from open spaced to close spaced (photo 2). In the upper layers, where the coarse material becomes more abundant, gefuric-enaulic intergrades are mostly observed; except in the sandy epipedons of the Spodosols (profiles 7 and 8), where a monic c/f related distribution was inferred.

4.5.5. Special features

4.5.5.1. Clay illuviation features

The microscopical identification of clay illuviation features was a matter of particular interest in this study. In the first place it represents the most important evidence on clay illuviation processes. On the other hand, thin sections became a fundamental tool to establish the presence of argillic horizons due to the particular difficulties encountered to recognize clay skins in the field, in this type of soils. Thus, having a relevant importance for soil classification purposes (Soil Taxonomy, 1975).

All the studied soils showed the presence of illuvial clay coatings in at least some part of the profile, and the illuviation intensities range from moderate to strong (Midema and Slager, 1972).

The different type of clay illuviation features recognized in thin sections include : limpid uniform clay coatings, laminated coatings composed of limpid and speckled clay, red yellowish clay coatings and fragments of the enumerated features.

The mineralogical composition of the clay that moves by illuviation and the clay of the soil matrix is supposed to be basically the same. Anyhow, the observed coatings are generally more limpid and/or paler in color, and sometimes more brownish than the clay in the groundmass. The remarkable limpidity observed in many illuvial features can be attributed to the finer size of the moved clay, this in agreement with Soil Taxonomy (1975). But sometimesn however, the material of the clay coatings is comparable to that of the groundmass, suggesting that not only the finest clay is accumulated in illuvial features (Eswaran, 1978) (see photo 1).

The paler colors frequently observed in the illuvial material with respect to the fine mass are generally attributed to their lower iron contents. The deferrification of the fine material could take place in the eluvial horizons as a necessary prerequisite for the clay to move according to Lespch et al. (1978). For others, it could be supposed that after coating formation, the water moving through the voids could remove some iron (Eswaran, 1979). The brown and dark brown colors, mostly found in laminated clay coatings, correspond to the presence of coarse textured layers, while the reddish colors, less frequently shown by some coatings, indicate the occurrence of iron-rich clay (Stoops, 1968, 1978).

The material forming the coatings normally appears well-oriented, with strong birefringence and sharp boundaries. All these features confirm an illuvial origin (Brewer, 1964; Stoops, 1968).

The illuvial features are principally located in coarse macropores (50-100μm) and megapores (very fine and fine, 0.1-0.2 mm) that currently correspond to vughs and channels. In the subsoils, where illuviation is highest, coatings are restricted to zones not showing biological disturbance. They mostly occur as total or partial infillings, indicating that probably illuviation processes are not currently operative (Stoops, 1968) (photos 1 and 2). In zones where biological activity is observed (reworked areas and channel infillings), illuvial features are absent, suggesting their destruction by soil fauna. In fissures, coatings are generally very rare and difficult to recognize.

All the profiles showed the presence of fragments of clay coatings. They always occur in horizons where also clay coatings are present and were observed within the fine material and inside channel infillings. Most of the fragments of clay coatings appear to be disrupted in situ features formed by the breakdown of simple coatings mixed by soil fauna.

Not only the identification of illuvial features in thin sections was a matter of interest for classification, but also its quantification is required by Soil Taxonomy (1975).

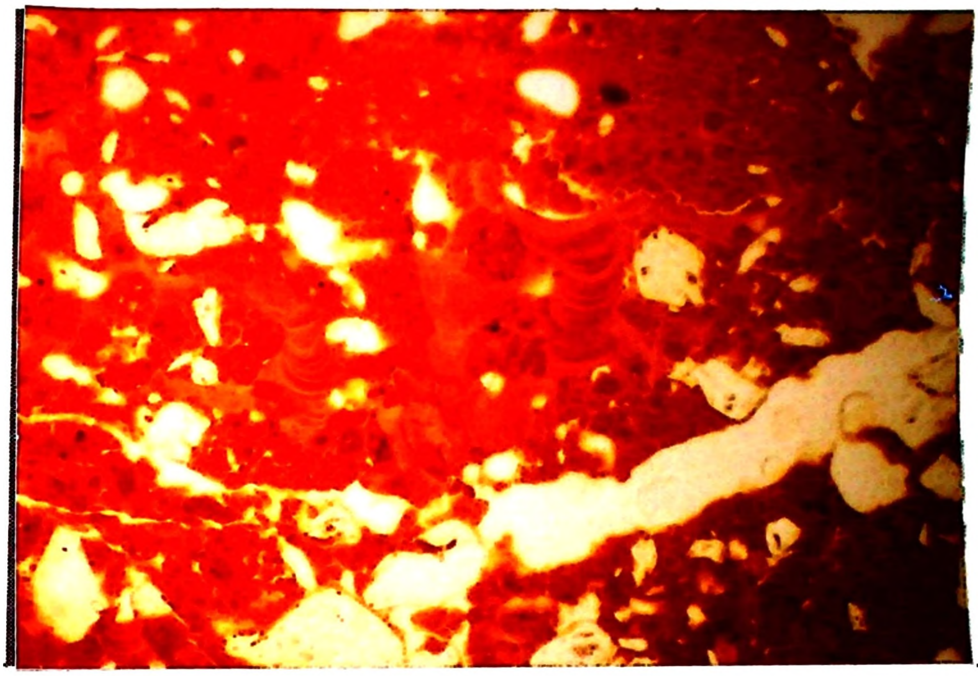


Photo 1 - Micromorphological features of a well-drai-
ned soil. Profile 4, 100-200 cm., plain
light, 25X.

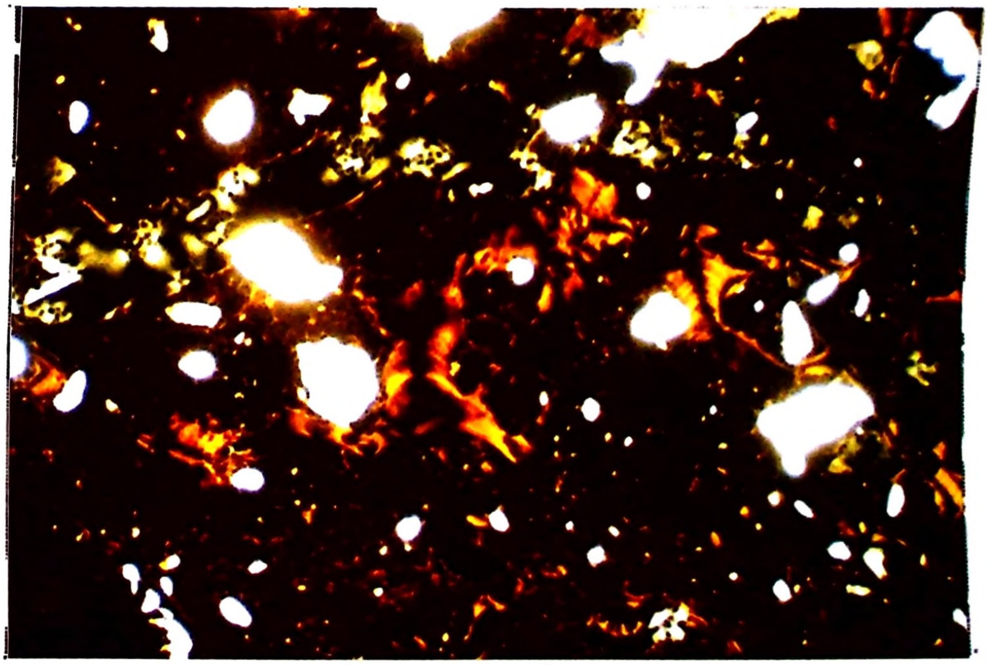


Photo 2 - Idem photo 1. Under crossed polarizers.

The results of point counting in thin sections indicate that all the studied soils have more than 1% of clay coatings in some horizon or subhorizon. Thus, fulfilling the requirements of the argillic horizon.

4.5.5.2. Monomorphic organic coatings and infillings

The accumulation of organic material in subsurface soil horizons takes place in profiles that occupy depressed zones (Palehumults and Spodosols). In thin sections these accumulations are mainly observed inside fissures and channels, and on the surface of quartz grains. The fissures are normally filled by the illuvial organic material and the grains appear partially covered by very thin organic coatings. In channels, coatings are thicker and where observed to occur on pore walls, and on top of pre-existing clay coatings as shown on photos 3 and 4. Therefore, thin sections suggest that the illuviation of the organic matter has taken place after the accumulation of illuvial clay. Furthermore, considering that in the eluvial horizons of the Spodosols organic matter is the only fine material present, it is possible to conclude that the illuviation of organic matter is the only current process.

4.5.5.3. Sesquioxidic nodules

Some large (6.0 to 13.0 mm Ø) rounded sesquioxidic nodules having sharp boundaries were observed in subsurface horizons (B22 of prof. 1 and 4). Moreover, their c/f related distribution presents a much denser packing of the coarse material when compared with the surrounding groundmass. Thus, the external shape, the type of boundary, and the contrasting related distribution suggest the transport of an inherited soil material.

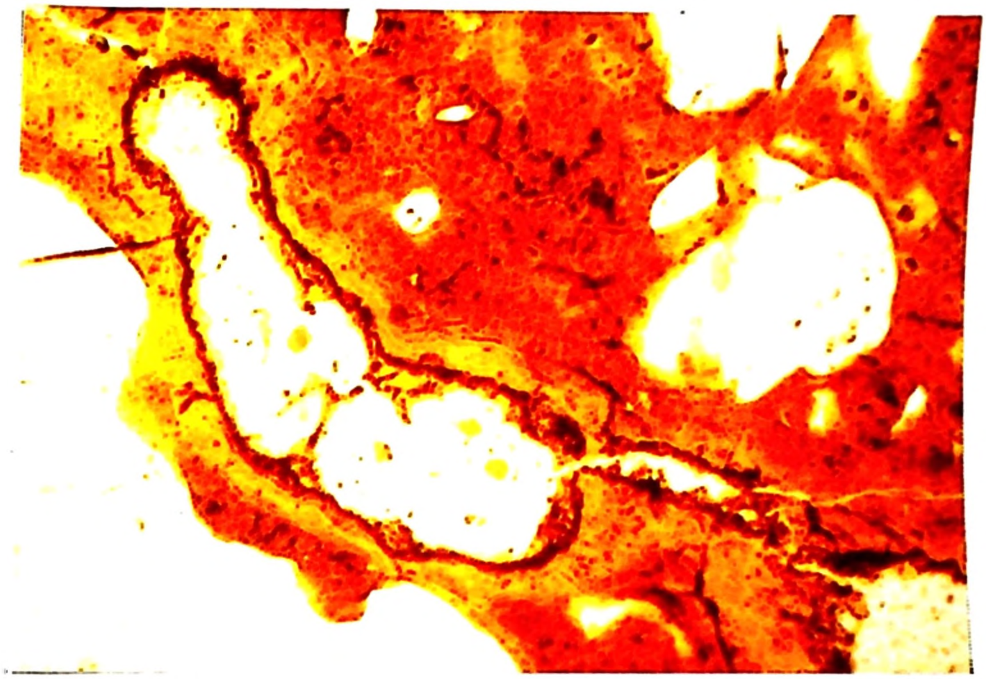


Photo 3 - Micromorphological features of a poorly drained soil located in a depression. Profile 7, 110/130-175 cm., Plain light, 65X.

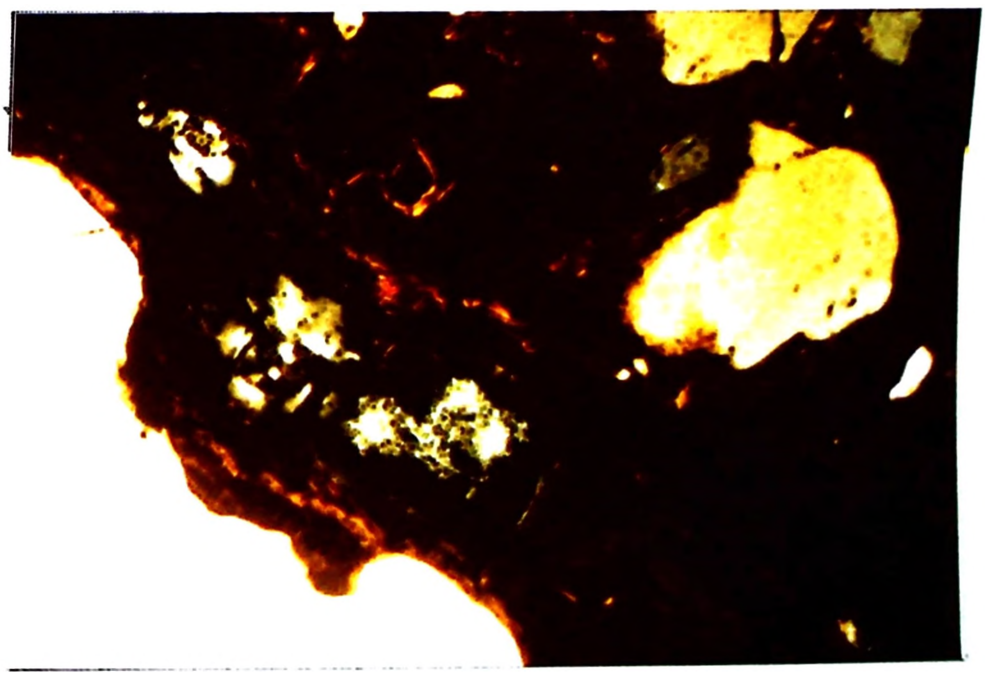


Photo 4 - Idem photo 3. Under crossed polarizers.

Other sesquioxidic nodules of variable size (from silt size to few mm Ø), having variable shape and diffuse boundaries, are most probably formed in situ. They are not necessarily associated with poor drainage.

4.5.5.4. Channel infillings

The channel infillings constitute the most striking microscopical evidence of the strong biological activity taking place in the studied soils. They occupy a very important volume in all profiles and influence the microstructure and associated pore pattern, especially in the upper layers. They normally include small aggregates of undifferentiated fine material and quartz grains. Fragments of clay coatings are also very frequently included. The recognition under the microscope is easier in the subsurface horizons, where biological activity is less intense, and a clear contrast exists between the infilling material and the non-disturbed soil mass. In the upper layers (about 50 cm depth), where termite activity is highest, the whole groundmass looks totally reworked and consequently, the identification of channel infillings is very often hard to establish.

4.5.5.5. Reddish isotropic coatings and infillings

The presence of well-developed reddish coatings and infillings was observed in the subsurface horizons of poorly drained soils, submitted to the influence of a fluctuating water table. Under these conditions, the redistribution of iron is a current phenomenon. Thin sections generally show a decolorated (iron empoverished) fine material and red isotropic coatings and/or infillings, which in most of the cases fill up fissures, vughs and channels.

4.5.6. Conclusions

1. All the soils appear to be formed from mineralogically similar and highly weathered soil parent material, as indicated by the nature and properties of the groundmass.
2. Transport of the soil forming material is suggested by the shape of the quartz grains.
3. The polycyclic character of these soils is indicated by the presence of Runiquartz and inherited sesquioxidic nodules.
4. The occurrence of translocated clay in all the profiles confirms that a moderate to strong clay illuviation has taken place in the whole region. On the other hand, clay coatings were exclusively observed inside pores. This particular location of the illuvial features explains the apparent contradiction between the high estimates of illuviation under the microscope and the scarcity v.z. the absence of clay skins on ped's surfaces observed in the field.
5. A very intense termite activity is indicated by the presence of reworked areas, channel infillings and disrupted illuvial features, which were observed throughout. Moreover, termite activity plays a major role in the definition of the microstructure.
6. The generalized presence of diffuse iron nodules in the well-drained soils suggests incipient epiaquic conditions, not enough developed to place these soils in such subgroups.
7. The poorly drained soils, submitted to the influence of a fluctuating watertable, show redistribution of iron compounds (prof. 7 and 8).
8. Independently of the type of vegetation cover, the soils, located in depressions, present a subsurface accumulation of organic matter.
9. The dominant soil of the studied region - Latosols and Red Yellow Podzolic soils - are identical from micromorphological viewpoint.

CHAPTER 5 - MAJOR CONCLUSIONS

1. In the plateaux of Alagoas the soil parent materials are highly weathered transported sediments which show a similar mineralogical composition throughout the region.

2. The sediments are composed of a relatively " inert " mineralogy, dominated by quartz and kaolinite, which in the present environment will not be transformed into other minerals, thus strongly controlling subsequent soil development.

3. Consequently, - appart " ferralitization " - chemical and mineralogical transformations of soil materials are not major processes in the genesis of the soils.

4. Besides their identical mineralogical composition - and with the only exception of profile 2 -, all the pedons selected for this study are developed on sedimentologically highly uniform materials. On the other hand, the different geomorphic units included in the studied region also present a very high sedimentological similarity throughout.
Thus, the differences observed in soil features, processes or rates within and between the studied soils depend on other factors than the materials of departure.

5. The general aspect of these surfaces suggest a long history of weathering and erosion related to the age of the landscape and to the climatic oscillations during the Pleistocene. Moreover, under the present conditions and no matter the vegetative cover type " selective erosion " caused by run-off, constitutes everywhere the dominant morphogenetic process, which leads to the impoverishment in fine fractions from the topsoil.

6. The presence of translocated clay in all the profiles and the occurrence of moderate to very high illuviation indices point out that clay illuviation has been a generalized and significant process in the whole area. Within those materials however, clay illuviation is normally not manifested by producing skins of oriented clay on ped surfaces. Ped surfaces are not well defined, soil structure is weak and the presence of clay coatings which is restricted to the pore walls, explain the disagreement between high illuviation estimates under the microscope and the scarcity v.z. the absence of clay skins in the field.

7. Although processes like clay illuviation and clay destruction in the epipedon may have contributed to the losses of fine material in the upper horizons, the observed textural gradients mainly result from lateral selective erosion whose rates are controlled by run-off intensities.
Thus, textural gradients are smooth in the dominant well drained sectors of the landscape and abrupt in the poorly drained depressions with free lateral drainage, where run-off is highest.

In close depressions within the well drained sectors of the landscape, where convergent run-off waters are mainly drained through deep percolation, textural gradients are smooth and maximal fine material (silt+clay) contents for the whole area occur.

8. Furthermore, a) in the dominant well drained segments of the landscape the leaching of organic matter and bases by the drainage waters - which under the natural vegetation are compensated by litter apports and biocycling -, and the lateral migration of organic matter and oxides of iron and aluminium associated with the solid eroded particles, prevail in the actual pedogenesis;

b) in depressed areas organic matter and aluminium oxides accumulate, and the iron is removed under the influence of high watertables. Therefore the lateral translocation of fine soil material constitutes a significant contributor to soil development. Moreover this feature shows the close relationship between landscape evolution and soil formation processes.

9. In agreement with the main pedogenetic and geomorphic processes actually occurring on these surfaces, the regional soil distribution shows the following pattern:

a) in the main well drained sectors of the landscape, differently eroded phases of the same soil type with similar mineralogical, sedimentological, physico-chemical and micromorphlogical properties are:

a1) in function of the horizonation classified in the field, under the Brazilian system, as Latosols or Red Yellow Podzolic soils; and

a2) depending on the presence or absence of textural gradients that satisfy the requirements of the argillic horizon, the soils are according to Soil Taxonomy (1975) and FAO/UNESCO (1974) systems respectivelly classified as Oxisols or Ultisols and as Ferralsols or Acrisols; whereas

b) in minor depressed areas:

b1) with free lateral drainage where run-off intensities are highest, Podzols (Brazilian and FAO/UNESCO systems) or Spodosols (Soil Taxonomy, 1975) are developed in the uppermost eroded layers of the soils enumerated under a1 and a2; and

b2) in cove positions where run-off waters are mainly eliminated through deep percolation the soils classify as Red Yellow Podzolic-Podzol intergrades under the Brazilian System, or respectivelly as Ultisols or Acrisols according to Soil Taxonomy (1975) and FAO/UNESCO (1974).

BIBLIOGRAPHY

AB' SABER,A.N.,1958. Conhecimento sobre as flutuaçoes climaticas do Quaternario no Brasil. Noticia Geomorfologica,1, abril 1958,Campinas, 24-30.

AB' SABER,A.N.,1977. Espaços ocupados pela expansao dos climas secos na America do Sul,por ocasiao dos periodos glaciais quaternarios. Universidade de Sao Paulo,Instituto de Geografia.

ACHA, L.P.,1976. Latossolo Vermelho Amarelo do Tabuleiro do Espirito Santo.Formaçao,Caracteristicas e Classificaçao. Tese Livre Doc., Recife,115 p.

A.C.S.A.D.,1981. P oceedings of the III International Soil Classification Workshop. A.C.S.A.D.,Damascus: 388.

ARENAS, A. et al.,1971. Desenvolvimento Agro-pecuario da Regiao Norte Fluminense; inventario dos solos. Roma,Italcont,38 p.

ARNOLD,R.W.,1979. Concept of the argillic horizon and problems of its identification. Proceedings of the II Int.Soil Classification Workshop, Part II, Thailand. Soil Survey Div. Land Develop. Department, Bangkok, Thailand: 21-33.

AUBERT, G. and SEGALEN, P.,1966. Projet de classification des sols ferralitiques. Cah.ORSTOM, ser.Pedol.vol. IV,fase 4.

BALDWIN, M., C.F.KELLOG and THORP, 1938. Soil Classification. In "Soils and Men", 479-1001. U.S. Dept.AGr;,Yearbook of Agriculture.

BARRERA, D., 1977. Caracterizaçao morfologica e fisicoquimica dos solos da regiao canavieira do Estado de Alagoas. Coleçao Pesquisa Canavieira N° 2, Rio Largo (Alagoas), 180 per.,1 mapa.

BARRERA, D., 1978. Caracterizaçao morfologica e fisicoquimica dos solos de tabuleiros da regiao canavieira do Estado de Alagoas. Coleçao Pesquisa Canavieira N° 4, Rio Largo (Alagoas), 59 pp., 3 mapas.

BARSHAD, I.,1964. Chemistry of Soil Development. In Firman E. Bear (ed.). Chemistry of the soils. Reinhold Publ. Corp., New York: 1-70.

BEAUDOU, A.G.,1972. Expression micromorphologique de la micro-aggregation et de l'illuviation dans certains horizons des sols ferralitiques centrafricains et dans les sols hydromorphes associés. Cah.ORSTOM, ser.Pedol., X; 4, 357-371.

BEINROTH, F.H. and PANICHAPONG, 1979. Second International Soil Classification Workshop. Part II : Thailand. Soil Survey Division - Land Develop. Department, Bangkok, Thailand. 499 p.

BEINROTH, F.H. and PARAMANANTHAN, S., 1979. Second International Soil Classification Workshop. Part I : Malaysia. Soil Survey Division - Land Develop. Department, Bangkok, Thailand. 344p.

BENAYAS, J. and GUERRA REFEGA, A.,1974. Aplicacion de la micromorfologia a la clasificacion de algunos suelos ferraliticos de Angola. An.Edafol. Agrobiol.,33, 283-294, 1 pl.

BENNEMA, J., R.C. LEMOS and VETTORI,1959. Latosols in Brasil. Proceedings of the III Interafrican Soil Conference,Dalaba, CCTA publ. 50 (1), 273-281.

BENNEMA, J.,1963. The red and yellow soils of the tropical and subtropical uplands. Soil Sci. 95 (4), 250-257.

BENNEMA, J. and CAMARGO, M., 1979. Some remarks on brazilian Latosols in relation to the Oxisols of the Soil Taxonomy. Proceedings of the II Int.Soil Classification Workshop. Part I : Malasia.

BIGARELLA, J.J. and AB' SABER, 1961. Quadro provisorio dos fatos sedimentologicos, morfoclimaticos e paleoclimaticos na Serra do Mar paranaense e catarinense. Bol. Paranaense de Geografia,No. 2/5,Curitiba, p.91

BIGARELLA, J.J.,1964. Variacoes climaticas no quaternario e suas implicacoes no revestimento floristico do Parana. Boletim Paranaense de Geografia, No.10-15.

BREWER, R.,1955. Mineralogical examination of a Yellow Podzolic soil formed on granodiorite. C.S.I.R.O.,Soil Publ. No.5,Australia, 28 pp.

BREWER, R., 1964. Fabric and mineral analysis of soils. John Wiley and Sons, Inc., New York - London - Sidney.

BUOL, S.W. and ESWARAN, H., 1978. The micromorphology of oxisols. Proceedings of the V International Working Meeting on Soil Micromorphology, Granada, Spain

BUURMAN, P. and SUKARDI, 1980. Brown Soils, Latosols or Podzolics? Red Soils of Indonesia. Centre for Agricultural Publishing and documentation. Wageningen. 93-104.

CAILLEUX, A. et TRICART, J., 1957. Zones phitogeographiques et morphoclimatiques du Quaternaire du Brésil. C.R. de la Société de Biogeographie, No. 293, pp. 7-13, Paris.

CAMARGO, M.N. et al., 1970. Reconhecimento dos solos da zona do Medio-Jequitinhonha - Minas Gerais. Equipe de Pedologia e Fertilidade do Solo, Boletim Tecnico, 9, Rio de Janeiro.

CAMARGO, M.N. and BEINROTH, F.H., 1978. Proceedings of the First International Soil Classification Workshop. Rio de Janeiro, Brazil, 376 p.

CHANG WANG and ARNOLD, R.W., 1973. Quantifying pedogenesis for soils with discontinuities. Soil Sci. Soc. Am. Proc., Vol. 37 (2), p. 271-277.

COMERMA, J.A., 1979. Low activity clay Alfisols and Ultisols of Venezuela. Proceedings of the II Int. Soil Classification Workshop. Part II Thailand. Soil Survey Division - Land Develop. Department, Bangkok, Thailand: 139-145.

DAMUTH, J.E. and FAIRBRIDGE, R.W., 1970. Equatorial deep-sea arkosic sands and ice-age aridity in tropical South America. Geol. Soc. of Amer. Bull., Vol. 81, p. 189-206.

DANIELS, R.B., E.E. GAMBLE, S.W. BUOL and H.H. BAILEY, 1975. Free iron sequence in an Aquult-Udult sequence from North Caroline. S.S.S.A. Proc. 39 (2) : 335 -340.

DE CONINCK, Fr., 1978. Physico-chemical aspects of pedogenesis. International Training Centre for Post-Graduate Soil Scientists. Rijksuniversiteit Gent, 154 p.

DE DAPPER, M. and DE MOOR, G., 1978. Mena on the Shaba high-plateaus (S.E. ZAIRE). Assessement of Erosion, ed. by M.De Boot and D.Gabriels. John Wiley and Sons.

DE DAPPER, M., 1979. The microrelief of the sandcovered plateau near Kolwezi (Shaba, Zaire).
I - The microrelief of the over-all dilungu.
Geo - Eco - Trop., 3 (1), 1-18.

DE LEENHEER, J., D'HOORE, J. et SYS, K.,1952. Cartographie et caractérisation pedologique de la Catena de Yangambi.
I.N.E.A.C.,Série Scientifique,N° 55, 62 p.

DUCHAUFOUR, Ph., 1965. Précis de Pedologie.
2e éd., Masson, Paris, 481 p.

ESWARAN, H., SYS, C. and SOUSA, E., 1975. Plasma Infusion-A pedological process of significance in the humid tropics.
Anales de Edafologia y Agrobiologia, Tomo XXXIV N° 9-10, Madrid.

ESWARAN, H., 1979. Micromorphology of Alfisols and Ultisols with low activity clays.
Proceedings of the II Int. Soil Classification Workshop. Part II : Thailand, 33-36.

FALESI, I.C. et al., 1964. Os solos da colonia agricola Tomé-Açu.
IPEAN, Boletim 44, Belem, 93 p.

FALESI, I.C. et al., 1970. Os solos da area Cacau Pirêra Manacapusu.
IPEAN, Solos da Amazonia, 3, Belem, 197.

FAO / UNESCO, 1974. Soil Map of the World.
Vol.I, Legend. UNESCO, Paris, 59 p.

FOLK, R.L. and WARD, W.C., 1957. Brazos River Bar : A study in the significance of grain size parameters.
J. Sed. Petrol, 27, pp.3-26.

FOLSTER, H., 1964. Die pedi-sedimente der Südsudanesischen pediplane, herkunft und bodembildung.
Pedologie, XIV, 1, Gent,pp.64-68.

FOLSTER, H. and LADEINDE T.A.O., 1967.
The influence of stratification and age of pediments on the clay distribution in ferruginous tropical soils.
Pedologie XXVII, 2, P.212-231.

FOURNIER, F., 1960. Climat et érosion.
Paris, P.U.F., 201 p.; 19 fig., 15 graphiques, 6 pl.

FOURNIER, F., 1967. Research on erosion and soil conservation in Africa.
Afr. Soils 12,p.53-96.

FRIEDMAN, G.M., 1962. On sorting, sorting coefficients, and the lognormality of the grain size distribution of sandstone. Jour. Geology, Vol. 70, pp.737-753.

FRIEDMAN, G.M., 1978. Principles of sedimentology. John Wiley and Sons, Inc. 792 pp.

HUGGETT, R.J., 1976. Lateral translocation of soil plasma through a small valley basin in the Northaw Great Wood, Hertfordshire. Earth Surface Processes, Vol.1,pp.99-109.

ISBELL, R.F., 1979. Low activity clay, Alfisols, Ultisols and Oxisols in tropical Australia and New Guinea. Proceedings of the II International Soil Classification Workshop. Part I : Malaysia. Soil Survey Division - Land Develop. Department, Bangkok, Thailand: 123-154.

JACKSON, M.L., 1956. Soil chemical analysis. Advanced course. University of Wisconsin College of Agriculture. Department of soils. Madison 6, Wisconsin.

JACOMINE, P.K.T. et al., 1971. Levantamento exploratorio-reconhecimento de solos do Estado do Rio Grande do Norte. Divisao de Pesquisa Pedologica, Boletim Tecnico, 21, Recife, 531 pp.

JACOMINE, P.T.K. et al., 1973 a. Levantamento exploratorio-reconhecimento de solos do Estado de Pernambuco. S.N.L.C.S., Boletim Tecnico, 26, Recife,359 p.

JACOMINE, P.K.T. et al., 1973 b. Levantamento exploratorio-reconhecimento de solos do Estado de Ceara. Divisao de Pesquisa Pedologica, Boletim Tecnico, 28, Recife.

JACOMINE, P.K.T. et al., 1975 a. Levantamento exploratorio-reconhecimento do Estado de Alagoas. EMBRAPA, Centro de Pesquisas Pedologicas, Boletim Tecnico, 35, Recife.

JACOMINE, P.K.T. et al., 1975 b. Levantamento exploratorio reconhecimento do Estado de Sergipe. Divisao de Pesquisa Pedologica, Boletim Tecnico,36, Recife, 560 pp.

JANSSEN, B.H. and VAN DER WERT H., 1976. The influence of fertilizers, soil organic matter and soil compaction on maize yields on the Surinam "Zanderij Soils". Plant and Soil, Vol. 46, Netherlands.

JIT SAI, L., M. SINGH KALSI and ESWARAN, 1979. Alfisols and Ultisols with low activity clays in Malaysia. Proceedings of the II International soil Classification Workshop. Part I Malaysia. Soil Survey Division - Land Development Department, Bankok, Thailand: 107-118.

KELLOG, C.E., 1949. Introduction to special issue on soil classification. Soil Science, 67, pp. 77-80.

KELLOG, C.E., 1949. Preliminary suggestions for the clasification and nomenclature of great soil groups in tropical and equatorial regions. Comm. Bur. Soil Sci. Techn., Comm. 46,pp.76-85.

KELLOG, C.E., 1950. Tropical soils. IV International Congress of Soil Science. Trans. Vol. 1, Amsterdam.

KLINGE, H., 1965. Podzols in the Amazon Basin. Journal of the Soil Science, Vol. 16,N° 1.

LANGOHR,R.,C. SCOPPA and A. VAN WAMBEKE, 1976. The use of a comparative particle size distribution index for the numerical classification of soil parent materials : application to Mollisols of the Argentinian Pampa. Geoderma, 15 pp. 305-312.

LANGOHR, R. and VAN VLIET, B., 1979. Clay migration in well to moderate well drained acid brown soils of the Belgian Ardennes. Morphology and clay concontent determination. Pedologie, 29 (3),pp. 367-385.

LASA ENGENHARIA E PROSPECCOES S.A., 1971 a. Usina Caeté S.A.; estudos basicos. V. 2 : agrologia, Recife.

LASA ENGENHARIA E PROSPECCOES S.A., 1971 b. Usina Camaragibe; estudos basicos. V. 2 : agrologia, Recife.

LASA ENGENHARIA E PROSPECCOES S.A., 1971 c. Usina Conceicao do Peixe; estudos basicos. V. 2 : agrologia, Recife.

LASA ENGENHARIA E PROSPECCOES S.A., 1971 d. Usina Santo Antonio; estudos basicos.
V. 2 : agrologia, Recife.

LASA ENGENHARIA E PROSPECCOES S.A., 1971 e. Usina Sinimbu; estudos basicos.
V. 2 : agrologia, Recife.

LEMOS, R.C.,J. BENNEMA, R.D. DOS SANTOS et al., 1960. Levantamento de reconhecimento dos solos do Estado de Sao Paulo.
Comissao de solos do C.N.E.P.A., Serv. Nac. Pesq. Agron., Bol. 12, Rio de Janeiro,pp.634.

LEPSCH, J.F., S.W. BUOL and R.B. DANIELS, 1977. Soil-landscape relationships in the Occidental Plateau of Sao Paulo State, Brazil : II. Soil morphology, genesis and classification.
Soil Sci. Soc. Am. J., Vol. 41.

MAACK, R., 1947. Breves noticias sôbre a geologia dos Estados do Parana e Santa Catarina.
Arg. Biol. Tecn., Vol. 2, Art. 7, Curitiba, pp. 66-154.

MAACK, R., 1948. Notas preliminares sôbre clima, solo e vegetaçao do Estado do Parana.
Agr. Biol. Tecn., Vol. 3, Curitiba,
pp. 103-200.

MEHRA, O.P. and JACKSON, M.L., 1960. Iron oxide removal from soils and clay by a dithionite-citrate system buffered with sodium bicarbonate.
Clays Clay Min., 7, pp. 317-327.

MEKARU, T. and UEHARA, 1972. Amion adsorption in ferruginous tropical soils.
Soil Sci. Soc. Amer. Proc. 36, pp. 296-300.

MIDEMA, R. and SLAGER, S., 1972. Micromorphological quantification of clay illuviation.
J. Soil Sci., 23, pp. 309-314.

MILLER, F.P., HOLDWAYCHUCK, N. and WILDING, L.P., 1971. Canfield Silt Loam, a Fragindalf ; I : Macromorphological,physical and chemical properties.
Soil Sci. Soc. Am. Proc., 35, pp. 319-324.

MILLER, B.J., 1983. Pedogenesis and soil taxonomy II : the soil orders - Utisols.
Ed. by L.P.Wilding, N.E. Smeck and G.F. Hall.

MOSS, A.J. and P.H. WALKER, 1978. Particle transport by water flows in relation to erosion, deposition, soils and human activities. Sedimentary Geology, 20, pp. 81-139.

MINISTERIO DA AGRICULTURA, 1958. Servico Nacional de Pesquisas Agronomicas. Levantamento dos Solos do Estado de Rio de Janeiro e Distrito Federal. Boletim 11,Rio de Janeiro, 350 pp.

MONCHAROEN, L. and P. VIJARNSON, 1979. Low activity clay Ultisols and Alfisols in Thailand. Proceedings of the II International Soil Classification Workship. Part II :Thailand. ed. by P.H. Beinroth and S. Panichapong.

MONIZ, A.C. and S.W. BUOL, 1982. Formation of an Oxisol-Ultisol transition in Sao Paulo, Brazil; I : Double water flow model of soil development. Soil Sci. Soc. Am. J., N° 46, pp.1228-1233.

MOORMANN, F.R., 1978. Report on the Brazil meeting of the Committee on the classification of Alfisols and Ultisols with low activity clays. Proceedings of the First International Soil Classification Workshop. Ed. by M.N. Camargo and F.H. Beinroth. EMBRAPA, S.N.C.C.S.,Rio de Janeiro:45-63.

MOORMANN, F.R., 1979. Taxonomic problems of low activity clay Alfisols and Ultisols. Proceedings of the II International Soil Classification Workshop. Part II Thailand. Soil Survey Division - Land Develop. Department, Bangkok, Thailand:13-20.

MOORMANN, F.R. and S.W. BUOL, 1981. The kandic horizon as a diagnostic subsurface horizon. Proceedings of the III International Soil Classification Workshop,A.C.S.A.D., Damascus, pp.328-342.

NEWHALL, F., 1972. Calculation of soil moisture regimes from the climatic record. Rev. 4, mimeographed,17 pages, 3 tables. Soil Conservation Service, U.S.D.A., Washington, D.C.

OLIVEIRA, L.B.,et al., 1968. Characterizaçao de adensamento no subsolo de uma area de tabuleiro da Estaçao Experimental do Curado. Pesq. Agrop. Bras. 3, Recife, pp. 207-214.

OLMOS, J.J.L. et al., 1969. Levantamento exploratorio dos solos da regiao cacaueira da Bahia e Espirito Santo.
Convenio C.E.P.L.A.C./D.P.E.S.-M.A., Itabuna, 1969.

PHELPS, H.O., 1975. Shallow laminar flows over rough granular surfaces.
Proc. A.S.C.F. 101, H.Y. 3, pp.367-384.

ROOSE, E.J., 1968. Notice technique: un dispositif de mesure du lessivage oblique dans les sols en place.
Cah. O.R.S.T.O.M., sér. Pédol. Vol. VI, N° 2.

ROOSE, E.J., 1970. Importance relative de l'érosion du drainage oblique et vertical dans la pédogénèse actuelle d'un sol ferralitique de Moyenne Côte d'Ivoire.
Cah. O.R.S.T.O.M., Sér. Pédol. Vol. VIII, N° 4.

ROOSE, E.J., 1972. Contribution à l'étude de l'appauvrissement des quelques sols ferralitiques et ferrugineux tropicaux situés entre Abidjan Ouagadougou par l'utilisation des méthodes expérimentales de terrain.
O.R.S.T.O.M., Bull. liaison Pédologues, thème N° 1, pp. 19-41.

SAVAT, J. and POESEN, J., 1977. Splash and discontinuous runoff as creators of fine sandy lay deposits with Kalahari sands.
Catena 4, 4, pp. 321-332.

SHEN, H.W. and RUH-MING LI, 1973. Rainfall effect on sheet flow over smooth surface.
Proceed. A.S.C.E., H.Y. 5, pp. 771-792.

SEYHAN, E., 1975. Fundamentals of hydrology.
Geografisch Instituut der Rijksuniversiteit te Utrecht.

SMITH, G.D., C.SYS and A. VAN WAMBEKE, 1975. Application of soil taxonomy to the soils of Zaire (Central Africa).
Pedologie, 25 (1), pp. 5-24.

SMITH, G.D., 1979. Problems of application of soil taxonomy with special reference to tropical soils with low activity clays.
Proceedings of the II International Soil Classification Workshop. Part II : Thailand.
Soil Survey Division - Land Develop.Department, Bankok, Thailand: 5-11.

SOIL SURVEY STAFF, 1951. Soil survey manual.
U.S.D.A. Handbook N° 18, U.S. Govt.Print. Office, Washington D.C., 503 pp.

SOIL SURVEY STAFF, 1960. Soil Classification, a comprehensive system.
7th. approximation, U.S.D.A. Washington.

SOIL SURVEY STAFF, 1967. Supplement to soil classification system; 7th. approximation.
Soil Conservation Service, U.S.D.A. , Washington, 207 pp.

SOIL SURVEY STAFF, 1975. Soil Taxonomy.
Agric. Handbook N° 436, S.C.S.-U.S.D.A., U.S. Govt. Print. Office, Washington D.C., 754 pp.

SOMBROEK, W.G. and J.B. SAMPAIO, 1962. Reconnaissance soil survey of the Araguaia Mahogny area: preliminary report.
F.A.O./S.P.U.E.A., Belem.

SOMBROEK, W.G., 1966. Amazon soils.
Centre for Agricultural Publications and Documentation, Wageningen, Nederland, 303 p.

SOMBROEK, W.G. and MUCHENA, F.N., 1979. LAC Alfisols and Ultisols in Eastern Africa; some problems to their identification and classification.
Proceedings of II International Soil Classification Workshop. Part II : Thailand.

SOUBIES, F., 1979. Existence d'une phase sèche en Amazonie brésilienne datée par la présence des charbons dans les sols (6000-3000 B.P.)
Cah. de l'O.R.S.T.O.M., Vol. XI,N° 1.

STOOPS, G., 1967. Le profil d'altération au Bas-Congo (Kinshasa). Sa description et sa génèse.
Pedologie, 17 (1), Gent, pp. 60-105.

STOOPS, G., 1968. Micromorphology of some characteristic soils of the Lower-Congo (Kinshasa).
Pedologie, 18 (1), Ghent, pp.110-149.

STOOPS, G. and JONGERIUS, A., 1975. Proposal for a micromorphological classification of soil materials. I : A classification of the related distributions of fine and coarse particles.
Geoderma, 13, pp. 189-199.

STOOPS, G., 1978. Provisional notes on Micropedology. Geological Institute, State University of Ghent, Belgium.

SYS, C., 1960. Principles of soil classification in the Belgian Congo. 7th. Int. Congress Soil Sci., Madison IV, pp. 112-118.

SYS, C., 1961. La cartographie des sols du Congo. Ses principes et ses méthodes. Série Technique N° 16, INEAC, 149 pp.

SYS, C., 1967. Tropical soils; their formation, classification, survey and utilization. International Training Centre for Post-graduate Soil Scientists, Rijksuniversiteit Gent, 108 pp.

SYS, C., 1968. The soils of Central Africa in the American classification. 7th approximation. African Soils 14 (1-2), pp. 25-44.

SYS, C., 1979. Regional Pedology. Tropical soils - Part II. International Training Centre for Post-Graduate Soil Scientists, State University of Ghent, Belgium.

SYS, C. and R. TAVERNIER, 1979. African Oxisols. Proceedings of the II International Soil Classification Workshop. Part I :Malaysia. Soil Survey Division - Land Develop. Department, Bangkok, Thailand.

TAVERNIER, R. and H. ESWARAN, 1973. Basic concepts of weathering and soil genesis in the humid Tropics. Proceedings of the 2nd. Asean Conference, (1), pp. 383-391.

TAVERNIER, R., 1981. Classification of soil moisture regime according to the method of Franklin Newhall. Unpublished data, Geological Institute, State University of Ghent, Belgium.

THORNTHWAITE, C.W., 1948. An approach forwards a rational classification of climate. Geogr. Revue 38 (55), pp. 55-94.

THORP, J. and G.D. SMITH, 1949. Higher categories of soil classification : order, suborder and great soil groups. Soil Science 67 (2), pp. 117-126.

TRICART, J. , 1974. Existence de périodes sèches au Quaternaire en Amazonie et dans les régions voisines.
Revue de Géomorphologie Dynamique, XXIII^{e} Année, N° 4, Paris, pp. 145-158.

VAN WAMBEKE, A., 1962. Criteria for classifying Tropical soils.
Journal Soil Sci. 13, pp. 124-132.

VAN WAMBEKE, A., 1976. Determination of climatic regime according to soil taxonomy (USDA, 1975), using Franklin Newhall system of computation, computed by FORTRAN programme VW 08.
Unpublished data, Faculty of Sciences, State University of Ghent, Belgium.

VAN WAMBEKE, A., 1981. Calculated soil moisture and Temperature regimes of South America.
S.M.S.S., Technical Monograph. N° 2.

VAN WAMBEKE, A. y D. BARRERA, 1974. Estudio de la migracion de arcilla en los suelos "Praderas Arenosas Gris-Amarillentas" desarrollados sobre la areniscas de Tacuarembo (Uruguay).
Anales de Edafologia y Agrobiologia, Tomo XXXIII, N° 11-12, Madrid.

VERHEYE, W., E. TESSENS and ISMANGUN, 1977. The Latosol and Podzolic soil concept in Indonesia.
Proceedings Clamatrops (Reprint).

VERHEYE, W. and G. STOOPS, 1975. Nature and evolution of soils developed on the granite Complex in the Subhumid Tropics (Ivory Coast).
11.Micromorphology and Mineralogy.
Pedologie 25 (1), pp. 40-55.

WANDERLEY LEITE, L., 1974. Geomorfologia dos tabuleiros costeiros de Sergipe.
Anais do XXVII Congreso Brasileiro de Geologia. 373-384.