W. G. Sombroek

Amazon Soils

A reconnaissance of the soils of the Brazilian Amazon region

Com sumário

Solos Amazônicos - Um reconhecimento dos solos da região amazônica brasileira

1966 Centre for Agricultural Publications and Documentation

Wageningen

The author was awarded the degree of Doctor of Agricultural Sciences, State Agricultural University Wageningen (Netherlands), on a thesis with the same title and contents

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The manuscript was submitted in October 1964. The Appendices 1–7 were already printed in 1963, but unfortunately with the provisional title: 'A study of soils of the Amazon valley'. In view of the Brazilian application of the maps, the Portuguese version of the explanatory texts is put first.

O manuscrito desta publicação foi apresentado em outubro 1964. Os Apéndices 1–7 foram impressos já em 1963, infelizmente com titulo de livro provisório: 'A study of soils of the Amazon valley'. Por causa da aplicação brasileiro destes mapas, o texto explicativo em português foi colocado em primeiro lugar.

"The luxurious vegetative cover led to the early assumption that the supporting soil was extremely rich. However, once it was realised that such growth is based largely on a closed nutrient cycle on tóp of the soil, and in view of the failure of agricultural settlements in the region, this opinion was completely reversed. Indeed, the great majority of the Amazon soils are 'poor' in the chemical sense."

Introduction

The name 'Amazonia' immediately conjures up visions of damp, vine-entangled greenery, infested with preying tarantulas and snarling jaguars. Such notions of 'the green hell' or 'the steaming jungle' are widespread among the average European and American, but also among many an inhabitant of southern Brazil. They have been fed on vast numbers of fictional impressions on the region, through vivid pictures on school walls, lush descriptions in novels, popular magazines, and impressive illustrated books. When their authors did not entirely draw on their own imagination, or simply copy from previous narratives, they often only peeped through riverside vegetation or a patch of secondary forest and took their pictures at the Belém zoo. They did a disservice to those interested in this part of the world. All the more admiration is due to such early explorers of Amazonia as COUDREAU, BATES, KATZER and LECOINTE for their perseverance and the veracity of their publications.

One's first sensation on actually penetrating the primeval forest of central Amazonia is one of deception. There are no entangling vines, hardly any wildlife, no steaming atmosphere. One soon discovers that the dangers of snakes, jaguars and wild Indians (the *cobras, onças e índios* of the indigenous *caboclo*) are very limited. The everlasting drone of insects is the only real nuisance. It takes some time before one becomes fully aware of the cathedral-like majesty of the high forest with its choir of rasping *cigarras* and howling *guaribas*, and begins to marvel at the delicate *igapó* growth along the cool rivulets.

The present soil study is the result of three years of plodding along straight transects through primeval forest, accompanying an experienced forest inventory team. Very divergent evaluations have been made of the Amazon soils. The luxurious vegetative cover led to the early assumption that the supporting soil was extremely rich. However, once it was realized that such growth is based largely on a closed nutrient cycle on tóp of the soil, and in view of the failure of agricultural settlements in the region, this opinion was completely reversed. Indeed, the great majority of the Amazon soils are 'poor' in the chemical sense. But until recently the only factual information on which to base such a conclusion was the 1926 report of MARBUT and MANIFOLD, whose investigations were an aftermath of the famous rubber boom. After its collapse, no new data on the Amazon soils were gathered until well after the second world war, when the SPVEA, the Federal Brazilian Development Board for Amazonia, was set up.

Drawing on the pioneering work of DAY, this book gives a new description and evaluation of the main Amazon soils based on present-day standards of soil study. It is endeavoured to combine the advantages of the morphometric method, as now applied in the U.S.A., with those of the more physiographical approach of certain European soil scientists. Thus, on the one hand, detailed morphometric descriptions are given of representative profiles and classification of the main soils is fully checked. On the other hand, much attention is given to the pedogenetic factors. Several of these factors as exhibited in Amazonia, have been little described, unlike those in such comparable regions as the central Congo basin. It was therefore necessary to relate extensively our own and others' data on such aspects as geomorphology, which is found to be of great importance for the understanding of the local pattern of soils.

The purpose of the study is twofold.

On the one hand it is a release of scientific data of more than regional interest – on the Amazon soils themselves, the genesis of tropical soils in general and on soil-plant relationships in a tropical region with limited human influence. But it is hoped that this publication will also serve as a kind of handbook for those Brazilians, and their associates, who are directly concerned with the Amazon soils and their use. An attempt is therefore made to facilitate future soil surveys in the region by providing a legend to all the soils hitherto encountered and by describing their geographic pattern. All existing data on the qualities of the main soils and their management is also provided.

The available field and laboratory data only cover a part of the region and they often give less information than might be wished. Moreover, conclusions on local pedogenesis and soil-plant relationships are often only tentative. The resulting picture of the Amazon soils is therefore far from complete, but it may well open the way to further soil studies on the immense region known as Amazonia.

Finally it should be stated that the opinions and conclusions expressed in this publication are the author's responsibility, and may not be taken to represent the official opinions or policies of either the *Superintêndencia do Plano de Valorização Econômica da Amazônia* or the Food and Agriculture Organisation of the United Nations.

Some terms and abbreviations

Amazonia: The Amazon region.

Amazon planalto (LIT. Amazon high plain): The Plio-Pleistocene plateau land of Amazonia, usually at 150–200 m altitude.

Planície (LIT. flat area of very large extent): All the upland in the axial part of Amazonia, comprising the Amazon planalto and the Pleistocene terraces.

Terra firme (LIT. stable terrain): All the upland, *i.e.* all non-flooded terrains, comprising the Planície and the older geomorphologic units.

Várzea (LIT. low, grassy land): Holocene lowland, intermittently waterlogged.

Igapó (LIT. marsh): Holocene lowland, or bottom lands, permanently waterlogged.

Massapé (LIT. sticking-to-the-feet): Strongly mottled, clayey soil; also used to denote terrains slightly above level of flooding, presumably of Early Holocene age.

Belterra clay: Very heavy, kaolinitic clay, deposited on top of the Amazon planalto.

Reworked Belterra clay: Belterra clay nowadays on terrains below the level of the Amazon planalto.

Terra Preta (LIT. black earth): Soil of Pre-Columbian Indian dwelling sites.

Hiléia (or *hylaea,* LIT. the great forest): The vegetative cover of Amazonia as phytogeographic unit.

Cipoal (LIT. *cipó-* or liana vegetation): Forest type composed largely of creepers and climbers.

Tabocal (LIT. *taboca-* or bamboo vegetation): Forest type composed largely of *Guadua* species.

Campo (LIT. field): Type of savannah.

Campina (LIT. small *campo*): Type of savannah.

Campina-rana (LIT. false *campina*): Type of savannah-forest.

Caatinga amazônica (LIT. Amazon *caatinga, i.e.* open forest): Type of savannah-forest.

Capoeira (LIT. the forest that was): Young secondary forest.

FAO: Food and Agriculture Organization of the United Nations

SPVEA: *Superintendência do Plano de Valorização Econômica da Amazônia,* the Federal Brazilian Development Board for the Amazon Region

IAN: *Instituto Agronômico do Norte,* the Federal Brazilian Agricultural Institute for Amazonia (as from October 1962, IPEAN: *Instituto de Pesquisas e Experimentações Agropecuárias do Norte*)

IQA: *Instituto de Química Agrícola,* the Soils Laboratory of the Federal Brazilian Soils Commission

I. The Environmental Factors

I.1 The Geographic Location

The extent of the Amazon region, later referred to as Amazonia, varies according to the criterion used.

Most of the catchment area of the Amazon river system is situated within Brazilian territory, but it also comprises considerable parts of Bolivia, Peru and Colombia. Compared to this, the phytogeographical area of Amazonia is smaller to the south and more extensive on the northern hemisphere, where it includes the Guianas and a part of Venezuela (Fig. 1).

Fig. 1 Alguns dados geográficos da Amazônia

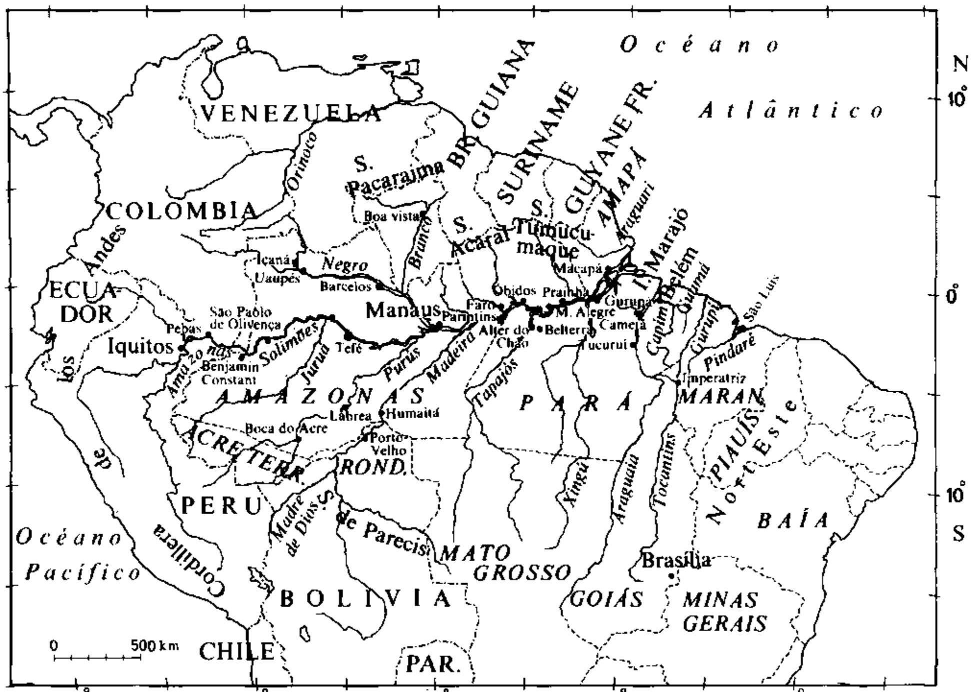


Fig. 1. Some geographical data of Amazonia

As a geologic basin Amazonia is much smaller. It consists of a relatively narrow stretch at the lower part of the river system, and a fan-like area towards the Andes.

This study deals with the Brazilian part of Amazonia. The limits of Brazilian Amazonia are partly arbitrary. In this publication, the transitions from the belt of equatorial forest to the savannahs of North-Eastern and Central Brazil and to those of Rio Branco – British Guiana are taken as boundaries. Brazilian Amazonia thus consists of all of the States Pará, Amazonas and Acre, the federal Territories Amapá and Rondônia, and parts of the States Maranhão, Goiás and Mato Grosso.

References to the Amazon river in general include the Solimões, which is the name given to the upper part of the central river in Brazilian territory. The axial part of Brazilian Amazonia may be divided into four areas, as follows:

1. the Upper Amazon region, from the frontier with Peru-Columbia to Manaus.
2. the Middle Amazon region, from Manaus to the boundary between the States Amazonas and Pará (Faro).
3. the Lower Amazon region, from Faro to the mouth of the Xingú river.
4. the Estuary region, including Marajó island, from the mouth of the Xingú river to the Atlantic Ocean.

I.2 The Climate

The climate of Brazilian Amazonia is humid and hot. The number of weather recording stations is small and they are far from evenly distributed. In the huge watershed areas at the north and the south side of the Middle and Lower Amazon region they are very rare. Nevertheless, the climate in its entirety is fairly well-known. Much relevant data and many maps are produced in a recently published book on the geography of Brazilian Amazonia (GUERRA, 1959). Therefore only the main characteristics are described.

The *rainfall* in Brazilian Amazonia is generally high. There is nevertheless much variation in total annual rainfall, as well as in the annual distribution. The data for total annual rainfall are given in Fig. 2. Highest recordings (over 3000 mm/year) are in the extreme east and the extreme west, namely in the north-eastern part of Amapá Territory and in the north-western part of Amazonas State. The Figs. 3 and 4 show the number of dry months – less than 50 mm and less than 100 mm rainfall per month –, and the central month of the dry season.

With regard to the *temperature*, Brazilian Amazonia shows high, but not excessively high values. The mean annual temperature varies from 23.5°C to 26.9°C. The rainy season *(inverno)* is generally slightly less warm than the dry season *(verão)*. The annual amplitude in the mean temperatures of the months is however very small at all stations of the region, namely below 5°C, and in most places even below 2.5°C. The

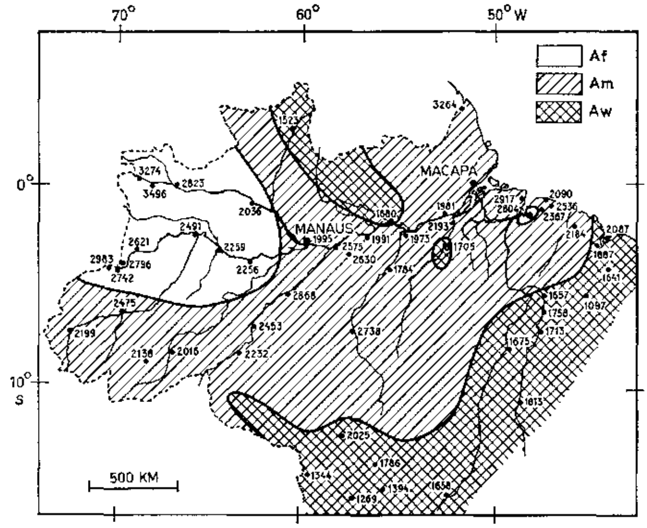


Fig. 2 Os tipos climáticos da Amazônia brasileira conforme a classificação de Köppen, e a precipitação anual total (de GUERRA, *1959; cf. I. 2)*

Fig. 2 The climates of Brazilian Amazonia as per the classification of Köppen, and the total annual rainfall (from GUERRA, *1959; cf. I. 2)*

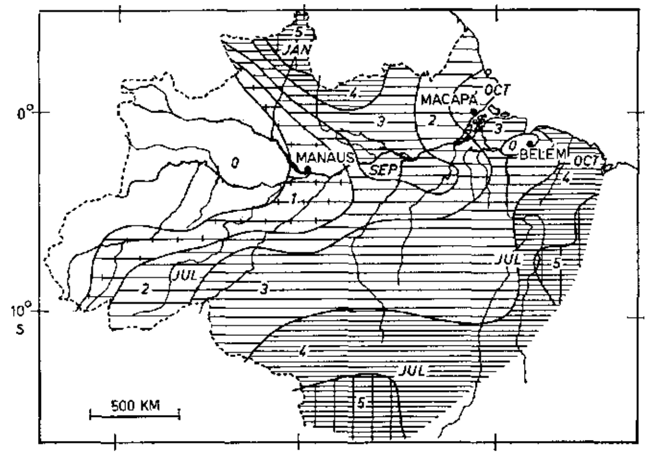


Fig. 3 Número de meses sêcos por ano, e mês central da estação sêca, sendo critério de um mês sêco uma precipitação de menos de 50 mm (coligido de dados de GUERRA, *1959)*

Fig. 3 Number of dry months per year, and central month of dry season, taking less than 50 mm rainfall as criterion for a dry month (compiled from data of GUERRA, *1959)*

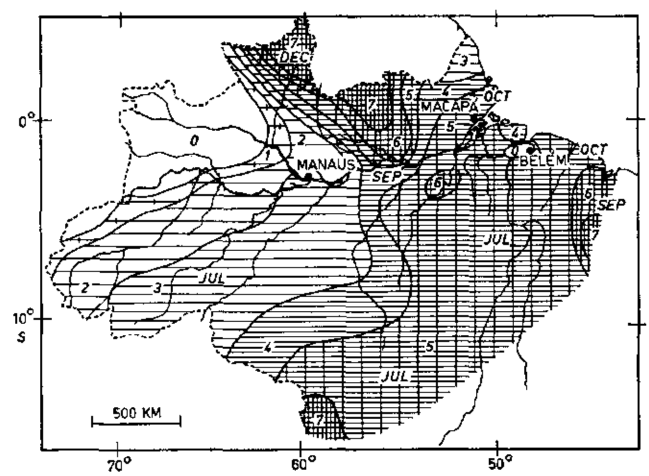


Fig. 4 Número de meses sêcos por ano, e mês central da estação sêca, sendo critério de um mês sêco uma precipitação de menos de 100 mm (coligido de dados de GUERRA, *1959)*

Fig. 4 Number of dry months per year, and central month of dry season, taking less than 100 mm rainfall as criterion for a dry month (compiled from data of GUERRA, *1959)* temperature of the coldest month is everywhere above 18°C. The absolute maximum temperature ever measured is only 44°C (Tefé). There is a distinct difference in temperature between day and night; high amplitudes are known for instance for Belém (9.6°C), Manaus (8.7°C), and Sẽna Madureira in Acre State (13.5°C).

The *relative humidity* is high. The variation over the region in the annual mean is between 73% and 94%. In the central part of Brazilian Amazonia the values are above 80% everywhere. The highest percentages are found near the Ocean coast, and in Acre and western Amazonas State.

The *winds* are usually weak, except for the coastal region where they may be moderate *(vento geral)*. Storms such as typhoons are unknown, but gusts of strong winds are frequent before afternoon rain showers. Exact data are lacking.

Figures for evaporation, cloudiness and dew are not available, as no systematic recording has been carried out.

With KÖPPEN'S classification, Brazilian Amazonia has three types of climate (Fig. 2). Type *Af* (hot and humid, without dry season) is found in the north-eastern part of Amazonas State, and in a pocket of as yet undetermined size around Belém. Type *Am* (humid and hot, with a short dry season) comprises the main part of the region, while type *Aw* (humid and hot, with a pronounced dry season) occurs on the south-eastern fringes of forest covered Amazonia, in the boundary area with British Guiana, and in a part of the Lower Amazon region.

I.3 The Geology

The geology of Amazonia was studied already at the end of the nineteenth century, for instance by DERBY (1877) and KATZER (1903). In recent years much more has become known, especially from the extensive surface and subsurface prospections of the national oil company Petrobrás. On the Figs. 5 and 6, this Company's data are given schematically, while use is also made of the most recent geological map of Brazil (LAMEGO, 1960).[1]

The Amazon valley constitutes a low, sedimentary area between the shields of Central Brazil and the Guianas. These shields consist of crystalline basement complexes of old age, namely of the Pre-Cambrian period. The rocks are principally granites, gneisses and mica schists. For the Guiana shield north of the Lower Amazon region, KATZER (1903) indicates that the granites are concentrated at the frontier zone with the Guianas, the gneisses occur in a band along this zone and the mica schists – with

[1]) The area of the Brazilian shield within Amazonia is very little explored. Omitted from Fig. 5 are several parts indicated as Cretaceous on early geology maps, and mainly as Carboniferous on the 1960 map (areas along the middle Tapajós, the middle Xingú and the lower Tocantins river).

intrusions of granites and syenites – occupy the southernmost part of this crystalline shield. In northern Amazonas State, as well as along the Tapajós river, granites seem to be dominant.

The comparatively young Andean mountain range, which is bordering Amazonia on the west side, consists of folded sedimentary rock, predominantly of Paleozoic or Mesozoic age. Much volcanic activity took place here.

The sedimentary part of Amazonia is not one basin, but consists of several: the basin of Acre, the large basin of the Amazon proper, the basin of Marajó, and the basin of Maranhão, which latter has two sub-basins, namely those of São Luis and Barreirinhas (*cf* Appendix 5). The first three basins are relatively deep, while the Maranhão basin is shallow. The Amazon basin is narrow in its eastern part, but very wide upstream, in the western part. The schematised stratigraphic sections of the main basins are given in Appendix 8. It can be seen that both in the Amazon, the Maranhão and the Acre basins a part of the beds was deposited under marine or lacustrine conditions.

In the Maranhão basin the deposits are largely Paleozoic or Mesozoic. They outcrop over extensive areas. The youngest deposits of considerable thickness are of Late Cretaceous or Tertiary age (Itapecurú or Serra Negra beds). They occupy the northern part of the present surface of the basin.

In the Amazon basin proper, the deposits are for a large part Paleozoic or Cenozoic. The Paleozoic deposits only outcrop on the edges of the basin in its narrow eastern part. At one place they form a Dome (Monte Alegre). Apart from the edges, the basin surface consists of Late Tertiary deposits (Alter do Châo or Barreiras beds).

The Acre basin consists of Cretaceous and Tertiary deposits for a large part. Their composition is different from that of the deposits of the same periods in the Amazon basin proper.

The Marajó basin has only deposits of Cretaceous and younger age.

Seen in its entirety, the sedimentary part of Amazonia has at its surface a large proportion of Cretaceous or Tertiary sediments. They are of varying textures and colours, consist of kaolinitic clays and quartz sands, and are little consolidated.

The thickness and the extent of the Pleistocene deposits proper, which consist also of kaolinitic clays and quartz sands, are apparently limited, especially in the western part of Amazonia. At Nova Olinda, near the confluence of the Amazon and the Madeira rivers, the Pleistocene sediments comprise only several metres. On the banks of the Amazon river between Manaus and Monte Alegre, the Tertiary Alter do Châo or Barreiras beds are well exposed. The contact of these beds with the overlying Pleistocene sands is found at varying heights above the river. The thickness of the Pleistocene deposits reaches a maximum of 50 m, namely at Monte Alegre (SAKAMOTO, 1960). The approximately flat terrains east and south of Belém (zona Bragantina, zona Guajarina) are covered with Pleistocene sediments, but only in a thin layer (5–10 m). The only thick Pleistocene deposits are in the Marajó area. Here they reach about 250 m thickness and consist of grey silts (Appendix 8).

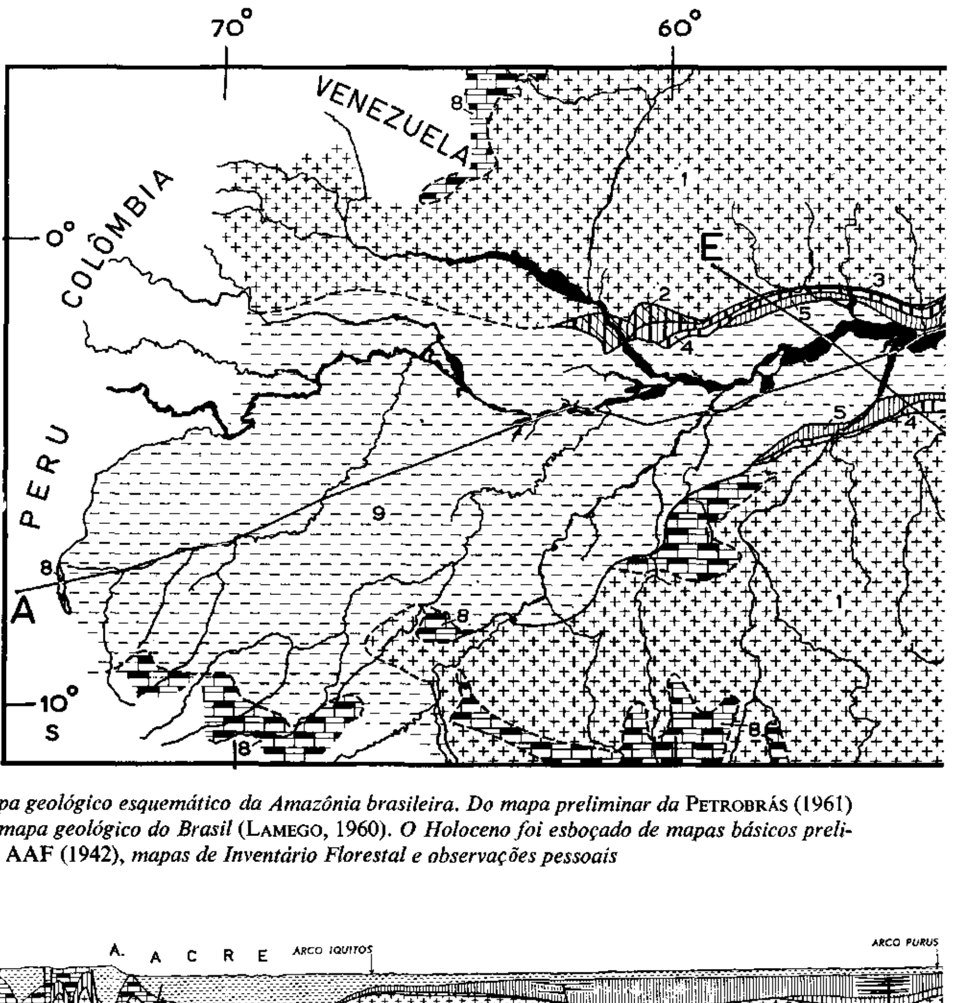


Fig. 5 Mapa geológico esquemático da Amazônia brasileira. Do mapa preliminar da PETROBRÁS (1961) *e o último mapa geológico do Brasil* (LAMEGO, 1960). *O Holoceno foi esboçado de mapas básicos preliminares da* AAF (1942), *mapas de Inventário Florestal e observações pessoais*

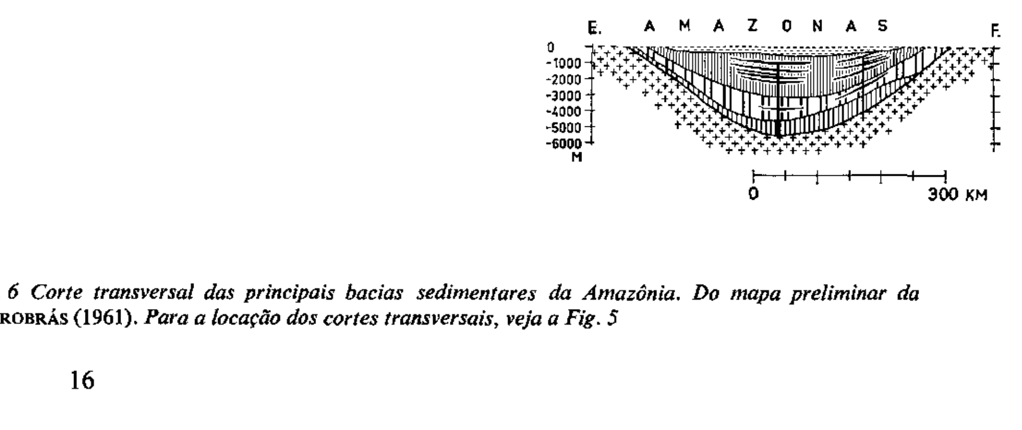
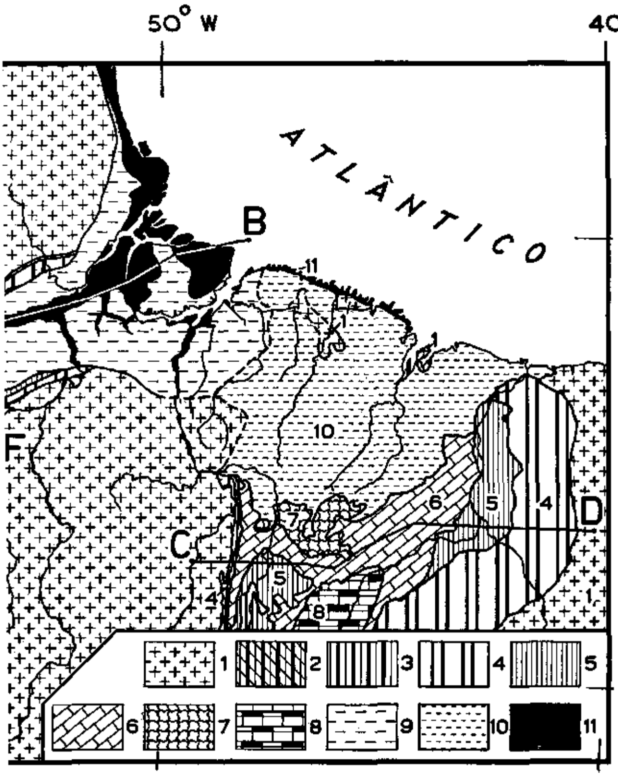


Fig. 6 Corte transversal das principais bacias sedimentares da Amazônia. Do mapa preliminar da PETROBRÁS (1961). *Para a locação dos cortes transversais, veja a Fig. 5*



1. Pre-Cambrian/*Pré-cambriano*

2. Pre-Silurian/*Pré-siluriano*

3. Silurian/*Siluriano*

4. Devonian/*Devoniano*

5. Carboniferous/*Carbonífero*

6. Jura-Triassic/*Jura-Triásico*

7. Jurassic (diabase)/*Jurásico (diabase)*

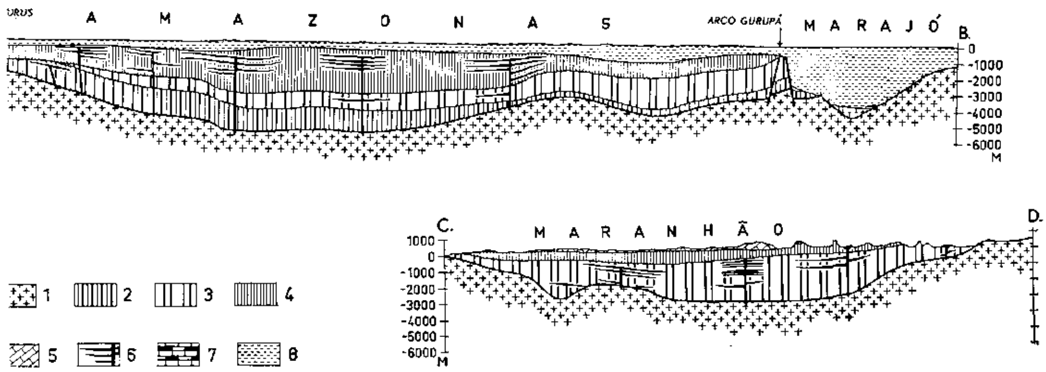
8. Mesozoic undifferentiated, probably largely Cretaceous/ *Mesozóico não diferenciado, provàvelmente mormente Cretáceo*

9. Tertiary and Pleistocene/ *Terciário e Pleistoceno*

10. Cretaceous, Tertiary and Pleistocene/*Cretáceo, Terciário e Pleistoceno*

11. Holocene and inland water/ *Holoceno e água no interior*

Fig. 5 Schematic geological map of Brazilian Amazonia. From preliminary map of PETROBRÁS *(1961), and the latest geological map of Brazil* (LAMEGO, 1960). *The Holocene sketched from AAF preliminary base maps (1942), Forest Inventory maps, and personal observations*



1. Pre-Cambrian/*Pré-cambriano* 2. Pre-Silurian and Silurian/*Pré-siluriano e Siluriano* 3. Devonian/ *Devoniano* 4. Carboniferous/*Carbonífero* 5. Jura-Triassic/*Jura-Triásico* 6. Jurassic (diabase)/ *Jurásico (diabase)* 7. Cretaceous/*Cretáceo* 8. Tertiary and Quaternary/*Terciário e Quartenário*

Fig. 6 Schematic cross-section of the principal sedimentary basins of Amazonia. From preliminary map of PETROBRÁS *(1961). For location of cross-sections see Fig. 5*

For geologists, truly Pleistocene deposits are therefore restricted in occurrence. But it will be shown that Pleistocene eustatic changes in sea level and Pleistocene river regimes have had a very great influence in reworking of the Tertiary deposits and the topography of the Amazon land (*cf.* I.4).
It should be borne in mind that considerable parts of Amazonia which are indicated as crystalline or Paleozoic on the geologic map, are, in fact, covered with thin layers of Tertiary or Pleistocene sediments. This applies, for instance, to the lower Gurupí area and the whole region of the Rio Negro.

The Holocene sediments consist largely of silts and clays. They cover the floodplain areas along the Amazon river proper and the lower parts of its main tributaries, and are also found in the Estuary region (Fig. 5). However, the Holocene areas, all together, comprise only about 1–2% of the total land surface of Amazonia. This is much less than assumed by early explorers. As they only travelled on the rivers they rarely saw any upland, and therefore obtained a wrong impression on the expanse of the floodplains.

I.4 The Geomorphology

I.4.1 Sketch of proto-Amazonia

Due to the absence of major orogenetic movements since the Pre-Cambrian period, other geomorphogenic factors were allowed to play a marked role in the development of the landscapes of Amazonia. The evolution of Amazonia as discussed below, is illustrated in the sketches of the Figs. 8 and 9.
A very extensive denudation and peneplanation[1] must have taken place after the Pre-Cambrian. The Andean mountain range did not then exist. Instead, a Peruvian trough was present. Because of the existence of marine Paleozoic deposits in the above mentioned Amazon sedimentary basin, DERBY (1877) assumed that there was no superficial connection between the two crystalline shields in those early periods. The shields would have constituted two separate islands at the northern and southern side of an Amazon trench[2], a trench which would have been connected with the Peruvian trough and the proto-Atlantic until the Tertiary. KATZER (1903), however, concluded that such an Amazon trench had no connection with water masses east of present Brazil. He stated that there must have been a superficial connection between the eastern parts of the shields, running over the present-day Estuary region. The existence of such a connection has been recently confirmed by the presence of the

[1]) It may concern actually 'pediplanation', as this term is applied more recently, for instance by KING; the existing geomorphologist's controversy on this subject is evaded by adhering to the old term 'peneplain' for an erosional surface, whatever its mode of formation.
[2]) 'trough of subsidence' according to SOARES (1956).

Gurupá arch (Fig. 6), and the fact that the Marajó sedimentary basin constitutes a Graben which has been acting only from the Cretaceous onwards. A connection with the Peruvian trough will have existed, although for several Paleozoic periods sills and land barriers are supposed to have occurred (KATZER, 1903; SAKAMOTO, 1960).

During the Paleozoic the erosion products of the shields were transported from the north and the south to the Amazon trench, and in a western direction to the Peruvian trough. Transport to the Maranhão basin also took place.

Permean, Triassic and Jurassic deposits are not found in the Amazon basin, except for some basic intrusions. KATZER (1903) supposes that during these periods there was a superficial connection between the Guianas and Central Brazil over a broad front.

As related, for instance, by OLIVEIRA *et al.* (1956), a general subsidence, accompanied by an intensive levelling, took place at the end of the Jurassic or the beginning of the Cretaceous. Cretaceous flat lying sand-stones, of continental origin, are found widespread in the interior of Brazil. From their reddish colour, and the presence of eolian elements, SAKOMOTO (1960) concluded that these sediments were formed in a relatively warm and dry climate, and spread over the plains close to their source. The sand-stones now apparently still cap many of the plateaux of the watersheds between the main rivers. Examples are the Chapada de Parecis, Serra do Roncador, Serra do Cachimbo on the Brazilian shield, and parts of the Serra de Tumucumaque, the Serra de Acaraí and the Serra de Pacaraima on the Guiana shield. These plateaux are often at an altitude of 400–600 m. Apart from capping these plateaux, Cretaceous sediments are found in parts of the basins, where they may be marine (Acre, Maranhão).

SAKAMOTO (1960) and VARGAS (1958) distinguish also an Early Tertiary peneplanation surface on the crystalline shields, at 250–400 m altitude. To this level for instancs would belong the Campos de Ariramba (90 km north of Óbidos), the Campos Geraie de Óbidos (200 km north of Óbidos), and the table lands of Almeirim-Prainha' amongst which is the Serra de Paranaquara.[1] The savannah areas in the region of the upper Paru river, near Surinam, probably belong also to this Early Tertiary peneplanation surface (*cf.* quotation of KATZER on p. 164), so also do the savannah areas of the middle course of the Tapajós (Campos de Cururú, Campos de Mucajazal) that are reported by LECOINTE (1922). The geologic material of the floor of this surface is not necessarily Pre-Cambrian crystalline. SIOLI and KLINGE (1961) mention that the substratum of the Campos de Ariramba consists of sand-stones of possibly Devonian age, and that of the Campos de Cururú of sand-stones of Cretaceous age.

Little can be said with certainty about the above mentioned peneplanation surfaces. The correlation with the surfaces in Central and Southern Brazil, as established by

[1]) From the geologic description of this table land by KATZER (1903) it seems likely that its top is similar to that of the planalto south of Santarém (Belterra clay over Ipixuna-like plinthite concretions; *cf.* I.4.2 and I.4.5). It seems therefore more probable that the tops of the Serra de Paranaquara and the adjoining table lands belong to the Plio-Pleistocene Amazon planalto level, and that their relatively high altitude is due to a Post-Tertiary relative uplift of the area between Almeirim and Prainha. This is in agreement with SIOLI (1957) who deduced from the absence of *rias* (*cf.* I.4.3) in this area, that such an uplift occurred.

KING (1957), also awaits further study. It is possible that the above mentioned Amazon ones are related to KING's Post-Gondwana and Sul-Americana levels respectively.

It is generally accepted (*cf.* OLIVEIRA *et al.*, 1956) that, from the Middle Tertiary on, a general uplift of Amazonia took place, except for the Marajó area (Graben of Marajó, see above). The extraordinarily extensive Tertiary sediments of the Amazon basin, known as the Alter do Chão or Barreiras beds, were probably deposited largely during the Miocene, under continental conditions. Until recently it was assumed that this had been done by the then westward flowing proto-Amazon river. BARBOSA (1959), however, casts doubt on the truly fluviatile character of the deposition. He states that the sedimentation took place with an endoreic drainage, related to what seems to have been a semi-arid climate of great extent, and that the Amazon river system proper originated only afterwards, during a subsequent humid climate.

Contrary to the general situation, the Tertiary deposits in the Acre basin, as well as those in the area east of Belém, were for a part laid down under marine conditions (Pirabas beds, Pebas beds.)

To sum up, the watershed regions on the north and the south sides of the Amazon river system may be divided into the following geomorphologic units:

1. Undulating terrains with outcropping crystalline basement.
2. Undulating terrains with outcropping Paleozoic, Mesozoic or Early Tertiary deposits.
3. Two peneplanation surfaces within the area designated as crystalline on the geologic maps, supposedly of Cretaceous and Early Tertiary age respectively.

I.4.2 The Planície. The Plio-Pleistocene Plateau or Amazon Planalto

Throughout the eastern part of Amazonia can be found a flat, terrace-like surface, at 100 or more metres above the level of the main rivers. The upper layers of this surface, about twenty metres thick, consist of uniform, yellowish, very heavy, kaolinitic, sedimentary clay without any visible stratification. After exposure to the weather, the clay falls apart into characteristic fine structure elements that are very resistant to destruction (see Photo 1). This particular material is scarcely mentioned in literature about Amazonia. The material will henceforth be called *Belterra clay*, after one of the localities where its occurrence is very conspicuous. Before dealing with the problem of its origin, an extensive description will be given of the occurrence of plateau land with Belterra clay cover.

I.4.2.1 *Description of Occurrence of Belterra Clay* (*cf.* Fig. 7)

A Belterra clay covered flat surface is very widespread in the upper Capím – upper Gurupí area, in most places at an altitude of about 200 m, but in the southernmost part, the Serra de Gurupí, at an altitude of about 350 m (*cf.* cross-sections of the BR-14 highway, Appendices 4 and 5). In the region between the rivers Xingú and Tocantins, the surface is present apparently only far south of the Amazon river; it occurs west of Tucuruí, *Foto 1 Argila de Belterra exposta à superfície. Após ser exposta às condições climáticas, a argila caolinítica muito pesada, denominada de Belterra, desagrega-se em elementos maciços bem finos e muito resistentes à destruição*

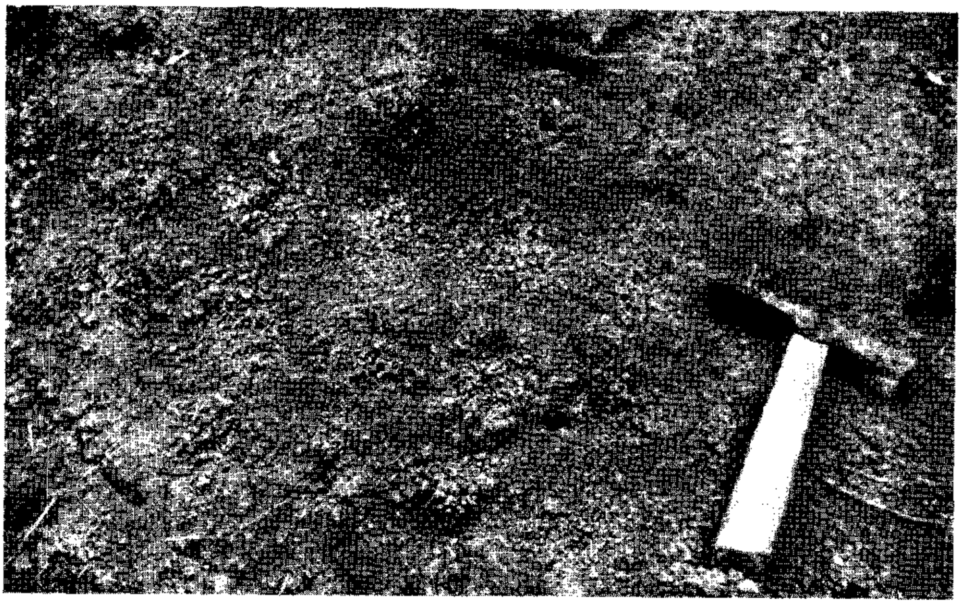


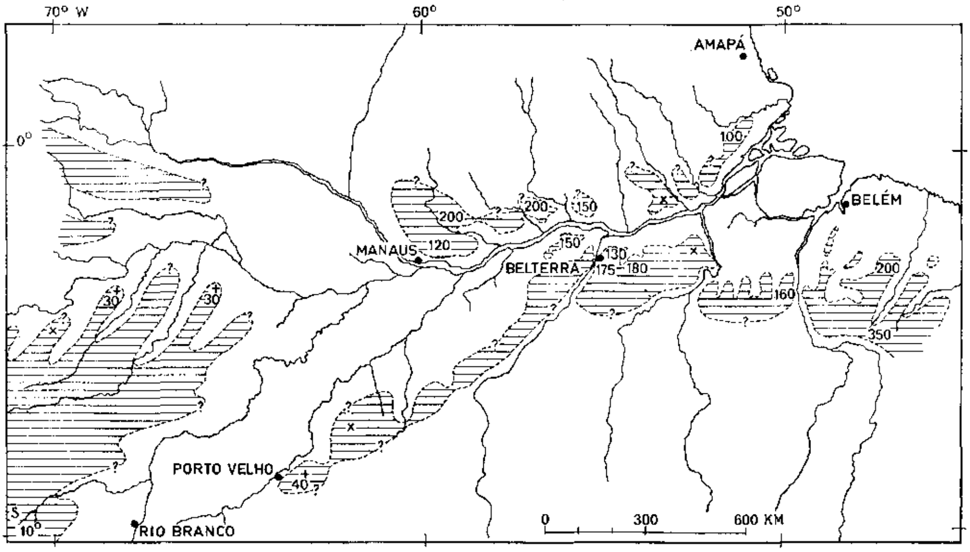
Photo 1 Belterra clay exposed at the surface. After exposure to the weather, the very heavy, kaolinitic clay, termed Belterra clay, falls apart into very fine blocky elements that are very resistant to destruction

at an estimated altitude of 160 m (Serra de Trocara). Between the rivers Tapajós and Xingú however the surface with Belterra clay cover is found near to the Amazon river. Directly south of Santarém the altitude is about 130 m (GOUROU, 1949). At Belterra Estate, about 40 km south of Santarém, the altitude is about 175 m. At the Curuá-una centre, about 80 km east-south-east of Santarém, the altitude is 180 m.[1] Near the Xingú the altitude is less and the surface seems in most places not flat. For the region west of the lower river Tapajós HEINSDIJK (1958c), who knew its characteristics well from a survey in the Curuá-una area, reports that the Belterra clay covered surface is also present, although much attacked. The plateau fragments in the area (Serra de Parintins, Serra de Balaio, and others) are reported to occur at about 150 m altitude (LECOINTE, 1922).

On the north side of the Amazon river the Belterra clay is also found. The clay occurs in the southern part of Amapá Territory, namely in the headwater region of Igarapé do Lago (about 60 km northwest of Macapá), at an estimated altitude of 100 m. The clay has been reported to occur at 'some distance' north of Prainha. The presence of Belterra clay was also established at a short distance north of the towns

[1]) In this area, the surface has a slight dip in an easterly direction.

Fig. 7 Ocorrência de argila de Belterra



× Locations/*locações*
30 Locations with established altitude (above sea level)/*locações com altura determinada (sobre nível do mar)*
+ Height above high-water of local river or rivulet/*altura sobre nível do rio ou igarapé local*

Fig. 7 Occurrence of Belterra clay

Terra Santa and Faro, between the rivers Nhamundá and Trombetas, there at a relatively low altitude, about 60 m. It seems probable that the terrain further north, which forms a plateau – Serra de Chinelo, Serra de Cunurú – at about 200 m altitude (KATZER, 1903) has also a cover of Belterra clay. A similar plateau is very conspicuously present east of the river Uatumá, forming the Serra de Santa Rita, Serra de Santa Rosa and others (VARGAS, 1958). The same author mentions a plateau of 150 m altitude directly north of Óbidos. Large parts of the stretch traversed by the recently constructed Manaus-Itacoatiara road (AM-1) have a cover of Belterra clay. The altitude of the approximately flat sections of plateau in this area, locally called *chapadas*, is about 120 m in the central stretch of the road (about 40 km north of the Amazon river). Near both Manaus and Itacoatiara the terrain tops are less flat and their altitude is somewhat lower.

There are few data about the occurrence of Belterra clay on plateau land in the western part of Amazonia. MARBUT and MANIFOLD (1925) report the existence of a plateau east of Humaitá on the Madeira river. Southeast of Porto Velho large flat stretches occur, at about 40 m above local river level, with a cover of Belterra clay. It has, however, a slightly less heavy texture than that in the eastern part of Amazonia. It seems probable that the western part of Acre State has a terrain cover similar to that near Porto Velho. Indications from AAF and CNG topographical maps are that the terrains in the central part of Amazonas State (Juruá-Purús-Madeira) have very little topographical differences and are relatively low lying, both with regard to altitude and to height above local river level. The textures of the surface materials seem to be mainly heavy, for instance around Tefé. MARBUT and MANIFOLD report that from the Catuá river (about 250 km west of the mouth of the river Purús) to the west, a dissected plateau is present. It seems to extend westward to at least within 50 km of the frontier (1925, p. 642), and also far southward (1926, p. 440). They estimate the level of this plateau to be about 30 m above the river Solimões. For this region they report soils that are similar, also texturally, to those of the plateau south of Santarém. In the frontier region there are apparently more topographical differences than in the Juruá-Purús-Madeira region. For the area south of Benjamin Constant, on the frontier, the existence is reported of sections of plateau similar to that of the Curuá-una centre (internal reports FAO/SPVEA Mission, Belém). The only available data about the adjoining parts of Peru are those of MARBUT and MANIFOLD, who mention a similarity with the Brazilian part of the region. For the Madre de Dios area in Bolivia widespread presence of plateau land is established (DREWES, 1961). No reliable data are available on the texture of the covering sediments.

In summarising these data, it may be said that over all of the axial part of Amazonia flat plateau land occurs with a cover of Belterra clay. The limited number of textural analysis data suggest that the heaviness of the clay slightly increases towards the east. Moreover, the lower part of the Belterra clay layer seems to be less heavy textured than the upper part.[1]

In the eastern part of Amazonia the blanket of Belterra clay on plateau land is underlain by a layer of plinthite (= laterite) concretions. The plinthite layer seems to constitute the weathered upper stratum of the sediments of the Barreiras or Alter do Châo beds which composes the base of the sections of plateau (*cf.* I.4.5).

I.4.2.2. *Origin of Belterra Clay* (*cf.* Figs. 8 and 9)

Neither dating nor explanation of the occurrence of the Belterra clay on plateau land has been found in literature. The deposition of the clay must have taken place after the first uplift of the Andean Cordillera and the flattening of the Amazon land by de-

[1]) The percentage of clay (separate <2μ) varies between 85 and 95%. Within the silt fraction (2–50μ), there is apparently no clear top; two samples gave the following granulometric data (by courtesy of DR. FAVEJEE of the Geology Department of Wageningen University):

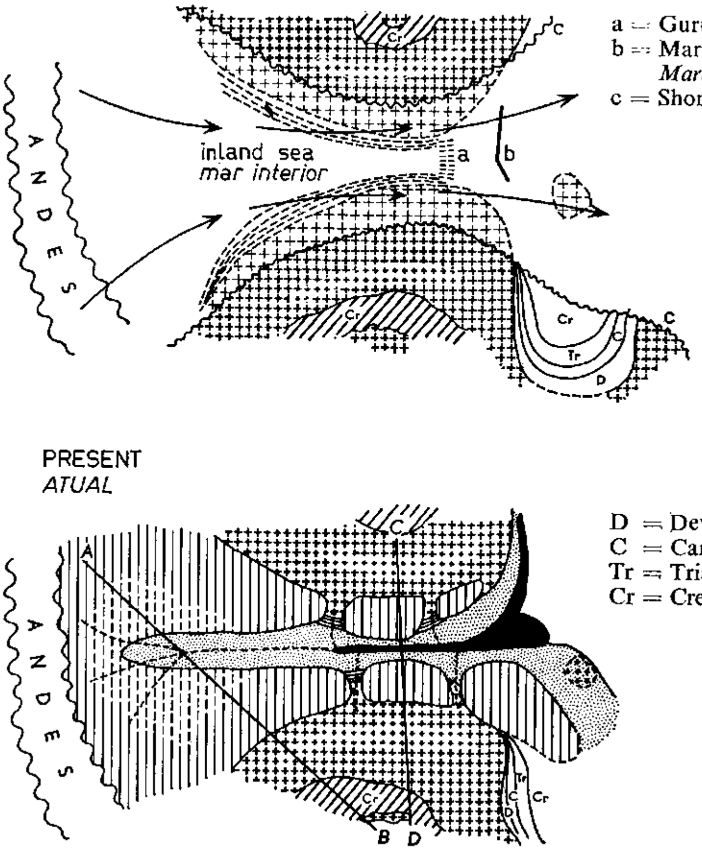
	>50 μ	50–32 μ	32–16 μ	16–8 μ	8–2 μ	<2 μ
(BR-14, km 366; 5–40 cm depth)	4.2	2.2	1.6	2.7	2.7	87.0
(Curuá-una, km 14; 95–150 cm depth)	2.6	2.2	1.6	2.8	4.9	85.9

The percentage of silt and/or fine sand is slowly increasing with depth, at the cost of the percentage of clay. This is illustrated on the lowest horizons of Profile 24 (III.2), as well on sample XI-1-6 of CATE (1960) from 280 cm to 470 cm depth on the planalto of Curuá-una Centre. These samples moreover show that the lower part of the Belterra clay 'blanket' is indeed kaolinitic in character, as was already believed because of the similarity in morphometric characteristics between the upper and the lower parts of the layer of sediment. It therefore does not concern a kaolinitisation by soil formation.

Fig. 8 Esbôço que demostra a formação do planalto amazônico

PLIO-PLEISTOCENE (CALABRIAN)
PLIO-PLEISTOCENO

PRESENT
ATUAL



a = Gurupá arch/*Arco Gurupá*
b = Marajó 'graben'/*'Graben' de Marajó*
c = Shore line/*Linha da costa*

D = Devonian/*Devoniano*
C = Carboniferous/*Carbonífero*
Tr = Triassic/*Triasíco*
Cr = Cretaceous/*Cretáceo*

1 Outcropping crystalline shields
Contrafortes cristalinos aflorantes

2 Early Tertiary peneplanation surface on the crystalline shields
Superfície de peneplanação do Terciário Inferior nos contrafortes cristalinos

3 Crystalline covered with thin layer of Pleistocene deposits
Cristalina coberta de camada delgada de depósitos do Pleistoceno

4 Cretaceous peneplanation level and deposits
Superfície de peneplanação e depósitos do Cretáceo

5 Paleozoic-Mesozoic deposits undifferentiated
Depósitos Paleozóicos-Mesozóicos, não diferençiados

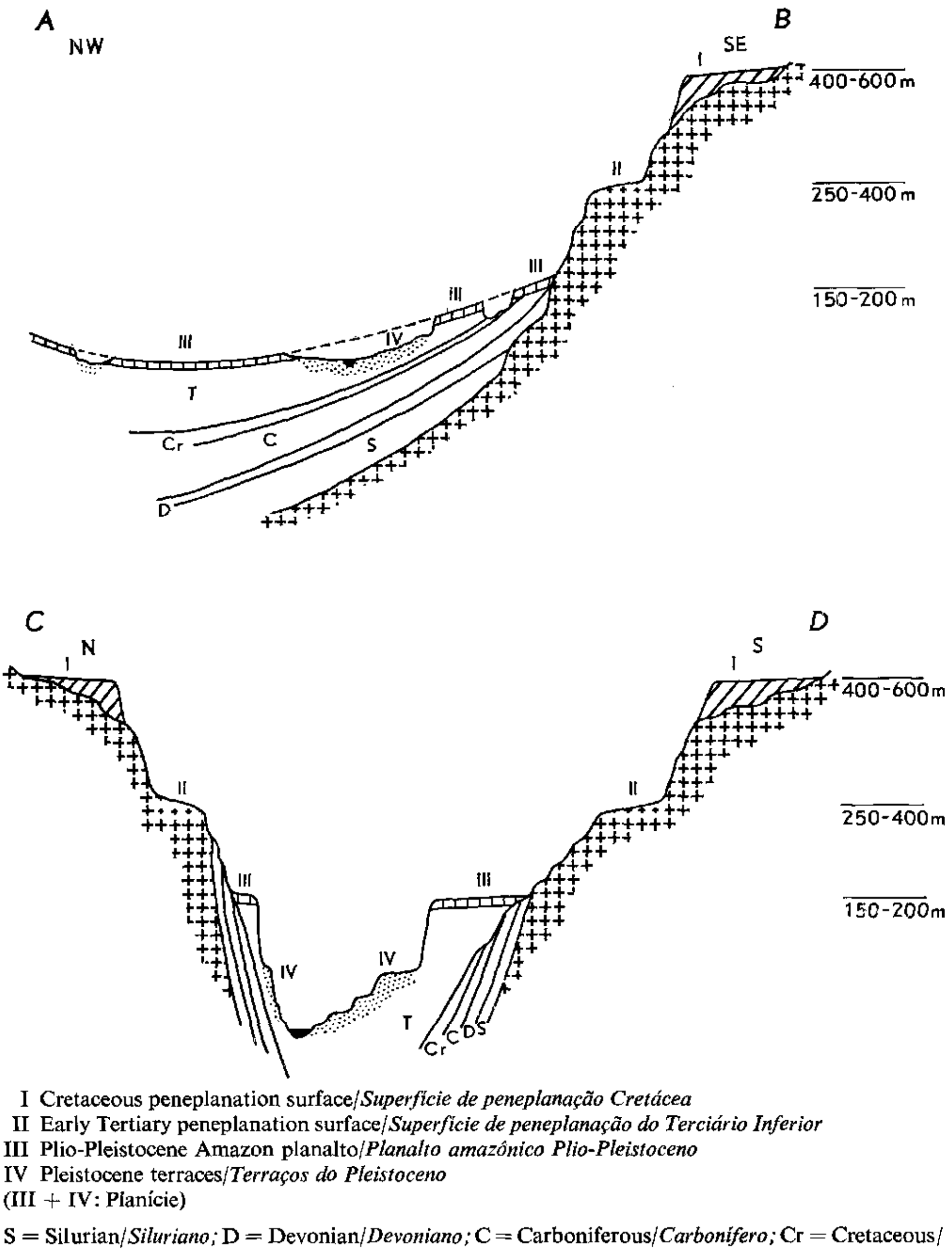
6 Plio-Pleistocene Amazon planalto (broken hatching: subsided) with Belterra clay
Planalto amazônico do Plio-Pleistoceno (sombreamento quebrado: a fundado) com argila de Belterra

7 Pleistocene terraces (6 + 7: Planície)
Terraços do Pleistoceno (6 + 7: Planície)

8 Holocene sediments
Sedimentos do Holoceno

Fig. 8 Sketch showing the formation of the Amazon planalto

Fig. 9 Cortes transversais esquemáticos da Amazônia nos sentidos Nordeste-Sudeste e Norte-Sul respetivamente, demostrando as várias unidades geomorfológicas (para a legenda e a locação dos cortes veja a Fig. 8)



I Cretaceous peneplanation surface/*Superfície de peneplanação Cretácea*
II Early Tertiary peneplanation surface/*Superfície de peneplanação do Terciário Inferior*
III Plio-Pleistocene Amazon planalto/*Planalto amazônico Plio-Pleistoceno*
IV Pleistocene terraces/*Terraços do Pleistoceno*
(III + IV: Planície)

S = Silurian/*Siluriano;* D = Devonian/*Devoniano;* C = Carboniferous/*Carbonífero;* Cr = Cretaceous/*Cretáceo;* T = Tertiary/*Terciário*

Fig. 9 Schematic cross-sections of Amazonia in northeast – southeast direction and north-south directions respectively, showing the various geomorphologic units (for legend and situation of sections see Fig. 8) position of Tertiary (Miocene) sediments of the Barreiras or Alter do Châo beds, and also after the upper stratum of the latter sediments became laterised in at least part of the region. The composition of the Belterra clay and its horizontal and vertical very gradual changes in texture lead to the assumption that this sediment was deposited in a huge, shallow lake or sea bay, and that the flow of suspensed material was in an easterly direction. The tentative conclusion drawn is the following: Kaolinitic, little consolidated deposits uplifted in the Andes region, eroding easily, gave sediments that were spread widely throughout the enormous inland sea or bay that a large part of Amazonia constituted during a time when the sea level was high. The coarsest sediments were laid down in thick layers near the foot of the Cordillera, and the minuscule kaolinitic clay particles were suspended in the bay water. Whilst being borne towards the east these particles were gradually deposited, thus forming a very regular thin blanket on the shallow and flat bottom of the inland sea (see the upper sketch of Fig. 8).

The present altitude of the plateau with the Belterra clay cover is usually 150–200 m in the eastern part of Amazonia. This corresponds approximately with the Calabrian sea level as given in Table 1. The deposition of the clay therefore probably took place in the Pliocene (according to ZEUNER'S classification) or in the Early Pleistocene (according to the classification of WOLDSTEDT). In the western part of Amazonia altitudes are generally lower. There a subsidence must have occurred after deposition of the clay. In the transitional areas between the Amazon trench proper and the crystalline shields a continuing gradual uplift of the shields has affected the altitude of the plateau with Belterra clay. The latter is illustrated in the southern part of the BR-14 cross-section (Appendices 4 and 5).

The non-eroded plateau with Belterra clay cover is referred to in the following as *Amazon planalto.*

As may be seen from the description of occurrence of Belterra clay, there are in the eastern part of Amazonia also terrains with Belterra clay at an altitude considerably lower than the planalto of 150–200 m, namely at 50 to 100 m (Igarapé do Lago; Faro; the western bank of the lower Xingú; near Manaus). These terrains are usually not quite flat and often occur near the main rivers. It is assumed that the clay in these places was re-deposited, with little or no admixture of lighter textured sediments, at these lower levels during the Early Pleistocene (Sicilian and Milazzian sea levels mainly; *cf.* Table 1 and the discussions in I.4.3). A good example of such a terrain is the km 130–km 190 section of the Guamá-Imperatriz area (Appendices 4 and 5). The Belterra clay on such terrains will be referred to in the following as *reworked Belterra clay.*

I.4.3 The Planície. The Pleistocene Terraces

I.4.3.1 *Origin of Terraces*

In the Early Pleistocene the river Amazon and its tributaries originated. They provided for drainage of Amazonia to the Atlantic and started cutting into the Plio-

Table 1 Coastal terraces of Pliocene-Pleistocene-Holocene age (compiled from WOLDSTEDT, *1958 and* ZEUNER, *1959)*

Strand lines *linhas costeiras*	Sea levels (m) *níveis do mar (m)*	Chronology/*cronologia* American *Americano*	West European *Europeio Ocidental* WOLDSTEDT	British *Britânico* ZEUNER
Flandrian/*Flandriana*	0 / +2 *ca.*	Recent	Holocene	Holocene *Holoceno*
		PLEISTOCENE/*Pleistoceno*		
– / Epi Monastirian *Epi-monastiriano*	–100 ? / + 3.5 *ca.*	Wisconsin	Würmian	Last Glaciation *Ultima glaciação*
Late Monastirian *Monastiriano superior* / Main Monastirian *Monastiriano principal*	+ 7.5 *ca.* / +17.5 *ca.*	Sangamon	Rissian-Würmian Interglacial (Eemian)	Last Interglacial *Ultima interglacial*
	–200 ?	Illinoian	Rissian	Penultimate Glaciation *Penúltima glaciação*
Tyrrhenian *Tirreniano*	+30–40	Yarmouth	Mindelian-Rissian Interglacial (Holsteinian)	Great or Penultimate Interglacial *Grande ou penúltima interglacial*
	. . . ?	Kansan	Mindelian	Ante-Penultimate Glaciation *Ante-penúltima glaciação*
Milazzian *Milaziano*	+60 *ca.*	Aftonian	Günzian-Mindelian Interglacial (Cromerian)	Ante-Penultimate Interglacial *Ante-penúltima interglacial*
	. . . ?	Nebrascan	Günzian	Early Glaciation *Primeira glaciação*
				PLIOCENE/*Plioceno*
Sicilian *Siciliano*	+100 *ca.*	Pre-Nebrascan	Danubeian-Günzian Interglacial (Waalian)?	Villafranchian *Vilafranquiano*
	. . . ?		Danubeian	
Calabrian *Calabriano*	+180 *ca.*		Biberian-Danubeian Interglacial (Tiglian)?	
	. . . ?		Biberian?	

Tabela 1 Terraços costeiros de idade Plioceno-Pleistoceno-Holoceno (compilado de WOLDSTEDT, *1958 e* ZEUNER, *1959)*

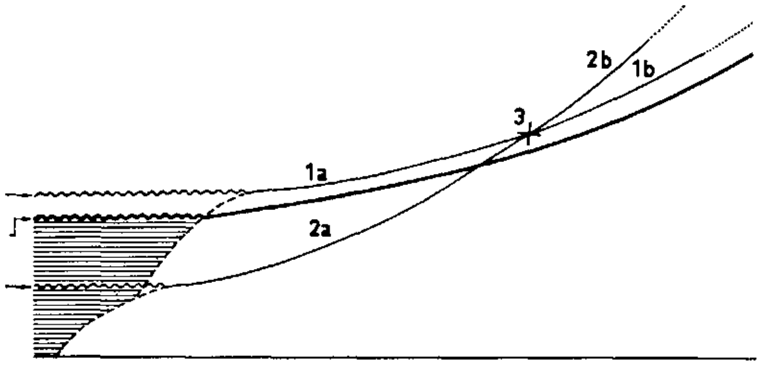
Pleistocene Amazon planalto. Below the level of the planalto, the land was shaped into terraces of various levels above the rivers.

It is generally accepted that during the Pleistocene glacials of Europe and North America the sea level was much lower than today, since much of the world's water was tied up as enormous masses of ice in the polar and subpolar regions. During interglacial ages, on the other hand, the sea level was higher than at present. Comparisons and correlations of ancient strand lines all over the world have been made. Mention is made of the studies of ZEUNER (1959) and WOLDSTEDT (1958) who arrived at several specific heights, which they named. These heights, and their correlation with the various ages of the Pleistocene, are given in Table 1. Many discussions have arisen as to whether or not glacials coincided with pluvials – *i.e.* times with humid climate – in the equatorial and subequatorial regions, and whether interglacials with interpluvials – *i.e.* times with dry climates – in these regions. For Africa and the Middle East much relevant data has been assembled. Many authors have accepted the above mentioned coincidences for these regions, but there are others whose opinions differ. In comparison, little is known for South America. Recently VAN DER HAMMEN and GONZALES (1960) established from pollen analysis at the Sabana de Bogotá that for this region of South America a coincidence of glacials with pluvials exists. WILHELMY (1952) mentions a pluvial, correlated with the last glacial, which would have occurred from Venezuela to Paraná.

The glacio-eustatic oscillations in sea level during the Pleistocene may be traced on ancient strand lines and marine coastal terraces.[1] Oscillations in the sea level cause also changes in the erosion base of rivers. At the same time differences in climate related with these oscillations normally cause differences in discharge and load of the rivers. Lowering of the erosion base of a river (regression time) normally results in entrenchment in its lower course until the river reaches a new equilibrium in its longitudinal profile (graded profile). The surrounding land, the valley bottom, is modelled into a floodplain with the same longitudinal profile. Subsequent raising of the erosion base (transgression time) requires normally another graded longitudinal profile of the river. In that case another, differing floodplain is formed. Along the lower course of the river, sedimentation on the old floodplain takes place normally, whilst more upstream entrenchment of the former floodplain may occur, resulting in terrace formation. In that case, present-day remnants of upstream terrace deposits are possibly of ages with low erosion base of the river – or glacials –, while present-day remnants of downstream terrace deposits are generally of ages with high erosion base – or interglacials. Therefore, terrace levels of different age may cross, at a certain point along the river course ('terrace intersection point', *cf.* scheme of Fig. 10). By means of careful studies, which bear in mind the above factors, it may be possible to trace the changes in sea level not only from coastal terraces, but also from fluviatile terraces as far as these latter have been formed under influence of changes in the erosion base.

[1]) Reference may be made to the study of RUELLAN (1945), who distinguished the following levels in the surrounding of Rio de Janeiro: 80–100 m, 50–65 m, 25–35 m, 15–20 m, less than 15–20 m.

Fig. 10 Conexão possível de terraços fluviais, na situação em que um nível baixo do mar precède um nível alto do mar



1a, 1b Fluviatile terrace deposits of interglacial time
Depósitos de terraço fluvial de época interglacial, nas partes interiores do perfil transversal do vale

2a Buried fluviatile terrace deposits of glacial time
Depósitos de terraço fluvial de época glacial, cobertos

2b Fluviatile terrace deposits of glacial time, at the outer sides of the cross profile of the valley
Depósitos de terraço fluvial de época glacial, no exterior do perfil transversal do vale

3 Terrace intersection point; terrace deposits of glacial and inter-glacial times on the same level
Ponto de intersecção de terraços; depósitos de terraço de épocas glacial e interglacial no mesmo nível

Fig. 10 Possible relationship of fluviatile terraces, with low sea level preceding a high sea level

These studies may be carried out at the different depths of the present burial of the deposits, or at the still present remnants of terraces at different heights on the upland. Conversely, if Pleistocene sea levels are taken as established data, then the age of present coastal and fluviatile terrace deposits may be assessed, which is of importance for discussion of soil genesis.

River surroundings far upstream, above resistant sills in the river course which are well above the highest ancient sea levels, are not affected by changes in the erosion base of the river. Here, the conditioning factors for terrace formation are only the water discharge and the load of the river on the spot. These factors are very much dependent on the climatic conditions. The terraces concerned are 'climatic' fluviatile terraces, in contrast to the fluviatile terraces of rivers downstream that are formed under influence of movements of the sea level ('thalassostatic' terraces in the terminology of ZEUNER, 1959).

It will be shown below that Pleistocene terraces of one kind or another have a great extent in Amazonia. As already mentioned in I.3, the sediments which for geologists are truly Pleistocene are apparently of limited expanse in Amazonia. The changes in the regimes of the rivers during that epoch have in many parts resulted apparently only in the re-working of Tertiary and/or older deposits.

I.4.3.2 *Terrace Levels in the Guamá-Imperatriz Area*

During the reconnaissance soil survey of the Guamá-Imperatriz area it was possible to study in detail the geomorphology of an extensive Tertiary-Pleistocene region, namely along the upper part of the newly opened BR-14 highway, which forms the spine of the survey area, 470 km long. For a considerable part of this section, the data of the constructors (Rodobrás) regarding the original topography of the line of the highway were studied. For the other parts the altitudes given on the kilometre posts were copied, and the height differences between these posts estimated. This permitted the drafting of a slightly schematised cross-section of the traversed terrain (Appendix 4), which was further schematised in Appendix 5. For discussion the stretch is divided into a northern (km 0–195) and a southern half (km 195–415).

The *northern half*, with land-units *Santana*, *Candirú*, *Médio Guamá* and *Alto Guamá*, belongs to the catchment area of the rivers Guamá and Capím. These rivers join at their lower course and make a large curve to the West before they reach their present erosion base in the Baia de Marajó. The *southern half*, with land-units *Cunhantá*, *Gurupí-mirim*, *Planalto* and *Itinga*, belongs to the catchment area of the Gurupí river, which drains in almost straight line into the Atlantic Ocean.

In the *northern half*, the following levels can be distinghuished (very concretionary tops excluded because of their resistance to erosion):

A completely flat terrace, covered with Belterra clay, is present from km 195 on, at an altitude of about 200 m (planalto terrace, *cf.* I.4.2). North of km 195 very gentle undulating terrain – also covered with Belterra clay – is present, which flattens out, in the north, to a terrace of about 100 m altitude. It is found, for instance, around km 120, but only east of the road itself it is conspicuously flat and extensive. Furthermore, a terrace may be discerned at about 65–70 m altitude (km 5 – km 15; km 70–km 90). Remnants of a somewhat lower terrace, of 40–45 m altitude, are also visible, for instance around km 20, km 33 and km 45. All these terraces have specific altitudes and appear to be unrelated to the present day drainage pattern. However, parts of the latter terrace may be, in fact, a terrace related to the present day level of local rivulets, all affluents of the river Guamá. Considered as such, the level of these parts is 20 m +.[1] The terrain directly around km 172 may also represent this terrace level of 20 m +. At varying altitude, but positively related to the present day detailed drainage system is a terrace at 8–10 m +. It is conspicuously present along all the rivulets between km 75 and km 160. Between km 15 and km 75 another well-defined terrace can be distinguished. It is situated in narrow bands along the rivulets, at 3–4 m +. At the same height as the present rivulets the valley bottom exists (várzea or igapó). In summarising it can be said that in the km 0–km 195 section the following terrace levels are present: *200 m altitude; → 100 m altitude; 65–70 m altitude; 30–35 m altitude (20 m +); 8–10 m +; 3–4 m +.*

[1]) With + is meant the height above the high-water level of the local river or rivulet. With 'altitude' (alt.) the height above sea level.

In the *southern half*, the section between km 195 and km 415, the situation is as follows: The completely flat planalto terrace is present at 200–220 m altitude in the northern 100 kms, and gradually increasing in altitude from 220 m to 360 m in the southern 220 kms.[1] The terraces below this have a varying altitude. They are apparently related to the present day level of the local rivulets, all affluents of the river Gurupí. Terrain tops occur at about 70–80 m +, in the stretch km 320–km 405. They are probably the remnants of a terrace at this or a slightly higher level. Another terrace occurs at 30–40 m +. This one is fairly well-defined in the southern part (km 320–km 405), but poorly defined in the northern part (km 195–km 320). In the latter part also a terrace level of about 10 m + may be traced, but this is also fairly poorly defined. Terraces at still lower levels are absent. In summarizing, it can be said that in the km 195–km 415 section the following terraces are present: *200–220 (→ 360) m altitude; 80 m +; 30–40* m *+; 10 m +*.

A tentative correlation will now be given of the established terrace levels in the Guamá-Imperatriz area with past sea level oscillations.

Of the *northern section*, the upper four terraces, with their constant altitude, are most probably marine coastal terraces of which the deposits were laid down during ages with high sea level. The 65–70 m one may be for a part deltaic coastal because on this terrace there was found, in the km 70–km 90 section, a horizontal alternation of light and heavy textured sediments. The three lower terraces are fluviatile terraces. To establish whether the deposits of the latter are of interglacial age (high erosion base) or of glacial age (low erosion base), it should be considered that the river Guamá has at km 0 a rocky bottom, consisting of hard sand stones of probably Paleozoic age, which is exposed at low tides. Owing to the presence of this sill, low sea levels will not themselves have influenced the longitudinal profile of the Guamá and its tributaries above km 0 (all the rivulets that drain to the east). Only sea levels higher than the present one will have permitted deposition of sediments. Therefore, the terrace deposits of the rivulets draining to the east are of interglacial age. For the lower Capím and the Guamá downstream of the confluence of the latter, resistant sills are unknown. Low erosion base deposits might therefore be present along the rivulets that are discharging via the Capím (all those running to the West, between km 60 and km 150). If so, then terrace intersection points, if present, would probably be located upstream of the road, in view of the small gradient of the rivulets from the road on. The Jabotí-maior-at-km-75–Capím–Guamá–Baia de Marajó section has a fall of only 30 m over 340 km. The Ipixuna-at-km-107–Capím–Guamá–Baia de Marajó section has a fall of 35 m over 390 km, and the Candirú-Açú-at-km-145–Capím–Guamá – Baia de Marajó section a fall of 65 m over 420 km. It is therefore probable that also the

[1]) It should be mentioned that the altitudes in the southern half of the BR-14 cross-section are not quite reliable, due to the uncertainty of the altitude of Imperatriz (probably assessed in excess), and the incongruency in the altimetric data for the central part of the stretch, as provided by the Rodobrás survey teams; one working form km 0, one from km 467. The relative heights over short and intermediate distances, however, may be taken as certain.

terrace deposits of the rivulets draining to the West are of ages with high erosion base.

The preliminary conclusion is therefore that all terrace deposits in the km 0 – km 195 section are of ages with high erosion base, or interglacials. Comparing the terrace levels with the established interglacial sea levels (Table 1), a rather striking conformity is found. This leads to a tentative dating of the terrace deposits in the section shown in Table 2.

Table 2 Age of the terraces in the northern part of the Guamá-Imperatriz area

Terrace level (m) and Origin *nível do terraço (m) e origem*	Sediment *sedimento*	High sea levels (m) *níveis do mar altos (m)*	Age *idade*
3–4+ fluviatile/*fluvial*	more or less sandy *mais ou menos arenoso*	3.5 Epi Monastirian *Epi-Monastiriano*	Lower interstadium of Würmian glacial (Wisconsin) *Interstádio inferior da glacial Wurmiana*
8–10+ fluviatile/*fluvial*	more or less sandy *mais ou menos arenoso*	7.5 Late Monastirian *Monastiriano superior*	Upper part of Rissian-Würmian interglacial (Sangamon) *parte superior da interglacial Rissiana-Wurmiana*
(20+) fluviatile/*fluvial*	more or less sandy *mais ou menos arenoso*	18 Main Monastirian *Monastiriano principal*	Lower part of Rissian-Würmian interglacial (Sangamon) *parte inferior da interglacial Rissiana-Wurmiana*
40–50 alt. marine coastal *costeiro marinho*	more or less sandy *mais ou menos arenoso*	32–45 Tyrrhenian *Tirreniano*	Mindelian-Rissian interglacial (Yarmouth) *Interglacial Mindeliana-Rissiana*
65–70 alt. marine coastal or deltaic coastal *costeiro marinho ou deltaico*	more or less sandy *mais ou menos arenoso*	60 Milazzian *Milaziano*	Günzian-Mindelian interglacial (Aftonian) *Interglacial Gunziana-Mindeliana*
→ 100 alt. marine coastal *costeiro marinho*	reworked Belterra clay *argila de Belterra remodelada*	100 *ca.* Sicilian *Siciliano*	Plio-Pleistocene (Pre-Nebrascan) *Plio-Pleistoceno*
200 alt. (planalto terrace) *(terraço de planalto)* marine-lacustrine *marinho-lacustrinho*	Belterra clay *argila de Belterra*	180 Calabrian *Calabriano*	Plio-Pleistocene (Pre-Nebrascan) *Plio-Pleistoceno*

Tabela 2 Idade dos terraços na parte Norte da área Guamá-Imperatriz

For the *southern section* of the Guamá-Imperatriz area (km 195 – km 415), draining to the Gurupí, the situation is as follows: In the lower Gurupí a rocky bottom of Pre-Cambrian age occurs, slightly above present day sea level, hampering navigation during time of low tides in conjunction with low water (GLERUM, 1960). Because of the existence of this resistant sill, low sea levels in themselves will not have influenced the longitudinal profile of the middle and upper Gurupí and its tributary rivulets. Only sea levels above the present one will have permitted deposition of sediments in the upper Gurupí system. Therefore, the deposits of established terraces in the km 195–km 415 section will be of interglacial age. No attempt will be made to date them fully as was done for the km 0–km 195 section, because of an apparent relative raising of the Gurupí head-water region, as is deducible from the position of the planalto terrace there.[1] The height of the terraces above the present rivulets would not have been as high without such a raising. The 30–40 m + and 10 m + terraces of the km 195–km 300 section may be related to the Tyrrhenian and Late Monastirian levels respectively of Table 1.

I.4.3.3 *Terrace Levels throughout the Amazon Valley proper*

Large scale topographic maps with detailed annotation of the contours do not exist for Amazonia. Several early explorers have however, written notes on the levels of the upland along the rivers. In recent years, more systematic studies have been undertaken, for instance by GOUROU (1950) and GUERRA (1954, 1959). Both SAKAMOTO (1960) and VARGAS (1958) attempted to correlate their observations with the various Pleistocene ages. The observations on terrace levels throughout the Amazon valley proper are listed in Table 3. In this table, many of the written notes are combined with personal observations and those deducible from the maps and reports of the FAO/SPVEA Forest Inventory Group. The latter surveyed a broad stretch of land at the south side of the Amazon river, from the river Madeira in Amazonas State to the river Maracassumé in Maranhão State (Fig. 22).

Many difficulties arise in attempting to correlate all the levels mentioned and determine their dependence on past sea level movements.

First of all, the data mainly concern scattered observations only. It is therefore not quite possible to establish whether the terrace level concerned has a constant altitude or follows the river level. If the terrains concern fluviatile terraces, absolute altitudes have little value for our purpose. The same applies to relative heights above the present river level of coastal terraces.

The data themselves are often not very reliable. When altitudes are given, they are estimations in part. If instruments are used, errors of several metres are quite conceivable in view of the vast distances (remarkable are the differences in indicated altitudes for Amazon towns, when comparing several descriptive atlases). When relative heights are given it is not always clear whether they relate to maximum annual high-water or high-tide level, to mean annual high-water or high-tide level, to the

[1]) See note on page 31.

Table 3 Observations on terrace levels throughout the Amazon Valley proper

Location *locação*	Estimated terrace levels (m) *níveis avaliados de terraço (m)*	Source *fonte*
SCATTERED OBSERVATIONS/*observações espalhadas*		
North of Monte Alegre/*ao Norte de Monte Alegre*	80 +	VARGAS (1958)
North of Prainha/*ao Norte de Prainha*	80 +	
North of Óbidos (Serra de Escama)/*ao Norte de Óbidos (Serra de Escama)*	80 +	KATZER (1903)
Guajarina: central course Capim, upper course Mojú, Acará-grande and Acará-mirim/*Guajarina: curso central do Capím, curso superior do Mojú, Acará-grande e Acará-mirím*	100 alt.	HEINSDIJK (1958b)
Tomé-Açú	50 +	VARGAS (1958)
Curuá-una (*cf.* Fig. 11)	(90) +	
Bragantina region/*região Bragantina*	⩽ 60 alt.	
Manaus; along the lower courses of the rivers Negro, Solimões, Tocantins and Madeira/*ao longo dos cursos inferiores dos rios Negro, Solimões, Tocantins e Madeira*	35–40 +	GOUROU (1949)
Santarém *(terraço de Santarém)*	30 +	GOUROU (1949)
Southern part of Canhumá and Maués regions (slightly undulating)/*parte Sul das regiões de Canhumá e Maués (levemente ondulada)*	20–30 +	HEINSDIJK (1958c)
Curuá village (70 km East of Santarém)/*povoação de Curuá (a 70 km ao Leste de Santarém)*	15–20 +	VARGAS (1958)
Marajó island (highest parts), surroundings Belém, Manaus (Ponte Pelada)/*ilha de Marajó (partes mais altas), arredores de Belém, Manaus (Ponte Pelada)*	15–20 +	GOUROU (1949)
Pariçó (Monte Alegre) and Tomé-Açú/*Pariçó (Monte Alegre) e Tomé-Açú*	8 +	VARGAS (1958)
Belém, Icoroací, Gurupá and other places/*Belém, Icoroací, Gurupá e outros lugares*	6–8 +	GOUROU (1949)
Cametá and Parintins, Maués, Codajás, Rosarinho (mouth of the river Madeira), opposite Itacoatiara: the 'Marajó level'/*Cametá e Parintins, Maués, Codajás, Rosarinho (bôca do rio Madeira), em frente de Itacoatiara: o 'nível de Marajó'*	8 +	MARBUT and MANIFOLD (1925)
Northern part of Canhumá and Maués region/*a parte Norte das regiões de Canhumá e de Maués*	5–8 +	HEINSDIJK (1958)
Between the Baia de Pracupí and the Camaraipí (slightly undulating)/*entre a Baia de Pracupí e o Camaraipí (levemente ondulada)*	5 +	HEINSDIJK (1958a)

Table 3 Continued/Tabela 3 Continuado

Location *locação*	Estimated terrace levels (m) *níveis avaliados de terraço (m)*	Source *fonte*
Between the Oeiras and the lower Tocantins (slightly undulating)/*entre o Oeiras e o curso inferior do Tocantins (levemente ondulada)*	4–6 +	HEINSDIJK (1958a)
South of Igarapé-mirím (northwestern part of the Guajarina zone)/*ao Sul de Igarapé-mirím (à parte Noroeste da zona Guajarina)*	5–10 +	HEINSDIJK (1958b)
Narrow strips along the rivers, *e.g.* Santarém; villages on the islands of the Estuary region; along the river Pará; the lowest course of the Tocantins; patches *(tesos)* within the lowland of eastern Marajó island/*faixas estreitas ao longo dos rios, p.e. Santarém; povoações nas ilhas do Estuário; ao longo do rio Pará; o curso inferior do Tocantins; tesos dentro da baixada do Leste da ilha de Marajó*	1–4 +	
Marajó (4 levels; if taken on local high-water level these heights are less)/*Marajó (4 níveis; caso de serem determinados em nível de enchente local, estas alturas são menores)*	20 alt. 15–16 alt. 10–12 alt. 4 alt.	GUERRA (1959)
Amapá Territory (upland banks along the Amazon and the Ocean coast)/*Território do Amapá (falésias ao longo do Amazonas e na costa do Oceano)*	4–7 +	GUERRA (1954)
TOPOGRAPHIC STUDIES OF COHERENT LARGE AREAS/ *estudos topográficos de vastas áreas coerentes*		
Caeté-Maracassumé area (*cf.* Fig. 19)		DAY (1959)
Maracassumé association (3 levels)/ *associação de Maracassumé (3 níveis)*	10–15 +; 5–8 +; 1–3 +	
Pitoró association (3 levels)/ *associação de Pitoró (3 níveis)*	10 + (partly to 15 +); 1–2 +; one in-between *[um entre êstes*	
Gurupí association/*associação de Gurupí*	2–5 +	
North of Pitoró (an 'old relatively high terrace', also existing in the map unit 'Agricultural Soils, undifferentiated')/*ao Norte de Pitoró (um 'terraço velho relativamente alto', que também existe na unidade de mapeamento 'Solos Agrícolas, indiferenciados')*	30 +	
Savannah region north of Macapá/*região dos campos ao Norte de Macapá*	80–100, 50–65, 25–35, 10–15, 5–7 alt.	GUERRA (1954)
Manaus and surroundings/*Manaus e arredores*	58 +, 31 +, 6 +	SOARES (1956), data of RUELLAN/*dados de* RUELLAN

Tabela 3 Observações sobre níveis de terraço de todo o vale amazônico pròpriamente dito

floodplain level, or to the annual low-water or low-tide level. Upstream, the differences between the annual high and low-water levels may be enormous (the mean difference at Manaus is 11 m). Differences between high-tide and low-tide level are *often several metres in the Estuary region (2–3 m in the Baia de Marajó).*

Another difficulty lies in the possibility of raising or subsidence of areas during the Quaternary. In the Estuary region one may expect a tendency for the terraces to drown, owing to the existence of the Marajó Graben (*cf.* I.4.1). In the Upper Amazon region a general gradual Quaternary subsidence is probable, in view of the low position of the planalto terrace in this region (*cf.* I.4.2). If not subject to general subsidence, the Middle and the Lower Amazon region have probably experienced local vertical movements (*cf.* SOARES, 1956; SIOLI, 1957). STERNBERG (1950) assumed the existence of minor faults from the pattern of drainage around Manaus.

The strikingly low level of the floodplain, and the abundance of lakes, in the Itacoatiara-Oroximiná area may be due to some special subsidence in this part. On the edges of the crystalline shields a tendency to gradual raising may exist, as illustrated on the southernmost part of the Guamá-Imperatriz area.

As explained above, the question of the interglaciality or glaciality of fluviatile terraces deposits and the possible crossing of terrace levels at some spot along the longitudinal profile of the river, has to be taken into account as well.

At present, the longitudinal profile of the Amazon river proper is extremely flat. Entering Brazil, 3000 km from the Atlantic Ocean, the river has an altitude of only 65 m. At Manaus, 1500 km from the Ocean, the altitude of the river is 15 m during the low-water season. Consequently, tidal differences are detectable to beyond Santarém, about 700 km from the Ocean. In view of the assumed gradual subsidence of the central part of Amazonas State, the longitudinal river profile was probably less flat during the Pleistocene. The difference however will not surpass 100 m (which is the estimated difference in altitude between the planalto terrace in Pará and that in the central part of Amazonas State) for the oldest part of the Pleistocene. The entire Brazilian part, therefore, belongs to the flatter lower part of the longitudinal profile of the river, where fluviatile terrace deposits are liable to be of ages with high erosion base, *i.e.* the interglacials.

Additional support for the interglaciality of the river terrace deposits is given by the existence of *rias*. This is the name for the strikingly wide, funnel-like mouths of many of the tributaries of the Amazon river, for instance the Tocantins, the Xingú, the Tapajós, the Rio Negro, the Trombetas. Several of these mouths are very deep, for instance that of the Tapajós (80 m –). An adequate explanation of the existence of the *rias* is that they were excavated during the last glacial (the Wisconsin, Wurmian), when the sea level dropped to 70–100 m below the present-day one (Table 1). The erosion base of the tributaries, *i.e.* the bed of the Amazon proper, also will have been much lower during that age. Due to the very restricted load of several of the tributaries in Holocene times, contrary to that of the Amazon proper, these excavated mouths are only partly silted up (SOARES, 1956; SIOLI, 1957; SAKAMOTO, 1960). Having been so many tens of metres lower, the Amazon cannot have left glacial deposits above its present level.

As yet, the data available on fluviatile terrace levels are not systematic and reliable enough to correlate and date them fully, in relation to the Pleistocene high sea levels. VARGAS (1958) made an attempt, but it is thought that both his grouping of levels and their dating are not quite correct. He assumed the highest levels, those of 80–50 m +, to be of Yarmouth age, and the lower ones, those of 20–30 m + and of 4–10 m +, to be of the two sub-phases of the Sangamon age. Only MARBUT and MANIFOLD's 'Marajó level' (8 m +) seems to be certain, and widespread. These authors report this level to extend as far as the mouth of the Japurá on the Solimões, and Borba on the Madeira. The Marajó level is most probably identifiable with the Late Monastirian phase of Table 1.[1])

It is likely that a large proportion of the terraces in the Estuary region and along the Ocean coast are marine coastal or deltaic coastal. This is certainly the case for at least the upper ones of GUERRA's terraces of the savannah region of Amapá Territory.

It is not yet possible to draw the geographic boundary between coastal and fluviatile terraces.

The Plio-Pleistocene Amazon planalto and the Pleistocene terraces of the Amazon valley proper will be referred to as *Planície* when considered in conjunction.

I.4.3.4 *Terrace Levels in Relatively High Situated Areas*

Very few data are available on the occurrence of Pleistocene fluviatile terraces in areas situated well above the highest Pleistocene sea levels, and separated from the lower course of rivers by erosion resistant sills.

On the latest geologic map of Brazil (LAMEGO, 1960), extensive areas of Pleistocene deposits are mapped in the region of the upper Xingú and along the Araguaia. During the reconnaissance soil survey of the Araguaia Mahogany area, large tracts of flat land were found at a level of 5–10 m above local rivers and rivulets. They are composed of very sandy sediments and are fully under forest cover (*cf.* Appendix 6, soil mapping unit KLS, F). There can be little doubt that a Pleistocene terrace is concerned. The whole survey area is located at 150 to 300 m altitude, separated from the Amazon valley proper by a long chain of rapids, both in the Araguaia river itself, and in the Tocantins river below the confluence of the Araguaia. Hence Pleistocene sea level movements cannot themselves have exerted an influence on the formation of the terrace. The terrace is probably a 'climatic' fluviatile terrace. The sediments must have deposited under a river regime that favoured deposition of coarse textured sediments over large expanses. This will have been possible only if the protecting forest cover in the region was absent, which indicates a relatively dry climate. The terrace material

[1]) SOARES (1956) refers to an unedited conference of RUELLAN in 1954 at Riberão Preto, in which the latter links terraces at 80–100 m, 50–65 m, 25–35 m, 18–20 m, 8 m and 4 m, in the vicinity of Marajó and Belém with the *Bas Monastirien* and the *Pré-Flandrien* of Europe.

therefore will have been deposited during, or at the end of, an interpluvial, when there was not enough rainfall to sustain forest growth, but torrential masses of water occurred during the wet season, which fiercely eroded uplands further upstream and deposited the coarse fraction of the erosion products in the area under discussion.

I.4.4 The Holocene Terrains

Next to the uplands of Pleistocene age, there are also, in a limited area within the Middle and Lower Amazon regions, terrains only slightly above normal high-water level (1–2 m +), which have clayey and reddish mottled soil. These *massapés* are found, for instance, on the savannah areas between Oroximiná and Faro (SUTMÖLLER *et al.*, 1963). VARGAS (1958) reports their existence around Parentins and Barreirinhas. The terrains are not recent, if only because the soils are fairly strongly weathered (compare Profile 3 of II.3.2). Already VARGAS (1958) suggested that these clays were deposited in a time between the deposition of the Pleistocene uplands and that of the recent floodplain. They are assumed to have been laid down during the Atlantic age of the Holocene, when the sea level was relatively high (Flandrian, Table 1).

The lowlands of eastern Marajó island are probably also of Early Holocene age, because they consist of sub-recent deltaic sediments. This can be deduced from the patterns of recent and ancient drainage, the meso-relief, and the soil characteristics on these terrains (see the section of an aerial photograph in SUTMÖLLER *et al.*, 1963, and SOMBROEK, 1962b).

The floodplains and the valley bottoms are certainly of Holocene age. They are commonly divided into two groups: the *várzeas* and the *igapós*. Although the literature concerned is not quite unanimous, they may be defined as follows: The *várzea* is lowland that is intermittently waterlogged, while the *igapó* is lowland that is permanently waterlogged. Defined as such, the former is found usually on extensive lowland areas, and the latter usually near or within upland areas. The várzeas may be subdivided according to the character of the variation of the water level and the quality of the water, namely:

1. Lowlands, along rivers, where the variation in water level is due to differences within the year of the river discharge *(várzea do rio)*.
2. Lowlands, away from rivers, where the variation in water level is due to differences within the year of the rainfall *(várzea da chuva)*.
3. Lowlands, in the Estuary region, where fresh water tides cause the variation in the water level *(várzea do maré)*.
4. Lowlands, along the Ocean coast, where sea or brackish water tides cause the variation in water level *(várzea do mar)*.

The várzeas are predominantly heavy textured (silts, silty clays, clays), the igapós often peaty. Together with the massapés and the lowlands of eastern Marajó, the floodplains are therefore strikingly different in their sedimental composition from the Pleistocene uplands in eastern Amazonia. The latter contain coarse sandy, and in several places, even stony elements.

The floodplains have the customary pattern of river basin lands (back swamps or *várzeas baixas*) and levees (river ridges or *várzeas altas*). The latter are sometimes very narrow and then often run parallel (point bars or *restingas*). Elevated floodplains that are almost well-drained are rare. They have been found only along the upper Madeira and along the lower Araguaia. This scarcity is related to the fact that at present the load of the Amazon river system is small (*cf.* LECOINTE, 1945), although with the enormous water discharge the total amount is enormous (SOARES, 1956). Several tributaries are practically without load, for instance the Rio Negro and the Tapajós. These are rivers of humic acids containing black water *(rio de água preta)*, or clear greenish or bluish water *(rio de água limpa)*. In contrast, rivers such as the Amazon proper and the Madeira which have a considerable load of sediments and are therefore turbid, are often called rivers of white or yellowish brown water *(rio de água branca)*; SIOLI (1951, 1956).

I.4.5 Levels of Occurrence of Fossil Plinthite (Laterite). Its Grouping and Its Dating

Throughout Amazonia, and especially in the eastern part, layers of reddish, iron-rich stony material can be found. They occur at varying altitudes and heights above local river levels, and are often accompanied by layers of highly reddish mottled, compact and soft material. Both materials are known as *laterite*, and more recently as *plinthite*. The origin of the Amazon plinthite will be discussed in II.3. The material is considered to be the result of the accumulation and segregation of Fe (and Al) largely in subsoil horizons under influence of intermittently imperfect drainage. In the same chapter it will be considered how to decide whether such plinthite is still in formation or is of fossil character. Also, if the latter is the case, whether it originated *in situ* or was carried along, colluvially or alluvially, from other places.

With this in mind, the study of fossil hard and fossil soft plinthite may help to form a picture of former land surfaces and climatic conditions. This is dealt with in the present sub chapter.

I.4.5.1 *Fossil Plinthite in the Guamá-Imperatriz Area*

The situation of Amazon fossil plinthite was studied in detail in the Guamá-Imperatriz survey area, namely on the BR-14 highway proper, which had many deep and fresh road cuts and of which a complete cross-section was available (Appendix 4). In this area, five main types of concretionary elements of hard plinthite were distinguished, each with a certain establishable area of occurrence[1]. The distinctions

[1]) not included are the very small plinthite concretions ('shot') found in small quantities in a few soil profiles just above a non-plinthitic B horizon (*cf.* Profile 38, III.2). They are apparently of recent age.

between the types were only made according to morphological field characteristics, since no laboratory analyses are available on relative contents of elements as Fe, Al, Mn and Ti, and on the form in which these elements occur. The names employed are taken from local settlements. The types are listed in Table 4 (see also Photo 2):

Table 4 The five main types of concretionary elements of hard plinthite in the Guamá-Imperatriz area

Name/*nome*	MÃE DO RIO	IPIXUNA	PARAGOMINAS	LIGAÇÃO	CAMPINHO
Size of elements (diameter)	small to very large (0.5–50 cm)	medium (2–10 cm)	very small (0.5–2 cm)	medium (2–10 cm)	rather small (0.5–5 cm)
tamanho dos elementos (diámetro)	*pequeno até muito grande (0.5–50 cm)*	*médio (2–10 cm)*	*muito pequeno (0.5–2 cm)*	*médio (2–10 cm)*	*bastante pequeno (0.5–5 cm)*
Form of elements	platy, angular or subangular blocky, or prismatic reticulate	prismatic to reticulate	subangular blocky	irregular blocky, usually subangular	irregular subangular blocky to prismatic
forma dos elementos	*laminar, em blocos angulares ou subangulares, ou reticular-prismático*	*prismático até reticular*	*em blôcos subangulares*	*em blôcos irregulares, usualmente subangular*	*em blôcos subangulares até prismático, irregularmente*
Grainage	fine to very coarse ('iron-cemented quartzite')	fine, with scattered medium sized quartz grains	fine	medium	usually fine
granulação	*fino até muito grosso ('quartzito cimentado de ferro')*	*fino com grãos dispersos de quartzo de tamanho médio*	*fino*	*médio*	*usualmente fino*
Colour	red, dusky red or black	red and light red	dusky red	black or very dusky red	dusky red
côr	*vermelho, vermelho escuro ou preto*	*vermelho e vermelho claro*	*vermelho escuro*	*preto ou vermelho muito escuro*	*vermelho escuro*
Arrangement (if not displaced)	usually horizontal	vertical	not specific	not specific	not specific
arranjo (caso de não ser deslocado)	*usualmente horizontal*	*vertical*	*não especificado*	*não especificado*	*não especificado*

Tabela 4 Os cinco tipos principais de elementos concrecionários de 'plinthite' duro da área Guamá-Imperatriz

For discussion, it is proposed to divide the studied section into the northern and the southern half.

Foto 2 Os principais tipos de elementos concrecionários de 'plinthite' duro da área Guamá-Imperatriz

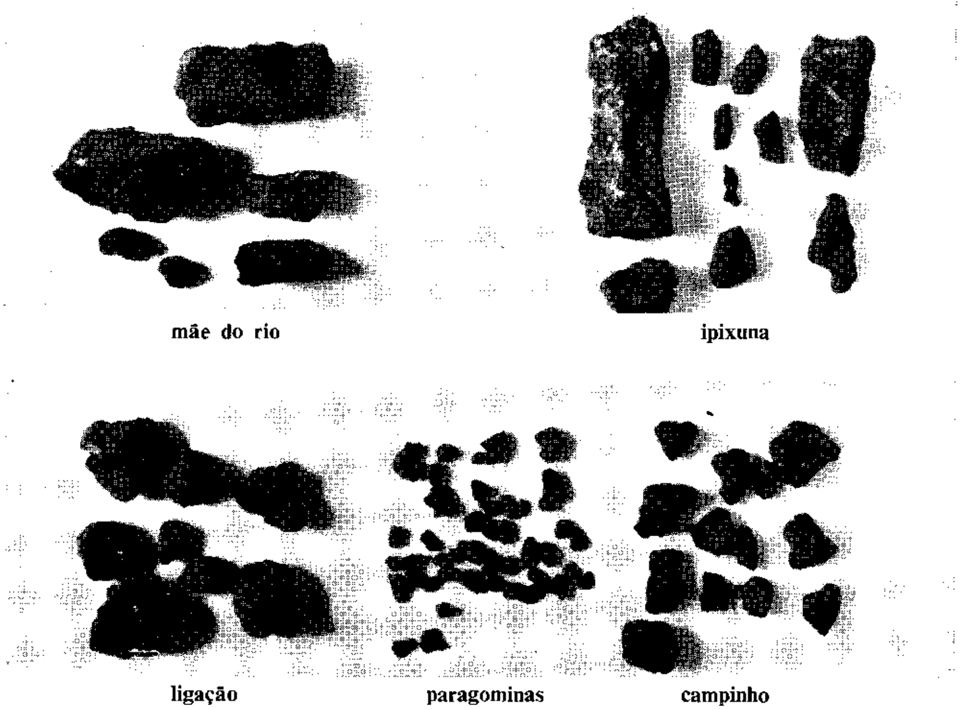


Photo 2 The main types of concretionary elements of hard plinthite of the Guamá-Imperatriz area

NORTHERN HALF

In the northern half, km 0–km 195, three types of plinthite concretions are found, namely the *Mãe do Rio*, the *Ipixuna* and the *Paragominas* type.

Mãe do Rio type concretions are present only north of km 78. The concretions form almost everywhere a layer of about 1 m thickness, and have a horizontal arrangement in the lower part of this layer. Below this, soft plinthite occurs, to which the transition is gradual, and which has predominantly a laminar pattern (Photo 15). The concretionary layer is commonly overlain by a layer of fairly sandy sediments without concretions. In the latter layer no 'pedologic' A_2 horizon, immediately above the concretionary zone, can be distinguished.

It may be concluded that the concretions were formed *in situ*. A former Ground Water Laterite soil profile must be concerned which was truncated and afterwards buried with sediments. The latter, in their turn, were stripped off in several parts. The topographic data of the cross-section indicate that the upper level of the concretions is at about 65–70 m altitude.

Ipixuna type concretions occur mainly between km 75 and km 150. They form a layer of 0.5–1 m thickness, and have a vertical arrangement in the lower part. This layer is underlain by a thick layer (up to 10 m) of soft plinthite, to which the transition is gradual. The soft plinthite has a coarse reticulate to prismatic-tubular pattern. The concretions are often outcropping, but locally are overlain by a thin (less than 5 m) layer of sediments without concretions, in most places of very heavy texture (reworked Belterra clay). In this sedimentary cover no 'pedologic' A_2 horizon, immediately above the concretions, can be discerned (Photo 18). It may be concluded that the concretions were formed *in situ*, and that a former Ground Water Laterite soil profile is concerned. This profile was truncated and soon afterwards buried with Belterra clay. The latter, in its turn, was stripped off in many places. An exception has to be made for a few stone-lines of the concretions, which are found in the sediments of a relatively young terrace in the section concerned (Photo 3). These will be of colluvial-alluvial origin. The stone-lines occur at varying depth and may therefore be designated as 'geologic stone-lines'.

Foto 3 Concreções do tipo Ipixuna que parcialmente cobrem 'plinthite' macio e parcialmente formam linhas de pedra em terra friável e não mosqueada. As concreções das linhas de pedra são depósitos aluvianos ou coluvianos. As concreções à esquerda, porém, originaram-se principalmente in situ de 'plinthite' macio anterior acima do 'plinthite' macio atual (abaixo à esquerda). É provável que ocorreu algum movimento lateral destas concreções, vista a delimitação bastante pronunciada entre as concreções e o 'plinthite' macio (BR-14, km 125)

Photo 3 Ipixuna-type concretions, partly capping soft plinthite, partly forming stone-lines in unmottled, friable earth. The concretions of the stone-lines were deposited alluvially or colluvially. The concretions at left, however, mainly originated in situ *from former soft plinthite on top of the present soft plinthite (bottom left). Some lateral movement of the latter concretions is likely to have taken place owing to the fairly sharp boundary between the concretions and the soft plinthite (BR-14, km 125)*

In a few places both Ipixuna type and Mãe do Rio type concretions occur (km 78, km 63, km 30). There, the Ipixuna type always overlies the Mãe do Rio type, and is sometimes vertically separated from it by soft plinthite. This indicates that Ipixuna type concretions originated in a less ancient time than the other type.

The upper level of Ipixuna type concretions is at about 75 m altitude at km 78, gradually increasing to 190 m altitude at km 195.

Paragominas type concretions are found predominantly south of km 150, although they have a scattered occurrence north of this (thin layers – less than 0.5 m thick – above the Ipixuna type; usually not indicated in the cross-section). These concretions form a layer of 0.5–1.0 m thickness. This layer is usually underlain by soft plinthite, to which the transition is gradual in most places. The soft plinthite is present only in thin layers – generally less than 5 m – and has a fine reticulate pattern. The Paragominas concretions are partly outcropping, partly overlain by Belterra clay. In the latter case no 'pedologic' A_2, immediately above the concretionary zone, can be discerned.

The Paragominas concretions may therefore be taken to have predominantly originated *in situ*.

At places where the Paragominas and the Ipixuna type concretions occur together (for instance at km 171, km 194), the former overlie the latter, indicating that the Paragominas ones are of later date.

The Paragominas type concretions are believed to have originated mainly *within* the Belterra clay. Their size and form is similar to the structural elements of the clay. Recent reddish mottling (*i.e.* the pre-stage of concretions) in the Belterra clay is related to these structural elements, by being fine spotty or fine reticulate. This type of mottling is found in a few places above the layer of Ipixuna concretions, and very distinctly in the B horizon of present Ground Water Laterite soil profiles in Belterra clay (*cf.* Profile 8 in II.3.2.1). In fact, transitions between Belterra clay mottling and the loose Paragominas concretions are found at several places.

The position and the form of the Ipixuna type concretions lead us to assume that they did not originate in Belterra clay, but in the upper layers of the planalto base material (medium to heavy textured sediments of the Barreiras or Alter do Châo beds).

The upper level of the Paragominas concretions is varying. Where they are not underlain by Ipixuna type concretions, the level is between 110 and 170 m altitude, 30–50 m above local river level.

SOUTHERN HALF

In the southern half of the stretch, between km 195–km 467, *Ipixuna*, *Ligação*, *Campinho* and *Paragominas* concretions are found. In general, the amount of concretions and soft plinthite is much less than in the northern stretch.

Ipixuna type concretions are outcropping at the planalto scarps in the km 195–

–km 250 section[1]. They occur immediately below the Belterra clay, at about 10 m below the level of the central sections of planalto. They are found in layers of 2–3 m thickness, and are underlain by their soft plinthite (see under northern section). It may be concluded that they were formed *in situ.*

South of km 250, *Ligação* type concretions are found at the scarps of planalto,[1] also immediately below the Belterra clay, at about 20 m below the level of the flat central sections. These concretions, forming a layer of 1–2 m thickness or less, are not underlain by soft plinthite (except at a few spots around km 270 and km 405), but by uniformly reddish coloured sediments of sandy clay loam to sandy clay texture. Normally the boundary is sharp (Photo 4). The Ligação concretions are more or less rounded, and have no pattern of arrangement. It is therefore concluded that the Ligação concretions are of alluvial (fluviatile) origin in most places.

The level of the Ipixuna or Ligação type of concretions is increasing gradually from north to south, together with the surface of the planalto terrace. At km 195 the altitude[2] is 190 m, at km 412 it is 330 m.

Paragominas type concretions are found scattered. Sometimes they occur in thin layers just above the Ipixuna or Ligação types at the planalto scarps, where they are without soft plinthite. At lower levels Paragominas type concretions may form thicker layers, and are then in some places underlain by their soft plinthite (see under northern section). At these latter places, for instance at km 269, they were certainly formed *in situ.*

Concretions of various types are found collectively on several slopes and terrain tops, below the level of the planalto terrace (Ipixuna + Paragominas; Ligação + Paragominas). At these places the concretions are very mixed. They may occur in a scattered pattern in the sedimentary layers, but more often they are concentrated in thin layers (0.5 m) at the transition zone from the yellowish A horizon to the red B horizon of the soil profiles (most probably they are concentrated there under influence of soil biological activity, and may therefore be designated as 'biotic stone-lines'). Soft plinthite is lacking. There is every indication that colluvia-alluvia from the planalto scarps are involved.

In the stretches km 195–km 220 and km 250–km 260 concretions of the *Campinho* type are found. They are partly outcropping, partly covered by sediments that are usually of sandy clay loam texture. These concretions form layers of about 0.5 m thickness and, according to a limited number of observations, they are underlain by

[1]) The concretions and the soft plinthite are not confined only to the scarps. At several deep road cuts it was established that both plinthite layers continue horizontally towards the central sections of planalto. There are, however, indications that the layer of soft plinthite has its greatest thickness near the scarps. It also seems that the Paragominas concretions, when occurring on top of the Ipixuna or Ligação types, are concentrated at the scarps.
[2]) See, however, note at page 31.

Foto 4 Concreções do tipo Ligação que cobrem terra não mosqueada e friável. A ausência de qualquer 'plinthite' macio, a delimitação inferior pronunciada e irregular da capa de 'plinthite' duro, a forma sub-angular dos mesmos elementos concrecionários e a ausência de qualquer arranjo dêstes elementos, em conjunto indicam que a capa de 'plinthite' duro não foi formada in situ, mas é de origem aluvial (BR-14, km 370 m. ou m.)

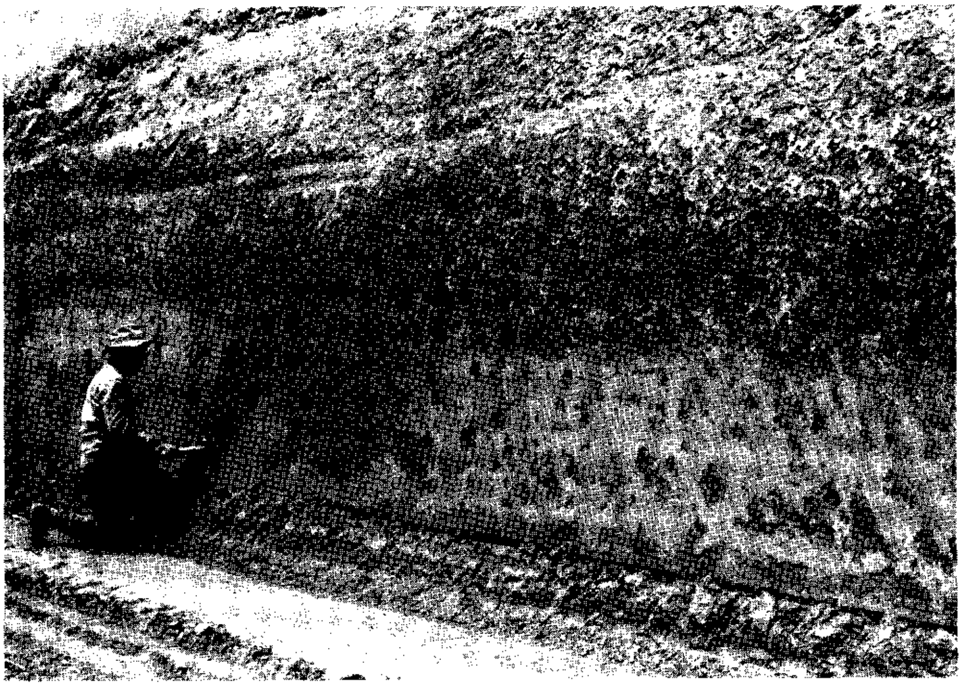


Photo 4 Ligação type of concretions capping unmottled, friable earth. The absence of any soft plinthite, the sharp and irregular lower boundary of the layer of hard plinthite, the subrounded form of the concretionary elements themselves, and the absence of any arrangement of these elements, together indicate that the layer of hard plinthite was not formed in situ, *but is of alluvial origin (BR-14, km 370 ca.)*

soft plinthite of only 1–2 m thick. It may be assumed that the Campinho type was formed *in situ* and is the relic of a Ground Water Laterite soil on a land surface that was at about 30 m above the present local river level.

South of km 415, concretions are sparse. They are of varying type (at several places platy, similar to the Mãe do Rio type of the northernmost stretch), and may grade into some soft plinthite. The observations made in this section are however too limited to warrant deductions as to the origin and level of the concretions.

An attempt will now be made to relate the different types of fossil plinthite with times of Ground Water Laterite soil formation, *i.e.* with the former existence of approximately flat land surfaces with intermittently imperfect drainage. The scarcity of reliable data on the surface geology in this region of unconsolidated sediments, is a serious drawback. There are, however, a few geological notes on outcropping older deposits at the extreme north and south sides of the part of the BR-14 studied[1]. Personal observations on the characteristics of the substratum were made at deep road cuts, and there are the conclusions about the age of terrace deposits (*cf.* I.4.3.2). These together enable a sketch to be made of the geologic-geomorphologic genesis of the region. This is done in Appendix 5, from which the age of the fossil plinthite may be established as follows:

After deposition during the Miocene of quartz sands and kaolinitic clays of the Barreiras or Alter do Châo beds, a time of stability existed, when neither sedimentation nor erosion took place. During this time, an approximately flat land surface, which would be nowadays at 65 to 70 m altitude, permitted Ground Water Laterite soil formation in the northernmost part of the area (km 0–km 70) because of imperfect drainage of the surface. This was followed by a time of erosion during which these profiles were truncated. The Mãe do Rio type concretions originated by hardening of the soft plinthite at the surface: *Late Miocene (?)*. There are indications, for instance at km 30, that the Mãe do Rio concretions are the relics of at least two, superimposed, Ground Water Laterite soil profiles. This would indicate the existence of more than one time with imperfect drainage of former land surfaces before, or at the beginning of, the Pliocene. Such a situation would also account for the variability in the characteristics of the Mãe do Rio concretions.

After this truncation a new deposition of sediments took place, similar to those described above, during a transgression time: *Pliocene* (?).

Subsequently, there was another time of neither sedimentation nor erosion, but soil formation. Imperfect drainage of an approximately flat land surface (which would be nowadays at varying altitude; generally increasing from north to south: 70 m altitude at km 80, 120 m at km 145, 145 m at km 195, 320 m at km 405) resulted in formation of Ground Water Laterite soil profiles in the part km 70–km 300, and possibly around km 400. This was followed by an erosive time (probably short, because of the flatness of the concretionary layer), during which truncation of these profiles and formation of Ipixuna and Ligação concretions took place. At the same time, the land surface in the section between km 300 and km 400 was covered with alluvial Ligação concretions: *Late Pliocene (?)*.

This was followed by a regression time, during which in several parts all the concretionary land surface was stripped off, especially in the km 150–km 195 section (Alto Guamá): *Late Pliocene* or *Earliest Pleistocene: Biberian (?)*.

A new transgression time, with lacustrine – marine conditions, caused the deposition all over the area of very heavy textured sediments (Belterra clay) in a thin layer (20 m thick at km 400, 10 m thick at km 200): *Plio-Pleistocene (Calabrian); cf.* I.4.2.

Subsequently, a regression time caused strong erosion, resulting in a landscape of table lands (the present day sections of planalto terrace). This erosion was most

1) For details *cf.* Sombroek (1962a).

pronounced in the central and southern parts of the area. The sharp edges are due to the presence of the erosion resistant layer of concretions. The same erosion gave gentle undulating terrains in the stretch km 150–km 195 (Alto Guamá) where this resistant layer was largely absent: *Early Pleistocene: Danubeian (?).*

Renewed raising of the general erosion base resulted in flattening of the Belterra clay covered land surface until it became a terrace of about 100 m altitude (re-worked Belterra clay): *Sicilian level of Early Pleistocene; cf.* I.4.3.2, Table 2).

Resumed erosion during a regression time hereafter resulted in sharpening of the table land feature of the general landscape: *glacial age* of *Pleistocene: Nebrascan (?).*

Alternating transgression and regression times during various interglacials and glacials of the Pleistocene followed. During the transgressions, sedimentation took place at various levels (*cf.* I.4.3.2).

In one of these ages, possibly the *Yarmouth interglacial*, a short time of stability existed during which a land surface with imperfect drainage in the stretch km 200–km 260, which would be nowadays at about 30 m above the local drainage system, gave Ground Water Laterite soil formation. These profiles, after truncation by a subsequent erosion, resulted in Campinho type concretions.[1] At the same time, or shortly before, the main part of the Ground Water Laterite soil profiles that gave Paragominas concretions, developed, predominantly in the stretch km 150–km 195, at a level 30–50 m above the present day local river level. The age of the latter type is, however, difficult to assess as a whole, because it is found in some places also immediately above the Ipixuna or Ligação concretions at the scarp of unattacked sections of planalto. For these, *Plio-Pleistocene* age seems plausible. On the other hand, the Paragominas concretions appear to be formed in present times too, as pointed out before.

Summarising, it may be said that a large proportion of the fossil plinthite in the Guamá-Imperatriz area was formed *in situ*, during and after at least two epochs of the Late Tertiary (Miocene and Pliocene) with approximately flat land surfaces of imperfect drainage. During a part of the Pleistocene plinthite of limited expanse was produced.

I.4.5.2 *Fossil Plinthite throughout Amazonia*

The classification and dating of the fossil hard plinthite elsewhere in the region requires further research. For full comparison with the situation in the Guamá-Imperatriz area, it would also be necessary to use laboratory data on fossil plinthite as a means of identification. Provisionally the following may be said:

[1]) Their formation during a time of the Early Tertiary or even of the Late Cretaceous might be considered. This old age is however more likely to be true for the blocks of 'iron cemented quartzite' that are encountered on a few places in the stretch km 195 km – 220, but not along the highway itself. Should this be the case, comparable fossil plinthite would occur deep down (about 100 m) under the sections of planalto terrace. This could not be checked.

1. The fossil plinthite situation in the *region southeast of Santarém* was studied to some extent. For Curuá-una centre, the data of the road from the river to the planalto are given in Fig. 11. Concretionary elements are outcropping at the scarp of planalto. This hard plinthite is found immediately below a 15 m thick cover of Belterra clay. The layer is about 1 m thick, and has in many places a gradual transition to underlying soft plinthite, 1–2 m thick. The concretions are of a type very similar to the Ipixuna type of the Guamá-Imperatriz area. Their arrangement is vertical in the lower part, sometimes strikingly disturbed in the upper part of the layer. Immediately above the Ipixuna-like concretions, namely in the lowest part of the layer of Belterra clay, a thin layer (about 0.5 m) of concretions resembling the Paragominas type are found. On the lower slope of the planalto escarpment, Ipixuna-like concretions are also present, but in thin, irregular, superficial layers. These are without soft plinthite, being underlain by homogeneous reddish, unconsolidated sandy sediments (planalto base material, Barreiras or Alter do Châo beds).

Throughout the length of the road before the planalto escarpment, plinthite is completely absent in any of its forms. Only in close proximity of km 0 a degree of plinthitic material is found. At an upper level of about 16 m above the river level, a superficial layer of hard plinthite of about 1 m thickness is present. The concretionary elements are resembling more or less the Campinho type concretions of the Guamá-Imperatriz area. The concretionary layer has a gradual transition to a layer of underlying soft plinthite, which is 1.5 m or more thick and has a fine reticulate pattern of mottling. Nearby, but at a lower level, namely 9 m above local river level, also concretions are found at the surface, however of quite another type. They resemble portions of the Mãe do Rio type of the Guamá-Imperatriz area. No arrangement was observed. Whether they are underlain by soft plinthite or not, was not established.

It may be concluded that the Ipixuna-like concretions at the upper planalto scarp were formed *in situ*, and are probably of Late Pliocene age. Those at the lower slope are colluvial. The Campinho-like concretions near the river were formed also *in situ*, possibly during some time of the Pleistocene. Their formation at this spot may be due to an impervious substratum of older concretions, that possibly were formed – or deposited – there at some time of the Tertiary, before the Pliocene.

Similarity in type as defined in the foregoing does not necessarily imply an identic time of formation of fossil hard plinthite. The similarity between the whole fossil plinthite situation at Curuá-una and that in the Guamá-Imperatriz area, in particular the stretch around km 200, does however suggest that with morphometric studies correlations can be made over large areas within Amazonia. The conditions as they exist on the planalto scarps in the Guamá-Imperatriz area and at Curuá-una centre, were found also at Belterra Estate along the lower river Tapajós, and behind Tucuruí on the river Tocantins. One is forced to believe that all of the original planalto terrace in eastern Amazonia has, below its blanket of Belterra clay, a layer of fossil plinthite with Ipixuna (or Ligação)-like concretions.

The conditions may be different for the remnants of planalto in the western part of Amazonia. Two examples will be given. In the Manaus-Itacoatiara area, the lower

Fig. 11 Mapa de topografia e solos da área ao redor do centro de Curuá-una e corte transversal AB da estrada para o planalto

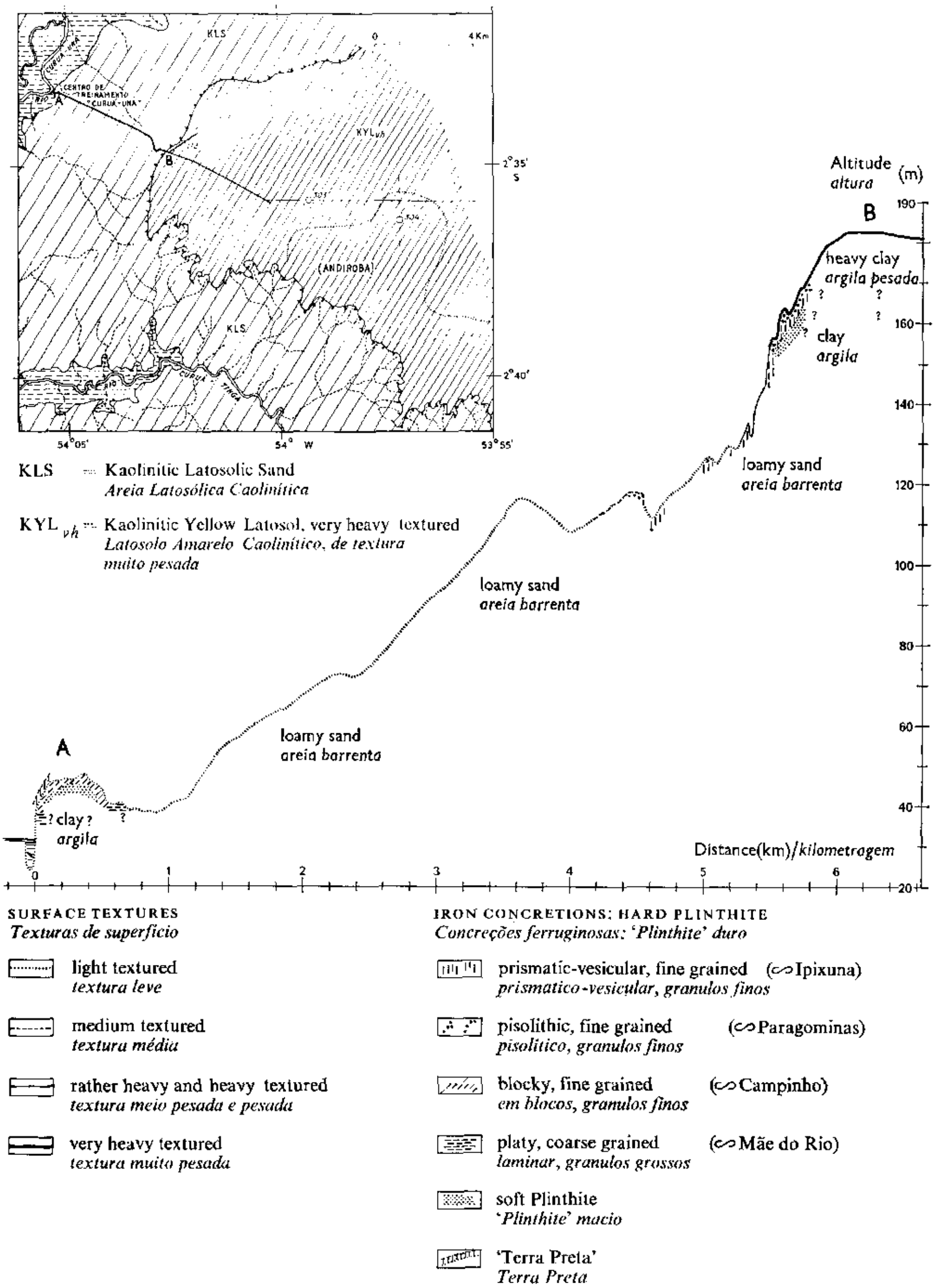


Fig 11 Map of topography and soils of the area around Curuá-una centre, and cross-section AB of the road to the planalto

boundary of the Belterra clay is only locally marked by concretionary elements, there as thin (1–3 dm) stone-lines, often without any soft plinthite. The concretions have similarity to the Paragominas type. The absence of Ipixuna-like concretions may be related to local re-working of the Belterra clay during the Early Pleistocene (*cf.* I.4.2). East of Porto Velho, at *cascalheiras* along the highway BR-29, thick (3–5 m) layers of hard plinthite were observed. The concretionary elements thereof resemble the Ipixuna type, and often have a (sub)vertical arrangement. Soft plinthite is seldom found. The hard plinthite is present at a slightly higher level than the planalto at the spot (*cf.* I.4.2), thus forming hilly outcrops (*cf.* GUERRA, 1953).

2. In the *Bragantina area*, located directly north of the Guamá-Imperatriz area, fossil plinthite is very frequent. The concretionary elements here often have the aspect of quartzitic sand stone with abundant ferrugenous cementing ('iron cemented quartzite'; *grés do Pará* or *pedra-Pará* of several geologists) and seem to be predominantly similar to the Mãe do Rio type of the Guamá-Imperatriz area. As in the latter area, the present day land surface is undulating to rolling where this type of fossil plinthite occurs at a shallow depth. This in contrast to the almost flat surface in the stretch of the Ipixuna or Ligação types. It is therefore likely that in the Bragantina area a large proportion of the fossil plinthite is of Miocene and/or older age. Here also, the complexity of the characteristics of the concretionary elements indicate more than one epochs of Ground Water Laterite soil formation in those epochs. On one location, namely Pirelli Estate, about 20 km east of Belém, even a complete and undisturbed buried Ground Water Laterite soil (A_1; A_2; B_2 of-soft-plinthite) was found, at 4–5 m depth. On top of this Mãe do Rio-like concretions were found, grading downward into soft plinthite.

3. In the area of the upland savannahs of *Amapá Territory*, plinthite both hard and soft, is also very frequent. CARNEIRO (1955) produced photographs of *laterita vesicular*, *laterita pisolítica*, *arenito laterítica (grés do Pará)* and *argila laterítica*, all from this area. Also GUERRA (1954) studied the crusts and sub-surface horizons of plinthite in this Territory, calling them *canga cavernosa*, *piçarra* or *arenito-Pará*. From a limited number of personal observations in the area it is concluded that, although existing Ground Water Laterite soils occur, most of the plinthite is fossil. Part of the fossil hard plinthite was formed *in situ* because it is underlain by related fossil soft plinthite. After truncation, it was partly buried by Pleistocene sediments. However, fossil hard plinthite of alluvial-colluvial character also occurs. The fossil plinthite in Amapá Territory is probably of various ages in the Tertiary and the Pleistocene. A small proportion of the hard concretionary elements there is apparently not fossil but recent: the vesicular blocks at the *falésias* of Macapá fortress and some other locations are the laterally exposed and therefore hardened parts of plinthite which is still in formation. The same seems to be the case with much of the *pedra-preta* on other beaches and banks in the Estuary region (*cf.* II.3.2.1; plinthite-in-formation below the solum). GUERRA (1959, p. 34–37) gives data on the occurrence of several horizons of

fossil plinthite, below the present day ground water level, in SESP drillings at Soure (Marajó island). From his limited descriptions of the horizons encountered, it is deduced that the fossil plinthite involved partly constitutes truncated Ground Water Laterite soil profiles and partly alluvial deposits.

4. Fossil plinthite seems to be frequent on the strip of uplands in the *Lower Amazon region* directly north of the river. The age is probably diverse, in view of the variability in type. This may however be only related to the outcropping of Paleozoic deposits of varying character in this region.

5. Other areas of frequent occurrence of fossil plinthite are indicated to be the Early Tertiary and Cretaceous peneplanation surfaces (*cf.* I.4.1) in the *watershed regions of Amazonia.* The fossil plinthite would conservate the table land feature of these terrains. On the presumably Cretaceous plateaux on the watersheds of Pará, Rhondônia and Mato Grosso, fossil plinthite seems to form a sub-superficial crust, outcropping at the edges (*cf.* notes of GUERRA, 1953, about the Serra de Parecis in Rhondônia Territory). Further data on these plinthites is not yet available.

I.5 The Vegetation

The vegetative cover of Amazonia in its entirety is often called *hileia* after VON HUMBOLDT. DUCKE and BLACK (1954) mention many families, genera and species that, to a greater or lesser extent, are characteristic for the hileia. AUBRÉVILLE (1958) specifies some of the differences in structure and composition of the hileia in comparison with tropical forests in Africa. DUCKE and BLACK found the limit of dispersion of the genus *Hevea*, its most famous trees, to constitute a well-fitting boundary of the hileia (Fig. 13). The hileia is present not only in northern Brazil, but covers also the main part of the Guianas, the northern part of Bolivia, the eastern parts of Perú and Colombia, and a part of Venezuela. Within Brazilian territory the hileia comprises about 3.500.000 km^2. The latest determination of its southern and eastern boundaries was carried out by SOARES (1953), from aerial photograph analysis.

Contrary to many popular descriptions of Amazonia, the hileia is largely far from impenetrable. On the uplands in the axial part of the region, the forests predominantly consist of high trees. Below the tree layers, the vegetation is relatively open. Shrubs, vines and palms are generally sparse. Consequently, it is not difficult to traverse the forest. The atmosphere below the canopy is fairly pleasant because of its coolness.

Although Amazonia contains the world's largest expanse of primeval tropical forest, there are within the region several parts with savannah or savannah-forest. Near the population centres there are terrains under cultivation or covered with secondary shrub and/or-forest. This is the case notably in the Bragantina area (east of Belém), along the lower Tocantins river (Cametá), around Manaus, Santarém and Amapá (Fig. 12).

Fig. 12 Mapa provisional da vegetação da Amazônia brasileira

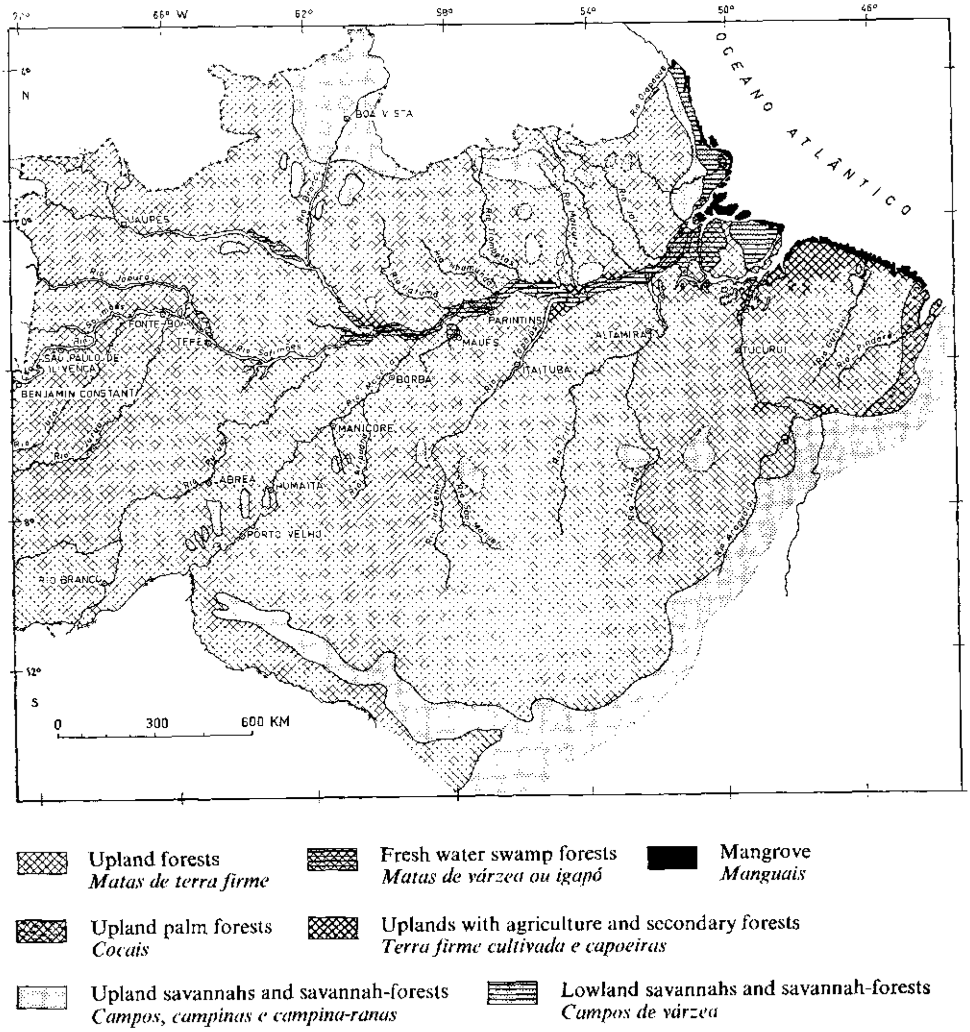


Fig. 12 Provisional vegetation map of Brazilian Amazonia

Apart from the collected information on the phytogeography of Amazonia by Ducke and Black (1954), the FAO/SPVEA Forest Inventory Program has provided lately for many systematic data (*cf.* Heinsdijk and Miranda Bastos, 1963). Continuously from 1954 to 1962, exploratory surveys were carried out over the vast area of 200.000 km². The areas constitute together an almost uninterrupted, longitudinal strip, 1700 km long, at the south side of the Amazon river, from the tributary Madeiras in Amazonas State to the river Maracassumé in Maranhão State. A latitudinal strip was surveyed along the forested, upper part of the newly opened BR-14 highway. As well as this, two special surveys were performed. They were to determine the dispersion and the timber volume of two valuable species. One took place on the lowlands along the lower Tocantins river for the species *Ucuuba branca (Virola surinamensis)*, and the other along the lower Araguaia river for the species mahogany or *Mogno (Swietenia macrophylla)*.

A provisional vegetation map is given in Fig. 12.

I.5.1 The Forest Vegetation

The coverage of primeval forest is far from homogeneous. The most conspicuous differentiating factor is the drainage condition. The following formations may be distinguished:

I.5.1.1 *Lowland Forests*

The forests of the terrains with poor drainage may be divided into three main formations:

1. *Mangue:* mangrove forest. The forest of the lowlands that are under influence of sea or brackish water *(várzea do mar; cf.* I.4.4). The formation is present along the Ocean coast and in narrow bands along the Baia de Marajó and the Rio Pará. Its composition is a part of the general flora of the coasts of tropical America (*Rhizophora mangle, Avicennia* sp.) and does not have relation to the composition of the hileia.

2. *Mata de várzea:* fresh water marsh forest[1]. The forest on the lowlands that are intermittently water logged with fresh water *(várzea do rio, várzea da chuva, várzea do maré; cf.* I.4.4). It has fewer species than the dryland forest, and the timbers are often lighter (more floaters). Salient species are for instance the *Sumauma (Ceiba pentandra)* and the *Andiroba (Carapá guianensis)*, and in some areas *Ucuuba* (*Virola* sp.). Several subformations may be distinguished. They are determined by the length and frequency of flooding and the quality of the flooding water. Upstream, and on the highest parts, the levees and point bars, of the floodplains in the lower courses of rivers, where flooding occurs only during the peak of the high water time, the quantity of species is largest. The formations concerned are nearing the dryland forest as regards their composition. In the region with tidal influence the quantity of species is low, especially on the floodplain parts that are flooded daily. The forest on the latter have a rather close resemblance to the formation 3. There is also a difference in composition and timber volume of the forests on the várzeas along rivers with transparent water (*água preta* or *água limpa; cf.* I.4.4) and those on the várzeas along rivers with

[1]) The applied distinction between *swamp* and *marsh* corresponds with the distinction between *várzea* and *igapó*. It is in agreement with the classification of Beard (1955), with the exception that lowlands flooded only during high tides *(várzea do maré)* are included with the marshes in the present publication.

turbid water *(água branca)*. The former generally have species of harder and better distinguishable kernwood (DUCKE and BLACK, 1954).

3. *Mata de igapó:* fresh water swamp forest: The forest on the lowlands that are permanently water logged with fresh water (igapó; *cf.* I.4.4). This forest formation has few tree species; palms are often frequent, sometimes constituting the entire vegetation. Characteristic species are for instance the *Ucuuba* (*Virola* sp.) and the *Anani (Symphonia globulifera)* and the palms *Açaí (Euterpe oleracea)* and *Paxiuba (Iriartia exorrhiza)*. The boles and crowns of the trees are usually laden with epiphytes.

I.5.1.2 *Upland Forests (matas de terra firme)*

These are the forests of the freely draining terrains of low altitude, in general all the land older than Holocene. These dryland or upland forests are characterised by an enormous variation of tree species, mainly of heavy timber. Palms are generally sparse, although many species of them are known (AUBRÉVILLE, 1958).

The forests are not quite uniform. There are differences in mean gross timber volume, and several species have a distinct optimum in some part of the immense region or are even restricted to specific areas. DUCKE and BLACK (1954), although admitting 'we cannot establish phytogeographical subregions in the hileia, because the flora of the high land between the navigable rivers is still almost completely unknown', made a tentative and schematic division of the hileia into subregions (Fig. 13). Each of their subregions has specific distinguishing species. Their sub-region 'Norte' is richest in species, but the trees are generally less high and the leaves smaller and darker than in the other regions. The subregion 'Norteste' contains several stretches of relatively dry and low forest.

The FAO/SPVEA Forest Inventory Program, already mentioned, has provided much quantitative data on the 'Sul' and 'Sudeste' regions. Several units, with geographical nomenclature, have been separated and mapped (*cf.* HEINSDIJK and MIRANDA BASTOS, 1963, and Fig. 22). An inventory unit was defined by:

1. the presence or absence of one or more tree species, in contrast to the situation in surrounding units.
2. the difference in mean gross timber volume, and
3. the degree of anthropogenic influence.

The characteristics for each unit were obtained by grouping of one hectare sampling units, which were laid out scattered (unbiased), as much as was possible at the mode of penetration. For the exact tracing of the geographic boundaries of a unit, the topography and the soils of the area with the most representative sample units were also taken as critera to some extent (for more details on the inventory system used *cf.* IV, Introduction).

It may be seen that the inventory units 1–15 do not vary greatly in mean gross timber volume. There is no clear change in the botanical composition of these fifteen units. HEINSDIJK (1960), after noting the tendency to increase and decrease respectively in

Fig. 13 A subdivisão provisional da hileia em regiões fito-geográficas conforme a DUCKE and BLACK *(1954) e os limites fixados por estes autores da dispersão do gênero* Hevea

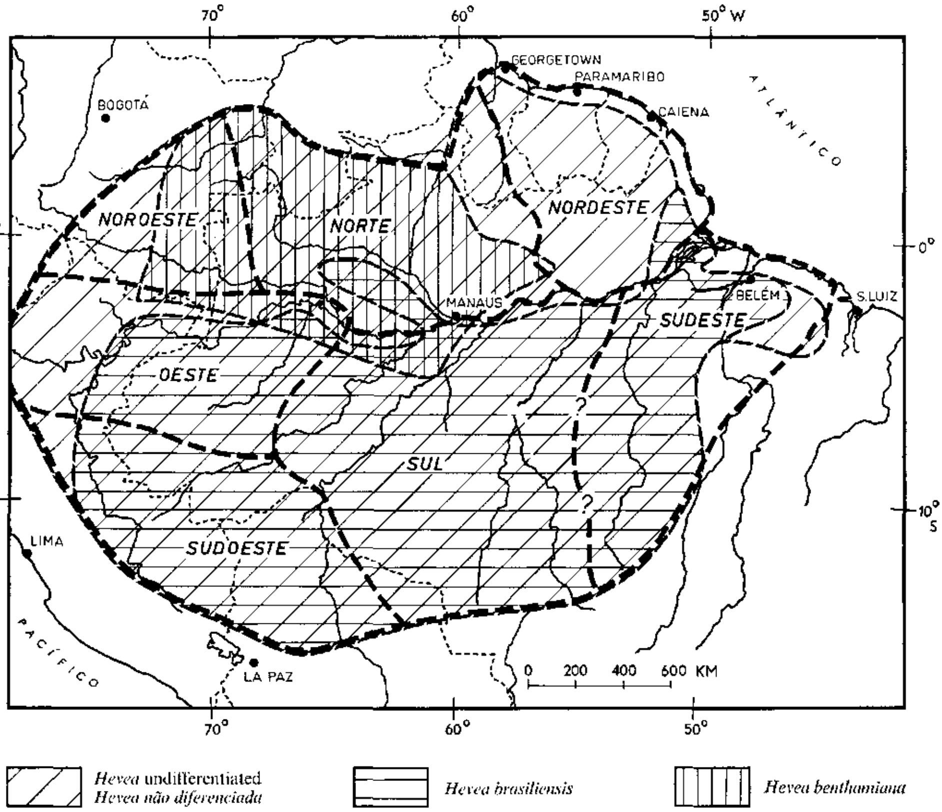


Fig. 13 The provisional subdivision of the hileia into phytogeographical regions according to DUCKE and BLACK (1954), *and these authors' boundaries of the dispersion of the genus Hevea*

frequency of several botanical families from east to west, states 'a regular change in representation of the families in the forest types sampled, in one direction can, except for the questionable examples given, be regarded as non-existent'. In fact, these units form together one forest type, called 'Pouteria association' by HEINSDIJK, after its most stable constituent. The various inventory units are facies of this one type (for their naming *cf.* HEINSDIJK, 1960). Nearing the south-eastern boundary of the hileia (units 16–24), there are more differences, not only in mean gross timber volume but also in the botanical composition. The latter units for a part form other types than that established for the centre of the valley. For the units 16, 17 and 18, for instance, the name 'Eschweilera Pouteria association' is proposed.

In the transition area which is located along the lower Araguaia river, unit 26, with soils different from those of the other inventory units, the composition of the forests is strikingly different from those near the Amazon river (*cf.* GLERUM and SMIT, 1962b). The number of tree species is considerably smaller. Parts of the area bear an almost pure stand of mahogany (*Swietenia macrophylla)*, which tree is reported to occur also in other parts of the southern and southwestern transition zone of the hileia (*cf.* DUCKE and BLACK, 1954).

I.5.1.3 *Special Upland Forest Types*

1. *Cipoal* (creeper forest). This is a kind of upland forest that is very difficult to traverse, contrary to the predominant situation. It consists of a dense clew of many thick creepers and climbers, with only few, big, emerging trees, often in small groups and laden with climbers ('climber-towers'). The transition of this type to the high forest is called *cipoalic forest* (*cf.* Photo 22).

Cipoal proper is present in patches on the central sections of the planalto south-east of Santarém (within units Planalto I and Planalto II), in rather extensive areas on the central sections of the planalto in the Guamá-Imperatriz area (units Ligação, Açailândia), and in very extensive areas between the rivers Jaraçú and Xingú (units Planalto II baixo, and especially Planalto II baixo cipoal; *cf.* HEINSDIJK, 1957 and the Figs. 22 and 24). The inventory unit Upper Guamá consists mainly of cipoalic forest. A vegetation somewhat comparable to the cipoal is found in the western part of the Araguaia Mahogany area. There however creepers and climbers are generally thin, the field layer is dense and palms abound. There are indications that other parts of southern Pará and parts of northern Mato Grosso have also cipoal-like forest. The cipoal may be taken to represent the real 'jungle'.

2. *Tabocal* (bamboo forest). This is a type of upland forest which consists predominantly of *Bambú* and/or *Taboca*, both *Guadua* species. They form an almost impenetrable cover of 3–10 m high. Emerging trees are practically absent, except for small patches. The tabocal vegetation is present, in broad strips, along the headwaters of the river Gurupí. (*cf.* GLERUM and SMITH, 1962a; *cf.* Fig. 23). Bamboo species are lacking elsewhere in area of the hileia, except for the extreme southwestern part (*Guadua superba* of Acre State; *cf.* DUCKE and BLACK, 1954).

3. *Cocal* (palm forest). In part of the transition zone between the hileia and the savannahs of North-Eastern Brazil, palms are very frequent. Often these palm forests are predominantly of *Babaçú (Orbygnia speciosa)*. This upland forest type is known as *cocal*, its area as *zona dos cocais.*

I.5.2 The Savannah and Savannah-Forest Vegetation

In this publication, 'savannah' is considered to be the vegetation type which consists of grasses with or without scattered small trees or clumps of trees ('open savannah'), as well as the vegetation type which consists mainly of shrubs, of variable density ('shrub savannah'). 'Savannah-forest' is considered to be that vegetation type which consists of trees that reach maximally about 20 m height and have thin boles (less than 0.25 m diameter at breast height). It seems actually to be more equivalent to 'savannah-wood' than to 'savannah-forest' as these vegetation types have been redefined recently. LINDEMAN and MOLENAAR (1959), for instance, describe the savannah-forest as having two storeys of which the upper one reaches about 25–30 m height, and the savannah-wood as having one storey, 8–15 or 20 m high, the trees having all thin boles.

The vegetation type here considered as 'savannah-forest' is discussed together with the savannahs, in view of its edaphic relationship with the latter (*cf.* Chapter IV).

The savannahs and savannah-forests of considerable expanse are mapped in Fig. 12. Only the boundaries of the ones near the main rivers are traced with a degree of accuracy, because only of these parts reliable maps exist, from interpretation of aerial photographs (AAF, 1942).

The boundaries of the savannahs of Marajó island, Amapá Territory and the Lower Amazon region are taken from AAF topographic maps, personal observation (*cf.* SUTMÖLLER *et al.*, 1963), and local information. The savannahs and savannah-forests of the lower Gurupí and those of the Rio Pará and the lower Tocantins (App. 7) are copied from forest inventory maps (HEINSDIJK, 1958a; 1958b; GLERUM, 1960). The savannahs and savannah-forests between the medium courses of the Purús and the Madeira are copied from BRAUN and RAMOS (1959). The savannah areas in the surroundings of Manicoré along the lower Madeira (Fig. 26) and those south of the Rio Negro, upstream of the confluence of the Rio Branco (Barcelos), are not reported in any publication known, but sketched in from indications on AAF maps. The savannahs of Rio Branco Territory are copied from GUERRA (1959). The savannah areas between the Lower and Middle Amazon regions and the Guianas are copied from the map of LECOINTE (1907), who bases his mappings on many observations of his own and those made earlier. Those of the medium course of the Xingú are taken from BOUILLENE (1926). The boundaries of the latter and, for that matter, even their existence, are however far from sure. The savannahs along the middle course of the Tapajós are reported by BOUILLENE (1926) as well as by LECOINTE (1922) which latter called them Campos de Cururú and Campos de Mucajazal. Also DUCKE and BLACK (1954) mention the existence of savannahs in this region, namely near Cachoeira de Mangabal. The whole southern and southeastern boundary of the hileia is copied from SOARES (1953).

The savannahs and savannah-forests within Amazonia are far from homogeneous. A well defined classification with full reference to similar vegetation types in other countries is however lacking. DUCKE and BLACK (1954) give a preliminary classification with local nomenclature. Of part of the Amazon savannahs and savannah-forests, the FAO/SPVEA Forest Inventory Program has provided for the geographic coverage. Although such areas were by-passed during the forest inventories, and any kind of 'key' to their identification is lacking, a preliminary classification of them is given, based on aerial photograph analysis. SUTMÖLLER *et al.* (1963) give many data on the habitat and the floristic composition of several savannah areas, in particular lowland savannahs.

For the following short and provisional subdivision of the Amazon savannahs and savannah-forests, the classification of DUCKE and BLACK is taken as a basis, and the units of the forest inventories are tentatively fitted therein.

I.5.2.1 *Lowland Savannahs and Savannah-Forests*

Under this heading is grouped the grassy, shrubby, or low forest vegetation on lowlands with intermittent or permanent waterlogging. Implied are the *campos de várzea* of DUCKE and BLACK and the *campo alagado, campo com arbusto alagado, arbusto alagado, floresta com arbusto alagado* or 'grassland on waterlogged soils' of forest inventories. Three main subformations exist, namely:

1. Campo de várzea do rio. This is the grassy vegetation on river floodplains that are half-yearly covered with turbid river water (*água branca; cf.* I.4.4).
A very characteristic grass is the floating *Canarana* (*Echinochloa polystachya,* a.o.) Shrubs and trees, especially on the highest parts (levees or point bars), are rather frequent. This type of vegetation is present in the Lower Amazon region.

2. Campo de várzea da chuva. This is the grassy vegetation on lowland that is half-yearly submerged with rain water.
On such lowland, trees and shrubs are usually absent *(campo limpo)*. This type of vegetation occupies for instance a large part of eastern Marajó island.

3. Campo de várzea do mar. This is the grassy vegetation on lowland that is regularly flooded with sea or brackish water. The vegetation type is associated with mangrove forest.

A special savannah-like lowland vegetation is still formed by the *mondongos,* which are lowlands in a part of eastern Marajó island that are permanently submerged, and therefore constitute a special type of igapó. Tall aquatic plants, like *Aninga (Montrichardia arborescens)*, abound here.
On the coastal lowlands of Amapá Territory all mentioned subformations are apparently present.

I.5.2.2 *Upland Savannahs and Savannah-Forests*

Under this heading is grouped the grassy or shrubby vegetation of non-flooded uplands of low altitude, in general all the Amazon land older than Holocene. Various subformations may be distinguished:

1. *Campo.* This is savannah that covers often extensive areas, but is encircled by forest. It is commonly located in watershed regions. Implied are the main parts of the *campo* and *campo com arbusto* or 'grass covered terra firme' of forest inventories. The greater part of the mapping unit 'upland savannahs and savannah-forests' of Fig. 12 are of this type.

The principal plants are *Gramineae*. Shrubs and small trees may be frequent *(campo coberto)*, scattered *(campo lavrado* or *campo sujo)*, or absent *(campo limpo)*. The trees and shrubs are stunted, have rough, thick rinds and xeromorphic leaves. Characteristic woody plants are for instance *Lixeira* or *Cajueiro do campo (Curatella americana)*, and *Murici (Byrsomina crassifolia)*. In part of the campos the *Mangabeira (Hancornia speciosa)* is frequent. Fires frequently sweep the terrains. In spite of the encircling by forest, the vegetation of the Amazon campos is not related to that of the hileia, but resembles the vegetation of the *campo cerrado* of Central Brazil, according to DUCKE and BLACK (1954).

The often used name *campo firme* is not quite adequate, because part of these savannahs are submerged by a shallow layer of rain water during the wet season (*cf.* IV.1.2). Really low parts (bottom lands) within campo areas are often forested. A characteristic species in the latter parts is the palm-tree *Buriti* (*Mauritia* sp.).

The extensive campos of Rio Branco Territory and the adjoining part of British Guiana are, in fact, outside the hileia region. Their floristic composition is different from the campos within the hileia (DUCKE and BLACK, 1954). No further mention will be made.

2. *Campina*. This name applies to small savannah patches in the middle of forest, frequently with some swampy parts that are submerged by a shallow layer of rain water during the wet season. Patches and windings of white sand alternate with shrubs or small trees. Implied are some of the *campo*, and *campo com arbusto* or 'grass covered terra firme' of forest inventories. According to DUCKE and BLACK (1954), the floristic composition of the campinas is different from that of the campos. *Gramineae* are less numerous than *Cyperaceae*, and the species of the former are different from those of the campos. The campinas have also a large diversity of wooden plants; these belong to the flora of the hileia and are related to that of the *caatinga amazônica* (see under 3).

The campinas are usually too small to be indicated on Fig. 12. The most numerous and typical campinas are located in the area between the lower courses of the Rio Negro and the Trombetas, where LECOINTE (1907) mapped them. They are especially frequent east of the Lake of Faro (which is the widened mouth of the river Nhamundá): Campos do Tigre, Campos de Maracanã. Near Manaus several campinas were observed, occurring as irregular strips along rivulets. Examples for the Estuary region are Vigia, Colares, Gurupá and Porto de Moz. For the lower Tocantins area, DUCKE and BLACK (1954) mention the campina of Breu Branco and that of Arumateua near Tucuruí. Also for the lower Madeira region campinas are reported: Campo Grande of Borba. The strip-like savannahs along the Marmelos and Manicoré rivers (Fig. 26) are probably also campinas.

The nomenclature is not quite satisfactory, because sometimes the word 'campina' is used for indicating a campo of small extent. On the other hand, areas with real campina vegetation are locally called 'campo' or even 'Campo Grande' (*cf.* examples cited above). The situation is still more complicated by the fact that campo vegetation and campina vegetation occur sometimes beside each other, for instance in the savannah area of Cupijó, west of Cametá, the savannah area of Mariapixí, west of the mouth of the Trombetas, and that of Ariramba (Ducke and Black, 1954).

3. *Caatinga amazônica.* This is a type of savannah-forest, which consists of low trees and shrubs with interspersed high trees, or shrubs and very low trees of approximately uniform height. The woody plants are practically all evergreen.
Its flora definitely belongs to that of the hileia. According to Ducke and Black (1954), the caatinga amazônica is the richest in species of any vegetative formation of Amazonia. This savannah-forest occurs in strips, and is found in the catchment area of the upper and middle Rio Negro (tributaries Curicuriarí, Içana and especially Uaupés) in its most typical form. Another region with strips of caatinga amazônica is the Upper Amazon region near São Paulo de Olivença.

4. *Campina-rana.* This is a type of savannah-forest which is isolated amidst the high forest, or occupies transitional areas between campo or campina and high forest (*cf.* Appendix 7). Most of the savannah-forests of Amazonia fall into this grouping. Implied are the *arbusto,* as well as the *floresta com arbusto* or 'caatinga forest' *c.q.* 'savannah-forest' of forest inventories.

Aubréville (1958) refers to *forêts basses et fourrés amazoniens sur sables blancs.* Both the caatinga amazônica and the campina-rana are apparently grouped under this latter heading.

I.6 Paleo Climate and Paleo Vegetation

Very little is known of the paleo climate and the paleo vegetation of Amazonia as yet, contrary to those of Africa (*cf.* d'Hoore, 1959). It is often accepted that the climate was constant since the Early Mesozoic, with only mild coolings during the Pleistocene, and that also the type of vegetative cover remained almost unchanged. Great age of the forest coverage has been deduced for instance from the great floristic richness of the hileia.

Recently however, doubts have arisen as to such constantness. In I.4.1 the supposition of Barbosa (1959) is already mentioned, namely that the sedimentation of the Tertiary Barreiras beds took place in a semi-arid climate of great extent.

Wilhelmy (1952) assumes that in the Late Tertiary a dry climate existed, during which extensive laterite crusts were formed form the Caribbean coast to 30°S, and open vegetation forms determined the landscape, including large parts of the area of the present day Amazon hileia. Ab'Saber (1959) states that the presence of various terrace levels, conserved by hard laterite crusts, and the existence of island-like campo in otherwise forest covered zones, presupposes that immediately before present times Amazonia had drier and inferior climates. They would be more comparable to the Senegalese than to the Congolese climates of today.

It can be seen in IV.1.2 that the island-like savannahs involved are edaphic predestined, and in II.3 that the formation of laterite or plinthite is not necessarily related to relatively dry climates. But it is true that truncation and burying of such plinthite took place in times when no protecting vegetative cover existed, therefore during relatively dry climates. In agreement with the tentative dating of the Amazon fossil plinthite (*cf.* I.4.5) this must have been during at least two epochs of the Late Tertiary (Miocene and Pliocene), and on a restricted scale during a part of the Pleistocene.

The whole construction of the Amazon valley proper in well distinguishable terraces of different levels and sedimentary materials, as described in I.4.3, points also to distinct changes in climate and vegetation. Present-day deposition comprises only non-kaolinitic, mainly heavy textured sediments (*cf.* I.4.4). This is quite reasonable considering the present day climatic conditions where almost all of the surrounding upland is covered with protecting tropical forest. Because of this coverage, erosion is very limited. Only bank falls *(terras caidas)* and a few sandy areas where the vegetative cover has been artificially destroyed are involved. By far the main part of the load of the large rivers comes from far upstream, outside the forest belt. For the Amazon and the Madeira the main cource of sedimentary material is the Andean mountain range (*cf.* SIOLI, 1951).

In contrast, the sediments of the Pleistocene fluviatile terraces are kaolinitic, often light textured, and sometimes even contain stony material (quartz pebbles, or plinthite concretions as geologic stone-lines; *cf.* I.4.5). In view of the small grade of the rivers, the source of these sediments was certainly local. Principally involved was the basis material of the Amazon planalto: kaolinitic clays and quartz sands of the Barreiras beds, with one or more layers of fossil plinthite. The pronounced erosion of the Amazon planalto and the accompanying formation, with the erosion products, of well-defined floodplains (nowadays terraces) at lower levels seem plausible only when the vegetative cover at that time was much sparser than the protecting cover of nowadays. The climatic conditions in the valley proper, during the deposition of the Pleistocene terrace materials, were therefore probably of similar interpluvial character as that thought necessary for the building-up of the 'climatic' fluviatile Pleistocene terrace of the Araguaia Mahogany area (*cf.* I.4.3). Those former climates must have had a long and pronounced dry season which limited the growth of vegetation, and a short but intense rainy season with a large erosional force. In view of the conclusion in I.4.3, namely that the fluviatile terrace deposits of the valley proper were laid down during interglacial times, the foregoing also supports the view that interglacials and interpluvials coincided in Amazonia.

The tentative conclusion regarding the sedimentation of the Belterra clay in a huge inland sea during the Plio-Pleistocene (Calabrian) implies that all of the axial part of Amazonia was devoid of any vegetation at that time.

In summarising, it is concluded that during parts of the Tertiary and the Pleistocene the forest coverage was absent or restricted to relatively small areas. For instance, it must have been restricted to the higher parts of the Guiana and the Brazilian shields during the Plio-Pleistocene at the time of the Belterra clay sedimentation. During the interglacials – interpluvials of the Pleistocene, real forest vegetation was probably confined to the western part of Amazonia, near the Andes (all-year orographic rains). This picture confirms the statements made by WILHELMY (1952), namely that the hileia only developed during the Pleistocene, from pockets of forest of Early Tertiary age[1]. Also very interesting in this respect are the conclusions of VAN DER HAMMEN (1957), that are based on analysis of fossil pollen of the Colombian Andes area. This author arrives at a distinct periodicity in vegetational and therefore also climatic changes during the Late Cretaceous and the Tertiary, for the N.W. part of South America. He also notes that the centre of the Guiana shield (the boundary area of the Guinanas and Brazil) constitutes a centre of distribution of plant species, amongst which several genera of the palm family *Mauritiaceae*.

[1]) Quote: '*Der Urwald, der heute das Amazonasbecken erfüllt, hat sich erst im Pleistocän aus kleinen alttertiären Restbestände entwickelt, nachdem noch im jüngeren Tertiär offene Vegetationsformationen im wesentlichen das Landschaftsbild Amazoniens bestimmten. Aus seinem äquatorialen Rückzugsgebiet heraus ist der Wald seit Beginn der Pluvialzeit allmählig nach S vorgestoszen, ein Prozesz, der jedoch auf den laterisierten Böden der Tertiären Landoberfläche bei den im Postpluvial wieder abnehmenden Niederschlägen nur sehr langsahm und unvollkommen vonstatten ging*' (WILHELMY, 1952, p. 125).

II. The Main Amazon Latosols and Plinthitic Soils

II.1 Evolution of the Concepts of 'Latosol' and 'Laterite' or 'Plinthite'

The term 'laterite' was first used by BUCHANAN (1807), as descriptive of a highly ferruginous deposit, observed in Malabar (India). It hardens upon exposure and is therefore used as building material. Afterwards, apart from indicating building qualities, the word laterite became associated with red colour of soil material, either soft or hard. Almost every reddish coloured material on the earth's surface in the tropics and elsewhere was termed 'laterite'. The meaning of the term became more narrow after the work of BAUER (1898) on the chemical character of hardened material. The presence of free aluminum oxihydrates *(Tonerde hydrat*, gibbsite) was taken as the criterion. Generally speaking, such aluminum oxides were assumed to be present if the ratio SiO_2:Al_2O_3 (value Ki) of the quartz-free soil material was lower than 2. Later authors assumed it to be general characteristic of weathering in the tropics that the ultimate products are iron and aluminum oxides, and that therefore even Si-Al products as kaolinite are not stable. HARRISON (1933) concluded from studies in British Guiana that on basic rock primarily gibbsite is formed ('primary laterite'), which can afterwards be resilificated into kaolinite, and that on acid rock kaolinite is formed directly. HARRASSOWITZ (1926, 1930), also adopted the criterion that 'allitic' constituents should be present to call a soil material lateritic. He could therefore speak of *lateritischer (allitischer) Rotlehm*, but was obliged to exclude iron oxide crusts that apparently had no free aluminum, for instance those formed in 'superficial' horizons of tropical savannah soil *(Savanneneisensteine)*. HARRASSOWITZ took it as proven that lateritic crusts develop by evaporation of sesquioxide rich soil water and he made a scheme for the various 'laterite profiles' (*cf.* II.3.1).

The HARRASSOWITZ concept was attacked by MARBUT (1932), who based his conclusions on findings in Cuba and in the Amazon valley. The Cuba data concern the *lateritischer Rotlehm*, which HARRASSOWITZ had difficulty in placing in his scheme. The Cuba soil, called 'Nipe series,' had developed on serpentine rock. It was considered to be a true laterite in the sense that Ki values are below 2 (0.2–0.3 actually). It lacks however a sesquioxide crust, as well as a mottled layer and a grey zone, all of which HARRASSOWITZ considered to be essential constituents of the 'laterite profile'. Indications for the wandering of sesquioxides to the surface were not found. The intensity of the red colour in the upper part of the profile would be due merely to a greater degree of dehydration of the iron oxides than in lower horizons. MARBUT concluded that normal laterites develop under conditions of good drainage, free from the influence of high ground water. Concentration of iron and aluminum oxides is mainly, if not entirely, mere residual (no active upward movement), brought about by the removal of silica, the alkalis and the alkaline earths. Sesquioxide segregation may or may not take place in the form of concretions.

MARBUT found that all laterite profiles in the area of the unconsolidated sediments of the Amazon valley have the HARRASSOWITZ horizons, but, *below* soil material. According to his observations the sequence only originates under the influence of fluctuating ground water level at shallow depth, resulting in a specific, imperfectly drained soil. Sesquioxide crusts on dissected plateaux are fossil, and the relics of such a soil after erosion of the surface layer (for details *cf.* II.3). MARBUT therefore distinguished:

1. 'laterite', as the lateritic red loam from Cuba;
2. 'ground water laterite', as the leached soils with mottled, and in part concretionary, subsoil of the Amazon valley.

Gradually, MARBUT's concept as to the origin of lateritic soils and lateritic crusts was accepted. It was fully adopted by the U.S. Soil Survey Staff. In 'Soils and Men' (BALDWIN, KELLOGG and THORP, 1938), a clear distinction is made between the intrazonal Great Soil Group of the 'Ground Water Laterite' and the zonal 'Yellowish Brown Lateritic', 'Reddish Brown Lateritic' and 'Laterite' Great Soil Groups. For the latter three Great Soil Groups, afterwards the term 'latosol' was preferred (Yellowish Brown Latosol, Reddish Brown Latosol and Red Latosol respectively, and some additional groups; KELLOGG, 1949). The Latosols therefore should comprise 'all the zonal soils having their dominant characteristics associated with low silica/sesquioxide ratios of the clay fractions: low base-exchange capacities, low activities of the clay, low content of most primary materials, low content of soluble constituents, a high degree of aggregate stability, and (perhaps) some red colour. KELLOGG proposed to confine the word 'laterite' to such ferruginous materials as harden on exposure, and to the relics of such materials. This includes:

1. soft mottled clays that change irreversibly to hardpans or crusts when exposed;
2. cellular and mottled hardpans and crusts;
3. concretions;
4. consolidated concretions.

Such materials, especially, but not exclusively, in fossil form, may be found in several of the zonal soils, but their presence may be regarded as accidental at the categorical level of the Great Soil Groups.

Only in the Ground Water Laterite soil, laterite is an essential feature. KELLOGG (1949) describes the soil as having a 'Gray or grayish-brown surface layer over leached yellowish gray A_2 over thick reticulately mottled cemented hardpan[1] at a depth of one

[1]) But a cemented hardpan and concretions are apparently not essential. KELLOGG and DAVOL (1949) give Ground Water Laterite soil profiles of Central Africa, in which no mention is made of a hardpan character of the B horizon, and of which they state 'may have concretions'.

foot or more. Hardpan up to several feet thick. Laterite parent material. Concretions throughout'.

Recently, namely in the VIIth Approximation for a comprehensive system of soil classification, the U.S. SOIL SURVEY STAFF (1960) has introduced the terms 'Oxisol' and 'Plinthite'. Oxisol includes 'the soils that have been called Latosols, and many, if not most of those that have been called Ground Water Laterite soils'.[1] The diagnostic characteristic of an Oxisol is that it has an 'oxic' subsurface (B) horizon (*cf.* II.2). The term 'plinthite' replaces 'laterite'.

The clear distinction between lateritic soils or Latosols, and the material laterite or plinthite, as made by the U.S. Soil Survey Staff, is nowadays also adopted in other countries. PRESCOTT and PENDLETON (1952) relate that in Australia the word 'laterite' is not used as a criterion in high-level soil classification, but retains its original geological meaning as a complex parent material. Also MOHR and VAN BAREN (1954), basing their conclusions on a large number of observations, mainly in Indonesia, agree with the distinctions as originally made by MARBUT, although they object to the term 'Latosol'. Recent French and Portuguese literature on classification of tropical soils also takes a clear distinction between plinthite formation and Latosol formation. AUBERT (1954), for example, distinguishes *cuirassement* versus *ferralitisation.*

II.2 Latosols

II.2.1 The Definition and Subdivision of Latosols as Applied in Brazil

The soil classification applied in Brazil by the national Soils Commission of the C.N.E.P.A.[2] is based upon the U.S.A. system. The classification of red and yellow tropical soils in the U.S.A. system is not yet fully elaborated. The definition and subdivision of the 'Latosols' or 'Oxisols' order is still greatly debated, in part because of their rarity inside U.S. territory. Detailed soil surveys of the U.S. Soil Conservation Service in regions with tropical soils are those of Puerto Rico (ROBERTS *et al.*, 1942; re-classification by BONNET, 1950) and of Hawaii (CLINE *et al.*, published in 1955). For some other regions exploratory studies were made, for instance of Congo (KELLOGG and DAVOL, 1949).

Soils with latosolic appearance are frequent in the vast land mass that constitutes the Federal Republic of Brazil. In recent years, many systematic fields studies have been carried out, particularly in the eastern and southern part of the country (*cf.* BARROS, DRUMOND, CAMARGO *et al.*, 1958; LEMOS, BENNEMA, SANTOS *et al.*, 1960). A detailed definition and classification of Latosols is being established in co-operation with, amongst others, the FAO Soil Survey and Fertility Branch. The latest trend in the U.S. system, as published in the VIIth Approximation (SOIL SURVEY STAFF, 1960)

[1]) According to the concept of Ground Water Laterite soil as used in this thesis (*cf.* II.3.2.1), most of them belong to the 'Ultisols' of the VIIth Approximation.

[2]) *Centro Nacional de Ensino e Pesquisas Agronômicas.*

has been considered, and the new definitions of diagnostic horizons (argillic horizon, albic epipedon etc.) and other distinctive characteristics are discussed and applied to some extent. But the new system is not taken as a *basis* by the Brazilian Soils Commission, one of the reasons being the above mentioned provisional character of the definition of Oxisols.

II.2.1.1 *The Modal Latosol*

The first extensive description of the characteristics of the Brazilian Latosols as recognized by the Soils Commission, is given by BENNEMA, LEMOS and VETTORI (1959). The elaborated concept, as presented at the ISSS Congress at Madison U.S.A. by BENNEMA (1963), is fully discussed in the following:

The fundamental characteristics of the Latosols lie in the nature and constitution of the mineral soil mass, indicating a thoroughly weathered soil. It consists of sesquioxides, silicate clay-minerals having a 1:1 lattice, quartz and other minerals that are highly resistant to weathering. Primary silicate minerals with less resistance to weathering are either absent or are present in only a small amount. The same applies to clay minerals having a 2:1 lattice, and those amorphous gels of Si and Al that have high base exchange capacities. Free aluminum oxides are often present, but not always. Concretions of iron, manganese, aluminum or titanium oxides may be present. The silt content of the samples in the solum is generally low.

To this constitution can be ascribed a large number of the characteristics and properties of the Latosols. The most salient of them are the following:

1. Indistinct horizon differentiation, with often diffuse or gradual transition between the horizons (except when an Ap is present).
2. Absence, or scarcity, of distinct silicate clay skins on peds or distinct silicate clay linings in the channels.
3. Low cation exchange capacities of the clays.
4. Red, yellow or brown colours of the subsoil[1] (B) horizon or part of the subsoil horizon.
5. Absence, or near absence, of electro-negative 'natural clay'[2] in parts of the subsoil horizon that have a low percentage of Carbon (C/clay ratio less than 0.015).
   Additionally, the typical Latosols have:
6. Absence of well-developed blocky or prismatic structure. The structural elements are often very fine granules, which may be more or less coherent, forming together a porous, friable, massive soil mass.
7. Deep solum (A + B horizon).
8. Very friable or friable consistency when moist.
9. High porosity and high permeability.

[1]) *Subsoil* considered in the sense as described in the supplement to the U.S. Agricultural Handbook No. 18, entitled 'Identification and Nomenclature of Soil Horizons' (1962).
[2]) *Natural clay* = the clay obtained by shaking with distilled water, being a measure of aggregate stability.

Foto 5 O principal Latosolo amazônico. O perfil de um Latosolo Amarelo Caolinítico (,Orto), de textura média, com a sua transição caraterísticamente difusa entre os horizontes A e B, e a macro-estrutura pouco pronunciada na secção sob-superficial

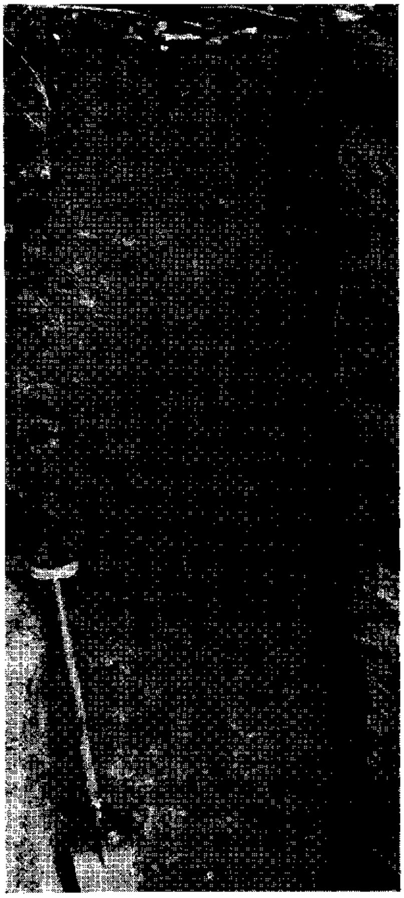


Photo 5 The main Amazon Latosol. The profile of a Kaolinitic Yellow Latosol (,Ortho), of medium texture, with its characteristic diffuse transition between the A and the B horizons, and the little pronounced macro-structure in the sub-superficial section

10. Low base saturation in the whole profile, or, at least, in the subsoil.
11. Relatively high anion exchange capacity and high phosphorus fixing power.
12. Relatively low amounts of exchangeable aluminum, or low active cation exchange capacity.
13. High resistance 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 (*cf.* II.1).

II.2.1.2 *The Distinction of the Latosols from other Soils; Latosolic-B versus Textural-B*

Besides the Latosols, the other main well drained red and yellow soils of tropics and subtropics are the Red Yellow Podzolic soils (including Rubrizems), the Andosols, the Red Yellow Mediterranean soils, and the Reddish Prairie soils. Of them, especially the Red Yellow Podzolic soils are sometimes hard to separate in the field from

Latosols (for the definition of the modal Red Yellow Podzolic soils *cf.* III.2). Latosols and Red Yellow Podzolic soils often occur in close proximity in Brazil. Transitional soils between the modal types of both are frequent. Both morphological and analytical studies are then required to decide whether the soil concerned is a Latosol, intergrading to Red Yellow Podzolic soil, or a Red Yellow Podzolic soil, intergrading to Latosol. The Brazilian Soils Commission has paid much attention to finding generally valid quantitative boundaries between predominant latosolic and predominant podzolic character. This is described in the following:

1. *Textural differentiation.* In the light textured soils (frequent throughout Brazil) the presence of silicate clay skins and linings cannot always be used as a differentiating characteristic. Peds are often absent, and consequently also the clay skins even when the illuviation process is well advanced. Linings in channels also are not easily formed, due to the small amounts of clay present and the relatively short life of the channels. Also, many morphometrical characteristics of typical latosolic soils lose their diagnostic importance because they are also characteristics of many sandy podzolic soils. In this case the horizon differentiation is often the only reliable field characteristic for the separation. The changes in texture within the profile are of special importance. The subsoil horizon of many podzolic soils is clearly distinguished from the topsoil due to a rapid or rather rapid change in texture. A number of the Latosols, namely those with relatively small percentages of sesquioxides, have also a change in texture in the profile (see below), especially the sandy ones, but in this case the change is gradual. If no other differentiating characteristics occur, for instance the presence of small amounts of 2:1 lattice silicate clay minerals, it has been proposed (BENNEMA, 1963) that the maximum *textural gradient*[1] for sandy Latosols should be as follows: an increase of 70% over 20 cm of the initial clay content which should be at least 5%. However, few data about clay gradients exists as yet because the available soil data refer predominantly to the mean of each different horizon, and not to a change over a certain distance. Therefore an approximative value is used, namely the *textural ratio*[2] *B/A*. The value should not exceed 1.8 for the sandy Latosols. This ratio has to be based on analytical data. In the field, therefore, experience in feeling textural differences has to be relied upon.

In the very heavy textured soils, an illuviation process does not lead so easily to a distinct horizon differentiation as expressable in a textural ratio B/A (*cf.* BENNEMA, 1963). Heavy clay soils, however, when subject to an illuvation process, show distinct clay skins. Therefore, absence of clay skins is the most important morphometrical field characteristic for separation of the heavy textured Latosols from the heavy textured Podzolic soils.

[1]) *Textural gradient* = the difference in texture, especially in clay content, over a certain distance.

[2]) *Textural ratio* B/A = the arithmetic mean of the clay content of the subdivisions of the B horizon except the B_3, divided by the arithmetic mean of the clay content of the subdivisions of the A horizon.

For the very sandy red and yellow soils, a classification as Latosol or Red Yellow Podzolic soil is thought to be inadequate. In this case, the latosolic or podzolic character is very difficult to assess, and has moreover little sense. The presence of inactive quartz sand becomes by far the predominant characteristic, instead of the constitution of the colloidal part. The structure, if present at all, is often weak, the soil mass consisting of bridges of sand grains only. Also those soils of which the very small colloidal part is 'latosolic' may therefore be quite susceptible to (gully) erosion, resistance to which is one of the practical properties of Latosols. In Brazil, for such very sandy acid soils the name *Acid Red Yellow (Quartz) Sand* is preferred, instead of Latosol or Red Yellow Podzolic soil. For the upper textural limit of these Acid Red Yellow Sands 15% clay sized particles in the subsoil[1] horizon is taken: light sandy loam and lighter textures (*cf.* LEMOS, BENNEMA, SANTOS *et al.*, 1960). When soils with less than 15% clay still clearly exhibit important 'latosolic' or 'podzolic' characteristics, they may be classified, within the described concept, as *Latosolic Sand* (or Latosolic Regosol), and *Podzolic Sand* respectively. The former name is applied for a part of the Amazon soils (see below).

2. *Mineralogic composition of the clay fraction.* The absence, or near absence, of 2:1 lattice silicate clay minerals can be checked by X-ray and DTA analysis, preferably combined. This, however, is elaborate and expensive. Data on the chemical composition of the clay fraction are therefore often used as an index of the presence or absence of 2:1 lattice silicate clay minerals. The molecular ratio of the chemically determined silicium and aluminum oxides ($SiO_2:Al_2O_3$ = Ki) is often used for this purpose. The criterion for latosolic character is then a ratio below 2. Objections to this are made, for instance, that a value above 2 does not necessarily mean the presence of 2:1 silicate clay minerals, but may be due to presence of uncombined, colloidal, silica (*cf.* MOHR and VAN BAREN, 1954). But many soil scientists working in tropical regions have found the ratio to be a reliable characterisation tool.

3. *Cation exchange capacity.* An additional, and often more convenient, gauge for determining the composition of the mineral soil mass are the cation exchange capacities of this mass, especially in view of the possible presence of amorphous gels of Si and Al. A part of the latter, and 2:1 lattice silicate clay minerals, have higher cation exchange capacities than those characteristic for the latosolic soils. In using the cation exchange capacities as a scale, a correction has to be made for the organic matter present which often accounts for the bulk of the determined cation exchange capacities. Also, it has to be clearly kept in mind which of the cation exchange capacities is being determined. The typical Latosols so far found in Brazil have a cation exchange capacity according to the NH_4OAc method (pH=7) varying from 0 to 8 m.e./100 g clay, while the ones that are intergrading to other soils have values up to 10–12 m.e./100 g clay (*cf.* BENNEMA, 1963).

[1]) See note at page 66.

Table 5 Principal characteristics of latosolic and textural B horizons (after BENNEMA, LEMOS and VETTORI, 1959 *and* LEMOS, BENNEMA, SANTOS *et al.*, 1960)

TEXTURAL-B/*B-textural*	LATOSOLIC-B/*B-latosólico*
Normally very distinct contrast with the other horizons. The transitions are either abrupt, clear or gradual *O contrasto com os outros horizontes normalmente é muito distinto. As transições são abrupta, clara ou gradual*	Weak contrast with the other horizons. The transitions are normally diffuse or gradual *O contrasto com os outros horizontes é fraco. As transições são normalmente difusas ou graduais*
At least 15% clay-sized mineral particles, and more clayey than the A horizon *Ao menos 15% de fração argila, e mais argilosa que o horizonte A*	At least 15% clay-sized mineral particles *Ao menos 15% de fração argila*
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 *Se o horizonte é de textura pesada* (clay, sandy clay, clay loam), *a estrutura é em blôcos subangulares e angulares, ou prismática, fortemente a moderadamente desenvolvida. A cerosidade é forte ou moderada, muitas vezes contínua. A porosidade é relativamente baixa*	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 *Se o horizonte é de textura pesada* (clay, sandy clay), *a estrutura é, geralmente, em granulos pequenos ou muito pequenos, formando uma massa porosa homogênea com coerência muito fraca. A estrutura apresenta-se também em blôcos angulares e subangulares, fracamente a moderadamente desenvolvida, sendo os blôcos compostos de granulos finos. Cerosidade, se é presente, é fraca e não continua. A porosidade é geralmente elevada*
When the horizon is medium textured (sandy clay loam, loam, heavy sandy loam), then the structure is weakly or moderately subangular and angular blocky, with rather well developed clay skins. Sometimes the structure is weak fine granular associated with single grains, forming a homogeneous porous soil mass with little coherence. The textural ratio B/A is above 1.6 *Se o horizonte é de textura média* (sandy clay loam, loam, heavy sandy loam), *a estrutura é em blôcos subangulares e angulares, fracamente a moderadamente desenvolvida, sendo a cerosidade fraca a moderada. Às vezes, a estrutura é granular pequena, fracamente desenvolvida e associada com grãos simples, formando uma massa porosa homogênea com pequena coerência. A relação textnral B/A é superior a 1.6*	When the horizon is medium textured (sandy clay loam, heavy sandy loam), then the structure is fine or very fine granular associated with single grains, forming a porous mass with very weak coherence. The textural ratio B/A is lower than 1.8 *Se o horizonte é de textura média* (sandy clay loam, heavy sandy loam), *a estrutura é muito pequena granular associada com grãos simples, formando uma masssa porosa homogênea com coerência muito fraca. A relação textural B/A é em baixo de 1.8*

Table 5 continued / Tabela 5 continuada

TEXTURAL-B/*B-textural*	LATOSOLIC-B/*B-latosólico*
The consistence when moist is firm or friable *A consistência, quando úmido, é firme ou friável*	The consistence when moist is friable or very friable *A consistência, quando úmido, é friável ou muito friável*
The 'natural clay' content can be relatively high. *O conteúdo de 'argila natural' muitas vezes é relativamente alto*	The 'natural clay' content is normally low. It is less than 1% in the B_2, 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) *O conteúdo de 'argila natural' é normalmente baixo. No subhorizonte B_2 é menor de 1%, com excessão quando o Ki é muito baixo e o pH-KCl é mais alto que o pH-H_2O, ou a relação carbono-argila é relativamente alta (C/argila > 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 *O valor Ki (relação molecular SiO_2/Al_2O_3) é normalmente superior a 1.8, raramente entre 1.8 e 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. *O valor Ki (relação molecular SiO_2/Al_2O_3) é normalmente mais baixo que 1.8, raramente entre 1.8 e 2.0.*
The cation exchange capacity is often larger than in the latosolic-B *A capacidade de permuta de cations é muitas vezes maior que no B-latosólico*	The cation exchange capacity is small. It is below 12 m.e./100 g of clay (NH_4OAc method) *A capacidade de permuta de cations é pequena. É mais baixo que 12 m.e./100 g de argila (método de NH_4OAc)*
Easily weatherable primary minerals may be present *Podem estar presentes minerais primários pouco resistentes ao intemperismo*	Weatherable primary minerals are practically absent. They comprise less than 4% of the sand fraction *Minerais primários sujeitos ao intemperismo são práticamente ausente. Compreendem em conjunto menos de 4% da fração de areia*
The silt content is often higher than in the latosolic-B *O conteúdo de silte é muitas vezes mais elevado que no B-latosólico*	The silt content is generally low. The silt/clay ratio is normally below 0.25 *O conteúdo de silte é geralmente baixo. A relação de silte/argila é normalmente mais baixo que 0.25*

Tabela 5 Caraterísticas principais de horizontes B-latosólico e B-textural (segundo BENNEMA, LEMOS and VETTORI, 1959 *e* LEMOS, BENNEMA, SANTOS *et al.*, 1960)

4. *Weatherable minerals.* It is suggested (BENNEMA, 1963) that the amount of minerals less resistant to weathering account for up to 4% of the sand fractions. The amount of minerals with small resistance to weathering should, however, remain considerably below this limit.

5. *Silt content.* As stated by VAN WAMBEKE (1962), the silt content of tropical soils appears to be closely related to the actual amount of weatherable minerals. Silt/clay ratios therefore are a helpful guide in distinguishing Latosols from less weathered tropical soils. In Brazil, a ratio of maximally 0.25 for typical Latosols is proposed, in agreement with D'HOORE (1960). BENNEMA (1963) however mentions that in some Latosols, for instance the Terra Roxa Legitima (see below), secondary minerals such as kaolinite and iron oxides form part of the silt fraction, as tiny concretions. In such soils the ratio may be higher than 0.25. In handling this ratio as a distinguishing device it should also be remembered that inaccuracies in determination of the mechanical composition are frequent because of difficult soil dispersion. This is especially so in early publications. Often a large portion of that which was determined as silt is actually non-dispersed clay (*cf.* SOIL SURVEY STAFF, 1960, p. 53–54).

The set of characteristics inherent to a latosolic-B (as the diagnostic horizon for Latosols), in comparison with that of a textural-B (as the diagnostic horizon of Red Yellow Podzolic soil and others), is summarised in Table 5.

The described concepts on latosolic-B and textural-B are not quite identical with the 'oxic horizon' and the 'argillic horizon' respectively of the VIIth Approximation (SOIL SURVEY STAFF, 1960). Latosolic-B and textural-B are mutually exclusive, which is not necessarily the case with the oxic and the argillic horizons: an oxic horizon can conceivably include an argillic horizon. With the applied maximum value for the latosolic-B of the textural ratio B/A, a part of the group of latosolic-B horizons falls under the argillic horizon. The lower textural limit (more than 15% clay) of latosolic-B and textural-B is the same as for the oxic horizon, but the argillic horizon can be lighter textured. An important difference between latosolic-B and oxic horizon is that the latter should have 12% or more free sesquioxides in percentage of the 1:1 lattice silicate clay minerals. Acceptance of the latter criterion would imply that some Latosols, for instance most of the Amazon ones (see below), fall outside the Oxisol Order. Also, the maximum percentage of weatherable primary minerals is smaller in the oxic horizon than in the latosolic-B, namely 1%.

II.2.1.3 *The Subdivision of the Latosols*

INTRODUCTION

In 'Soils and Men' only three types of Latosol were distinguished (BALDWIN, KELLOGG and THORP, 1938): Yellowish Brown Latosols, Reddish Brown Latosols, and Red Latosol. After the reconnaissance of the Congo by KELLOGG and DAVOL (1949), this was expanded to: Red Latosol, Earthy Red Latosol, Reddish Brown Latosol, Black Red Latosol, Red Yellow Latosol, and Yellow Latosol. The distinctions were principally made on the basis of colour, structure and consistence. BONNET (1950) subdivided the Latosols of Puerto Rico as follows: Coastal Plain Latosol, Upland Latosol, Ferruginous Latosol, and Rain Forest Latosol. CLINE (1955) discerned for Hawaï Low Humic Latosol, Humic Latosol, Ferruginous Humic Latosol, and Hydrol Humic Latosol. In that publication also the composition of the clay fraction was taken into account in differentiating. BRAMÃO and DUDAL (1958) mentioned Red Yellow Latosol, Dark Red and Dark Reddish Brown Latosol, Brown Latosol, and Low Humic Latosol (or Terra Roxa). In presenting the first draft of the 'Soil map of South America', BRAMÃO and LEMOS (1960) mention, besides the above mentioned, also Rego-latosols, Pale Yellow Latosols, Concretionary Latosols, and Areno-Latosols. LEMOS, BENNEMA, SANTOS *et al.* (1960) report for São Paulo the following Latosols: Terra Roxa Legitima, Dark Red Latosol (ortho, and sandy phase), Red Yellow Latosol (ortho, sandy, terrace, shallow phase), Humic Red Yellow Latosol, and 'Solos de Campos de Jordão'. The differentiating characteristics, also qua composition of the clay fraction, are described in extenso, and a comparison is made with earlier discerned units (see above).

All this is a still rather confused picture of the variation within the Great Soil Group of the Latosols. The whole of the rapidly growing mass of field and laboratory data on latosolic soils is being sorted out, in order to arrive at clearly defined, mappable units for all tropical regions. It forms part of the FAO 'Soil map of the World Program'.

Division according to colour alone is apparently not very valid, because this depends often more upon the stage of dehydration of the iron oxides than upon the total amount of Fe. Also, many morphometrical field characteristics vary little; all Latosols are deep, friable, porous soils with indistinct horizon differentiation. For subdivision, analytical data on the composition of the clay fraction have to be taken into account. This composition, in relative amounts of silicate clay minerals (kaolinite), Fe clay minerals (goethite), and Al clay minerals (gibbsite), is of much importance. It determines the stability of the structure, the natural fertility, and the effect of fertilizing. In Brazil, where a relatively simple and reliable method for characterising this composition is included in the standard analysis of all soil samples, a useful subdivision of Latosols mainly on the composition of the clay fraction has been developed.

After a preliminary subdivision as mentioned by BENNEMA (1963), it was elaborated at the Third Technical Meeting of the Brazilian Soils Commission (Rio de Janeiro, Dec. 1961) and presented by CAMARGO and BENNEMA (1962). For the tentative scheme see Table 6.

DESCRIPTION OF THE SUBDIVISION OF TABLE 6

Ad I. To this group, the *Acrox* of the VIIth Approximation, and representing the most advanced 'laterisation', belong for instance the Nipe series of Cuba (*cf.* II.1), and many of the soils around Brasília (*cf.* BENNEMA, CAMARGO and WRIGHT, 1962). The soils are usually found on old land surfaces with flat or gently undulating relief. In that case the parent material is varying. The colour also varies. The morphology of the

Table 6 *Tentative subdivision of the Latosols (after* CAMARGO and BENNEMA, 1962*)*

Groups and subgroups of the Latosols *grupos e subgrupos dos Latosolos*	Molecular ratios of the clay fraction *relações moleculares da fração argila* SiO_2/Al_2O_3	Al_2O_3/Fe_2O_3 soil texture *textura do solo* medium *média*	 heavy *pesada*	Other oxides *outros óxidos*
(I) LATOSOLS WITH LOW PERCENTAGES OF SILICATE CLAY MINERALS (Acrox) *Latosolos com baixas percentagens de minerais-de-argila de silicato (Acrox)* (Still to be subdivided, on Al_2O_3/Fe_2O_3 ratio and other characteristics/*a ser subdividido, na relação Al_2O_3/Fe_2O_3 e outras caraterísticas)*	< 1.0			
(II) LATOSOLS WITH INTERMEDIATE PERCENTAGES OF SILICATE CLAY MINERALS (Normal Latosols) *Latosolos com percentagens intermediárias de minerais-de-argila de silicato (Latosolos Normais)*	1.0–1.6			
(IIa) with relatively high percentages of Fe clay minerals and relatively high percentages of Mn and Ti (Latosol Roxo) *com percentagens relativamente altas de minerais-de-argila de Fe, e percentagens relativamente altas de Mn e Ti (Latosolo Roxo)*			< 1.7	MnO_2 > 0.10% TiO_2 4–8%
(IIb) with intermediate percentages of Fe clay minerals (Dark Red Latosol) *com percentagens intermediárias de minerais-de-argila de Fe (Latosolo Vermelho Escuro)*		2.0(?)–2.6	2.0–4.5	MnO_2 < 0.02%
(IIc) with relatively low percentages of Fe clay minerals (Red Yellow Latosol) *com percentagens relativamente baixas de minerais-de-argila de Fe (Latosolo Vermelho Amarelo)*		2.9–5.5	4.6–8.0	
(III) LATOSOLS WITH HIGH PERCENTAGES OF SILICATE CLAY MINERALS (Kaolinitic Latosols) *Latosolos com altas percentagens de minerais-de-argila de silicato (Latosolos Caoliníticos)*	1.6–2.0 *ca.*			
(IIIa) with relatively high percentages of Fe clay minerals, and relatively high percentages of Ti *com percentagens relativamente altas de minerais-de-argila de Fe, e percentagens relativamente altas de Ti*		2.0 *ca.*	3.0 *ca.*	TiO_2 3–4%
(IIIb) with intermediate percentages of Fe clay minerals *com percentagens intermediárias de minerais-de-argila de Fe*			4.0 *ca.*	
(IIIc) with relatively low percentages of Fe clay minerals *com percentagens relativamente baixas de minerais-de-argila de Fe*			> 4.6	

Tabela 6 Subdivisão tentativa dos Latosolos (segundo CAMARGO and BENNEMA, 1962)

profile of these soils is about the same as that of other Latosols. They have however a very 'earthy' feeling (*i.e.* the aggregates feel raw). A reliable differentiating characteristic is the fact that the pH-KCl is higher than the pH-H_2O if the organic matter content is low, *i.e.* in the subsoil (B) horizons. Unlike other Latosols, the typical ones of this group also have 'natural clay' in the B horizon (excess of electro-positive charges). The soils have an extremely low cation exchange capacity and effective fertilization is difficult.

Ad IIa. To this subgroup belong the *Terra Roxa Legitima* (also called Latosol Roxo) of São Paulo (LEMOS, BENNEMA, SANTOS *et al.*, 1960), and probably part of the Ferruginous Humic Latosols of CLINE (1955). They develop on basalt and diabase. The crushed dry soil sample is magnetic. The texture is clayey. The usual colours of the B horizon are reddish with low values and low chromas (<4), for instance dark reddish brown (2.5 YR 3/4) or dusky red (10R 3/4). The structure is fine granular *(pó de café)* and the solum deep. The soils have often relatively high natural fertility (coffee soils), but fertilization presents problems.

Ad IIb. To this subgroup belong many of the *Dark Red Latosols* and *Dark Reddish Brown Latosols*[1]. The soils are found on igneous rocks and consolidated sediments with considerable quantities of ferro-magnesium minerals. The crushed dry soil sample is only slightly magnetic. The texture is varying. The common colour of the B horizon is reddish, with low values (<3.5) but high chromas (5–7), for instance dark red (10 R 3/6, 2.5 YR 3/6). The natural fertility is often somewhat higher than those of *IIc.*

Ad IIc. To this subgroup belong many of the *Red Yellow Latosols* (BARROS, DRUMOND, CAMARGO *et al.*, 1958; LEMOS, BENNEMA, SANTOS *et al.*, 1960). They develop on igneous rock and consolidated sediments with only fair amounts of ferro-magnesium minerals. The texture varies, and there may be a slight difference in texture between the A and the B horizons. The common colour of the B horizon is reddish or yellowish, with high value (>3.5) and high chroma (6–8), for instance red (2.5 YR 5/8), yellowish red (5 YR 5/8) or strong brown (7.5 YR 5/8).

Ad IIIc. To this subgroup belong the so-called *Rego-Latosols;* several Yellow Latosols; many of the Regosolic Yellow Latosolic Podzolic soils which are also called 'Rego-latosol Amarelo, fase Tabuleiro' or 'Tabuleiro' (BARROS, DRUMOND, CAMARGO *et al.*, 1958); the Red Yellow Latosol, terrace phase (LEMOS, BENNEMA, SANTOS *et al.*, 1960). These Latosols are found on relatively young land surfaces with unconsolidated sediments. Gibbsite is absent or practically absent, and Fe_2O_3 comprises often less than 10% weight of the clay fraction. The texture varies and the B horizon is often

[1]) The concept of these soils as used in Brazil is more narrow than the current concepts of Reddish Brown Lateritic soils, and the Dark Red and Dark Reddish Brown Latosols of BRAMÃO and DUDAL (1957).

distinctly heavier than the A horizon. The common colour is yellowish, with high chroma and high value. The colour is often paler in regions without a dry season (10 YR or 7.5 YR 6/6, 6/7, 7/6) than in regions with a distinct dry period (7.5 YR 8/6 or 10 YR 5/6). The structure is often weakly subangular blocky, the porosity is lower than in most other Latosols. When dry then the profile is hard or slightly hard in the transition zone between the A and the B horizon (A_2, B_1). Plinthite is fairly common. The natural fertility is normally low, except in transition areas to arid regions. The response to fertilization is often favourable.

A further subdivision will be made both according to the thickness of the A_1 horizon (weak, intermediate, pronounced[1]; the latter known to exist for units *IIb* and *IIc*, *IIIa* and *IIIc*), and the base saturation (low, medium, high; the latter known to exist for units *IIa*, *IIIb* and *IIIc*). To augment the practical application of soil surveys, also 'phases' are used which are based often on variations of mesologic environmental factors (geomorphology, vegetative cover).

In addition to these groups, there are Latosols, at relatively high altitudes, of brownish colour and relatively thin (<1m) solum, commonly called *Brown Latosol* (*cf.* BRAMÃO and DUDAL, 1958). These have not yet been properly studied in Brazil, but it is thought that at least part of them intergrade to Andosols or Acid Brown Forest soils.

II.2.2 The Main Amazon Latosol

The most prominent geomorphologic units of Amazonia are the uplands, arranged as terraces, of the Late Tertiary and the Pleistocene which together are termed the Amazon Planície (*cf.* I.4.2 and I.4.3). These uplands are composed of unconsolidated acid sediments of varying texture. They consist very predominantly of kaolinitic clays and quartz sands, and locally of fossil plinthite. The well-drained soils developed on these sediments are for the main part very similar, considering the high categorical level of classification as is used in this publication. This similarity applies to both the morphometrical field characteristics and the analytical data. General occurring morphometrical field characteristics are the following (for individual profile descriptions *cf.* Chapter III; *cf.* also Photos 6, 7 and 8).

1. A deep, permeable solum.
2. Little horizon differentiation, with diffuse or gradual transitions between the horizons.
3. The texture is varying, from light to very heavy textured. The silt content is very low, especially in the subsoil[2] (B) horizon.
4. The structure is usually weak very fine granular, composing a slightly coherent porous massive soil mass, which easily falls apart into weak or moderate fine or

[1]) Percentage of Carbon at 20 cm depth larger than $0.3 + 0.057 \times$ moisture equivalent.
[2]) See note on page 66.

Foto 6 O principal Latosolo amazônico. Uma vista de perto da estrutura da secção sob-superficial do perfil do Latosolo Amarelo Caolinítico (,Orto), de textura meio-pesada. Os elementos estáveis muito finos da micro-estrutura constituem uma massa de solo poroso pouco coerente, massa que se desagrega em blôcos sub-angulares fracos a moderados (para a escala veja o palito; fotografia Dr. J. Bennema)

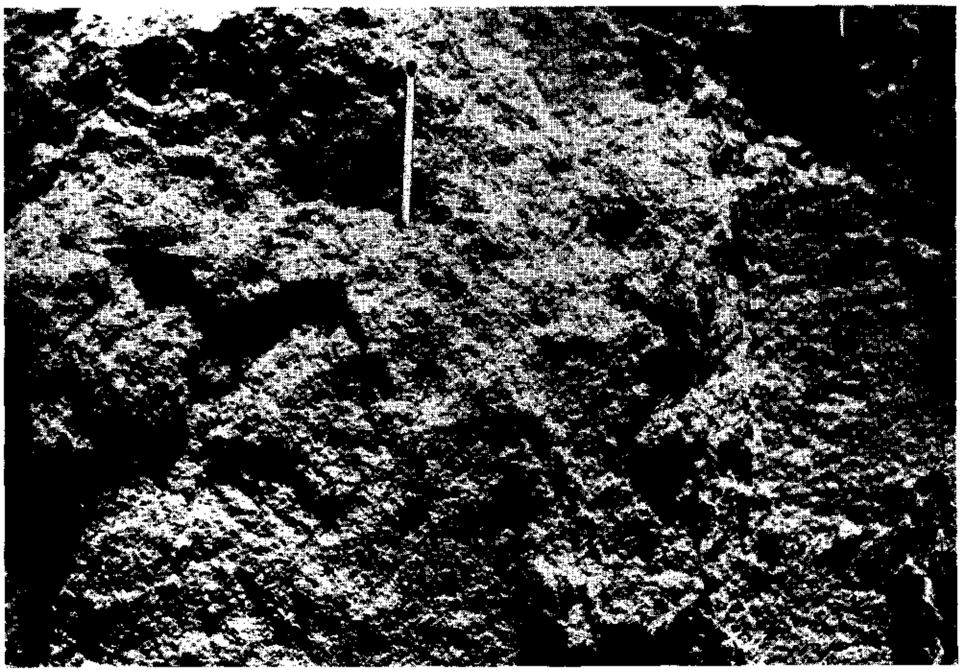


Photo 6 The main Amazon Latosol. A near view of the structure of the subsuperficial section of the profile of a Kaolinitic Yellow Latosol (,Ortho), of rather heavy texture. The very fine, stable elements of the micro-structure form a weakly coherent porous soil mass that falls apart into weak to moderate subangular blocks (cf. the upright match for the scale; Photo by Dr. J. Bennema)

medium sized subangular blocky elements (*cf.* Photo 6). No silicate clay skins or clay linings are present, except for a few faint ones in the very heavy textured soils. Except for the very light textured ones, the soils are little subject to gully erosion.

5. The consistence when moist is usually friable to very friable (loose in the lightest textured soils); when dry it is often slightly hard, to hard, especially in the upper part of the B horizon. In a number of the soils, the subsoil horizon is difficult to penetrate with a soil hammer.

6. The porosity is generally high, but apparently not quite as high as in most Latosols of Southern Brazil. In a number of the soils the subsoil horizon is compact or rather compact.

7. The soils show practically always some degree of illuviation (*lessivage* or 'podzolisation'). The subsoil horizon is namely slightly heavier in texture than the surface and subsurface horizons: the textural ratios B/A are between 1.2 and 2.1 for relatively light textured profiles, and between 1.1 and 1.6 for relatively heavy textured profiles.

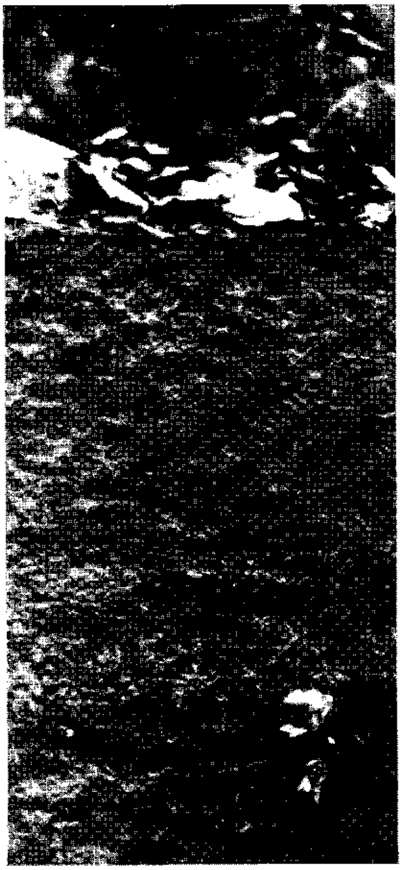


Foto 7 O principal Latosolo amazônico. A parte superior (50 cm m. ou m.) do perfil de um Latosolo Amarelo Caolinítico (,Orto), de textura muito pesada. É notável o horizonte A_1 muito delgado (3 cm m. ou m.)

Photo 7 The main Amazon Latosol. The upper part (50 cm ca.) of the profile of a Kaolinitic Yellow Latosol (,Ortho), of very heavy texture. Noteworthy is the very thin A_1 horizon (3 cm ca.)

8. The colour of the subsoil horizon is mostly yellowish, less commonly reddish, but has always high value and high chroma. The reddish colour may be found when fossil hard plinthite is present, or in transition zones to arid regions.
9. Plinthite, hard or soft, is rather commonly present.

The following are the analytical data:
10. The content of 'natural clay' is low; in the subsoil horizon it is very often completely absent: for the A horizons the indices of structure are between 40 and 80, and for the B horizons they are normally 100.
11. The soils are extremely or very strongly acid, with the pH-H_2O between 4 and 5. The pH-KCl is lower than the pH-H_2O, but normally less than one unit.
12. The base saturation of the soils under natural vegetative cover is very low (*ca.* 15%). Only in transitional areas to arid regions it may be low to medium.
13. Easily weatherable primary minerals are practically absent. The great majority of the non-clay sized particles consists of quartz grains. The other ones are vegetal detritus elements, some reddish coloured micro-concretions of plinthite, and cream

Foto 8 O perfil de um Areia Latosólica Caolinítica. É notável o horizonte A_1 relativamente espesso e a funda penetração das raízes

Photo 8 The profile of a Kaolinitic Latosolic Sand. Noteworthy is the relatively thick A_1 horizon and the deep rooting

coloured pseudo micro-concretions of clay. Turmaline, staurolite, ilmenite and weathering biotite and felspar, when present, form together only a trace.[1]

14. The potential cation exchange capacity of the soils (NH_4OAc method at pH7) varies from near zero to about 20 m.e./100 g soil in forest profiles. However, the cation exchange capacity of the organic matter-free soil material is always very low. Calculated on the basis of the clay sized particles it only amounts to 1.5–5 m.e./100 g clay (data obtained by extrapolation of relevant analytical data of individual profiles given in Chapter III; see also Table 7 (other method of analysis) and V.3.1.1). The active cation exchange capacity, or the exchangeable $(Al)^+$, of the subsurface and subsoil horizons is on the average only about 20–25% of the potential cation exchange capacity.

15. The mineralogical composition of the clay fraction is very uniform. The molecular ratios between SiO_2, Al_2O_3 and Fe_2O_3 are very constant. For about fourty analysed

[1]) Only in the separate 2–16 μ felspar may be present in higher quantities (*cf.* samples 233–3, 300-4 and 210-4 of Fig. 14 a–e and Table 8).

profiles scattered over the Planície, the SiO_2: Al_2O_3 values (Ki) are, with rare exceptions, between 1.7 and 2.1, throughout the profiles. SiO_2: (Al_2O_3 + Fe_2O_3) values (Kr) are only slightly lower – usually 0.2 unit –, and Al_2O_3: Fe_2O_3 values correspondingly high, namely about 9.0. Fe_2O_3 comprises 5–11 percent of the clay fraction. It is only in concretionary soils and very light textured soils that this percentage may become as high as 20.

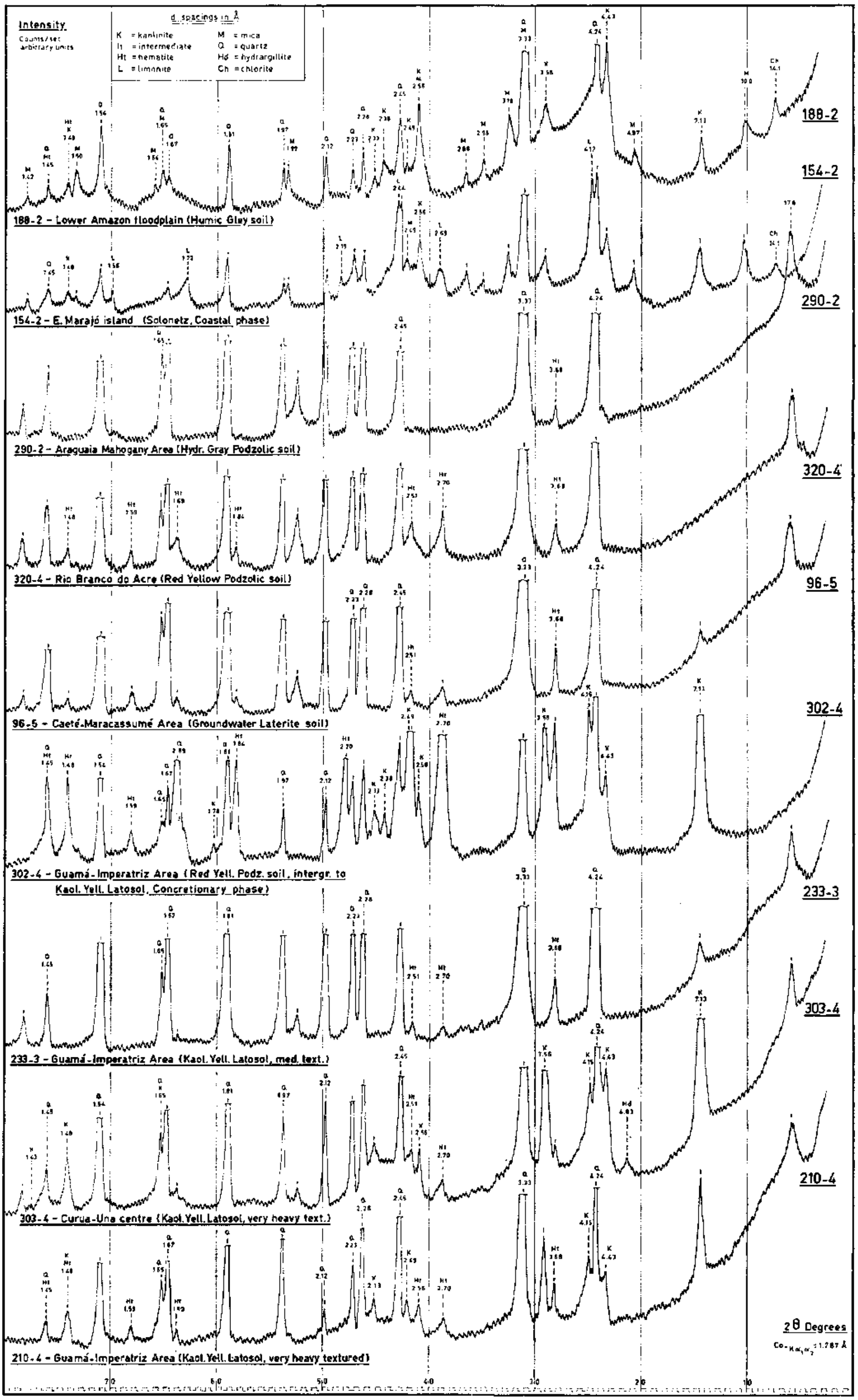
From the fact that Ki values are not above 2, it may be deduced that the silicate clay minerals are of 1:1 lattice structure. In view of the generally low cation exchange capacity of the clay (*cf.* under 14), it is likely that kaolinite is involved, not halloysite. From the fact that Ki values are only slightly below 2 the absence, or presence only in a small percentage, of free aluminum oxides (gibbsite = hydrargillite) may be deduced. It is likely that by far the majority of the determined Al_2O_3 is derived from the silicate clay minerals. The low values for Fe_2O_3 indicate the presence of only small amounts of free iron oxides (goethite = limonite; hematite). In view of the low cation exchange capacities one might assume that parts of the determined SiO_2 and Al_2O_3 are not from kaolinite, but from inactive gels of free SiO_2 and free Al_2O_3 respectively. However, full confirmation of the above deductions was given by several X-ray diffractions, Differential Thermal Analyses (DTA), and an electron micrograph. Subsurface (A_3 horizon) and subsoil (B horizon) samples of four profiles of the soils under discussion were analysed with X-ray at the Netherlands Soil Survey Institute of Wageningen, Holland, together with samples of some other Amazon soils. The results (*cf.* samples 233–3, 303–2, 303–4, 300–2, 300–4 and 210–4 of the Tables 7 and 8 and the Figs. 14 a–e) show that indeed kaolinite is the very predominant constituent (80–85%) of the clay fraction[1]. Iron oxides account for up to 12% and aluminum oxides up to 5% of the clay fraction, whilst clay sized quartz accounts up to 6%. An electron micrograph was also made of the clay fraction of one of the samples (*cf.* Photo 9). The pureness of the kaolinitic clay is remarkable; practically all of the sample consists of strikingly clean and pronouncedly hexagonal, relatively large kaolinite crystals. Comparison of the data for specific surfaces of the above mentioned samples with their cation exchange capacities (Na-acetate at pH = 8.2) shows that a specific surface of 100 m^2 gives only about 8.0 m.e. cation exchange capacity, which applies to both the total soil mass and to the clay fraction (*cf.* Table 7).

[1]) The presence of kaolinite in the coarser fractions is due to incomplete dispersion, and enclosing by cementing sesquioxides.

Fig. 14a–e X ray spectra of separates > 80μ (14a), 16–80 μ (14b), 2–16 μ (14c), < 2 μ (14d), < 2 μ-treated (14e) of the main Amazon Latosols (samples 233–3, 303–2, 303–4, 300–2, 300–4, 210–4) and plinthitic soils (samples 96–2, 96–5, 302–4, 178–4) in comparison with the composition of some other Amazon soils (cf. the Tables 7 and 8 and the electron micro-photographs 9, 10, 11 and 12)

Fig. 14a–e Curvas de Roentgengramas de separados > 80 μ (14a), 16–80 μ (14b), 2–16 μ (14c), < 2 μ (14d), < 2 μ-tratados (14e) dos principais Latosolos amazônicos (amostras 233–3, 303–2, 303–4, 300–2, 300–4, 210–4) e solos de 'plinthite' (amostras 96–2, 96–5, 302–4, 178–4) em comparação de alguns outros solos amazônicos (cf. Tabelas 7 e 8 e micrografias eletrônicas: fotografias 9, 10, 11 e 12)

Fig. 14a (>80 μ)



Intensity
Counts/sec arbitrary units
d spacings in Å
K = kaolinite
I1 = intermediate
Ht = hematite
L = limonite
M = mica
Q = quartz
Hd = hydrargillite
Ch = chlorite
188-2
154-2
290-2
320-4
96-5
302-4
233-3
303-4
210-4
188-2 - Lower Amazon floodplain (Humic Gley soil)
154-2 - E. Marajó island (Solonetz, Coastal phase)
290-2 - Araguaia Mahogany Area (Hydr. Gray Podzolic soil)
320-4 - Rio Branco do Acre (Red Yellow Podzolic soil)
96-5 - Caeté-Maracassumé Area (Groundwater Laterite soil)
302-4 - Guamá-Imperatriz Area (Red Yell. Podz. soil, intergr. to Kaol. Yell. Latosol, Concretionary phase)
233-3 - Guamá-Imperatriz Area (Kaol. Yell. Latosol, med. text.)
303-4 - Curua-Una centre (Kaol. Yell. Latosol, very heavy text.)
210-4 - Guamá-Imperatriz Area (Kaol. Yell. Latosol, very heavy textured)
2θ Degrees
70
60
50
40
30
20
10

Fig. 14b (16–80 µ)

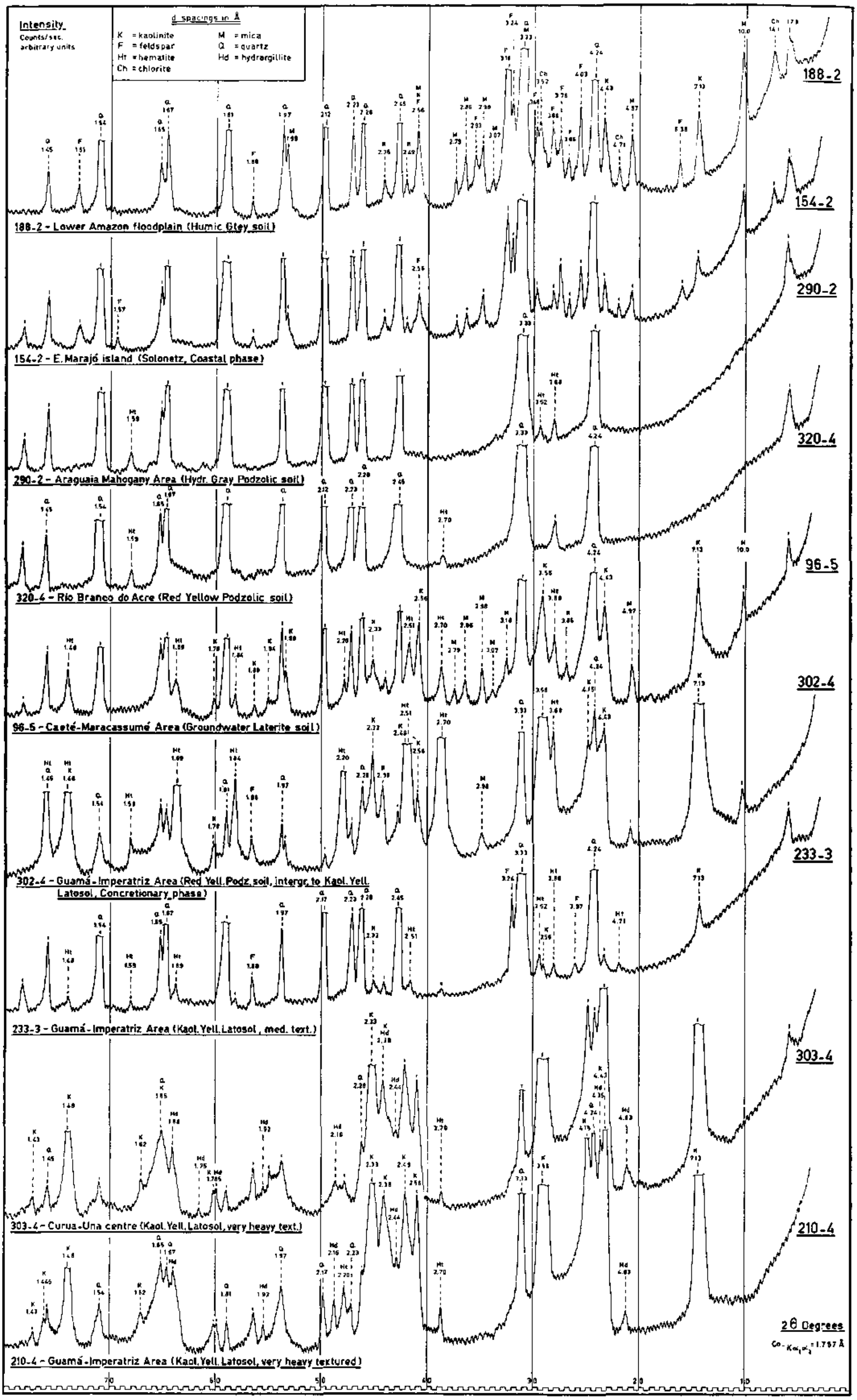


Fig. 14c (2–16 μ)

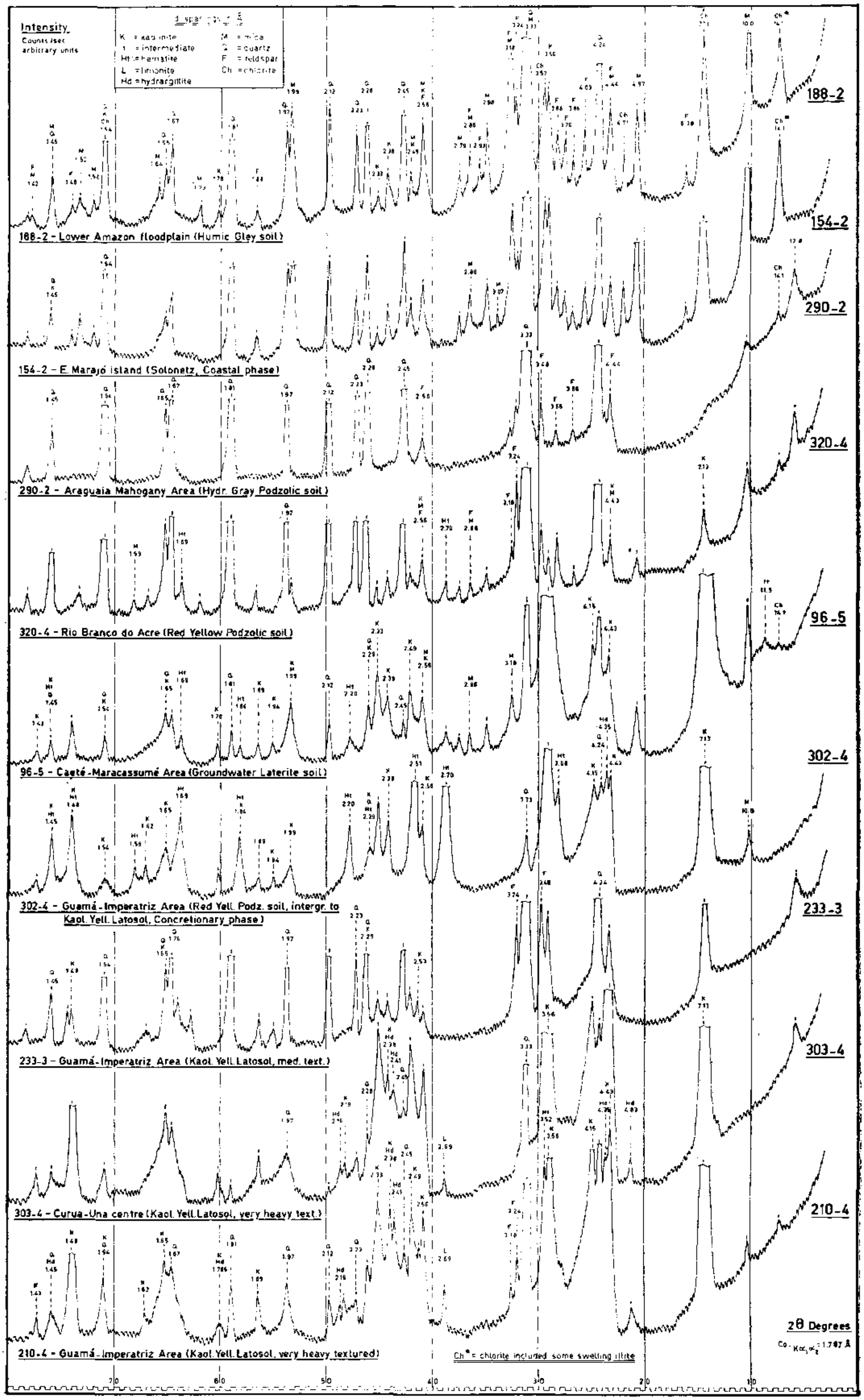

Intensity,
Counts/sec
arbitrary units
K = kaolinite
I = intermediate
Ht = hematite
L = limonite
Hd = hydrargillite
M = mica
Q = quartz
F = feldspar
Ch = chlorite
188-2
154-2
290-2
320-4
96-5
302-4
233-3
303-4
210-4
188-2 - Lower Amazon floodplain (Humic Gley soil)
154-2 - E. Marajó island (Solonetz, Coastal phase)
290-2 - Araguaia Mahogany Area (Hydr. Gray Podzolic soil)
320-4 - Rio Branco do Acre (Red Yellow Podzolic soil)
96-5 - Caeté-Maracassumé Area (Groundwater Laterite soil)
302-4 - Guamá-Imperatriz Area (Red Yell. Podz. soil, intergr. to Kaol. Yell. Latosol, Concretionary phase)
233-3 - Guamá-Imperatriz Area (Kaol. Yell. Latosol, med. text.)
303-4 - Curua-Una centre (Kaol. Yell. Latosol, very heavy text.)
210-4 - Guamá-Imperatriz Area (Kaol. Yell. Latosol, very heavy textured)
Ch* = chlorite included some swelling illite
2θ Degrees
70
60
50
40
30
20
10

Fig. 14d (< 2 μ)

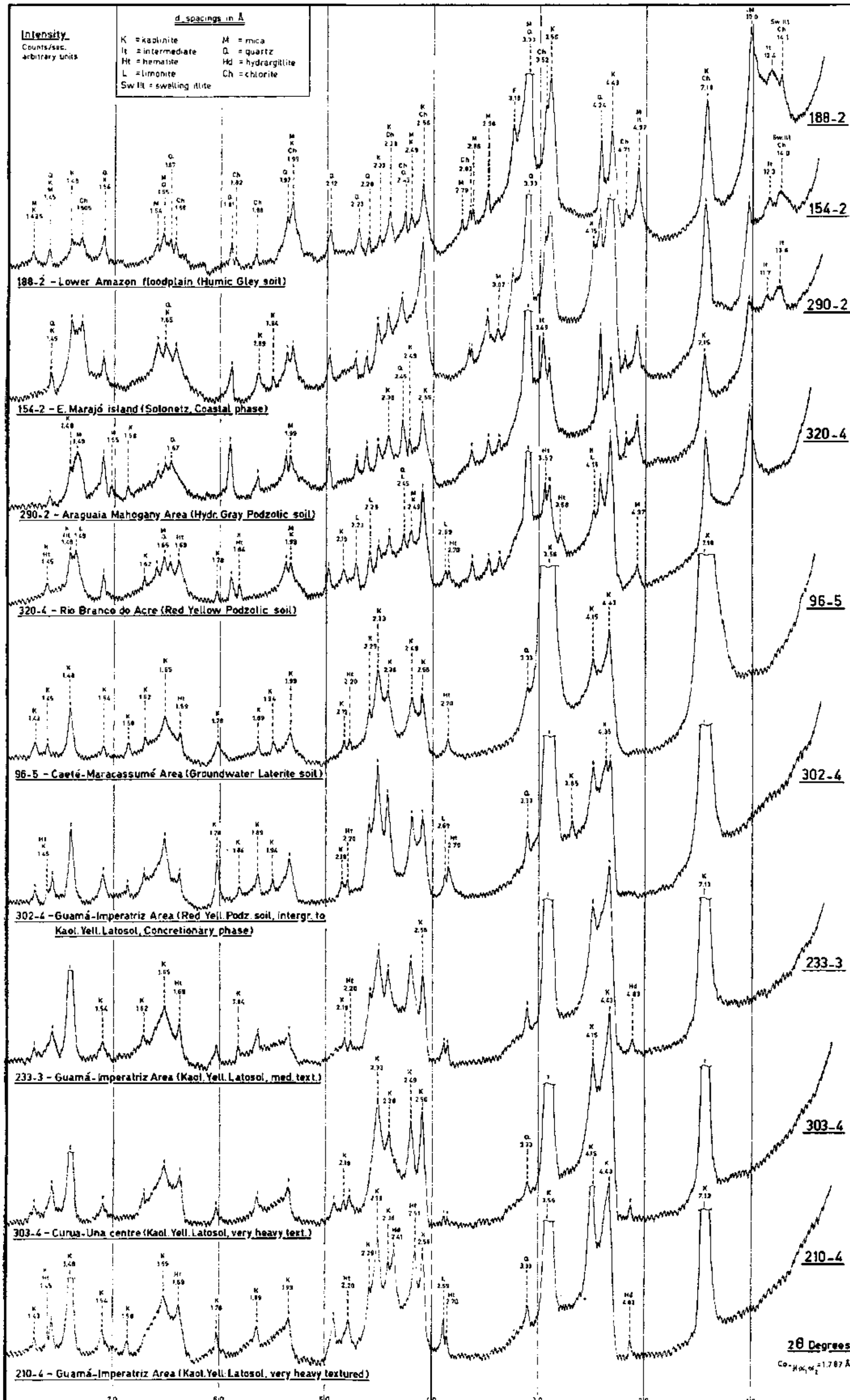

Intensity
Counts/sec. arbitrary units
d spacings in Å
K = kaolinite
It = intermediate
Ht = hematite
L = limonite
Sw Ilt = swelling illite
M = mica
Q = quartz
Hd = hydrargillite
Ch = chlorite
188-2
154-2
290-2
320-4
96-5
302-4
233-3
303-4
210-4
188-2 - Lower Amazon floodplain (Humic Gley soil)
154-2 - E. Marajó island (Solonetz, Coastal phase)
290-2 - Araguaia Mahogany Area (Hydr. Gray Podzolic soil)
320-4 - Rio Branco do Acre (Red Yellow Podzolic soil)
96-5 - Caeté-Maracassumé Area (Groundwater Laterite soil)
302-4 - Guamá-Imperatriz Area (Red Yell. Podz. soil, intergr. to Kaol. Yell. Latosol, Concretionary phase)
233-3 - Guamá-Imperatriz Area (Kaol. Yell. Latosol, med. text.)
303-4 - Curua-Una centre (Kaol. Yell. Latosol, very heavy text.)
210-4 - Guamá-Imperatriz Area (Kaol. Yell. Latosol, very heavy textured)
2θ Degrees
70
60
50
40
30
20
10

Fig. 14e (< 2 μ – treated/tratados)

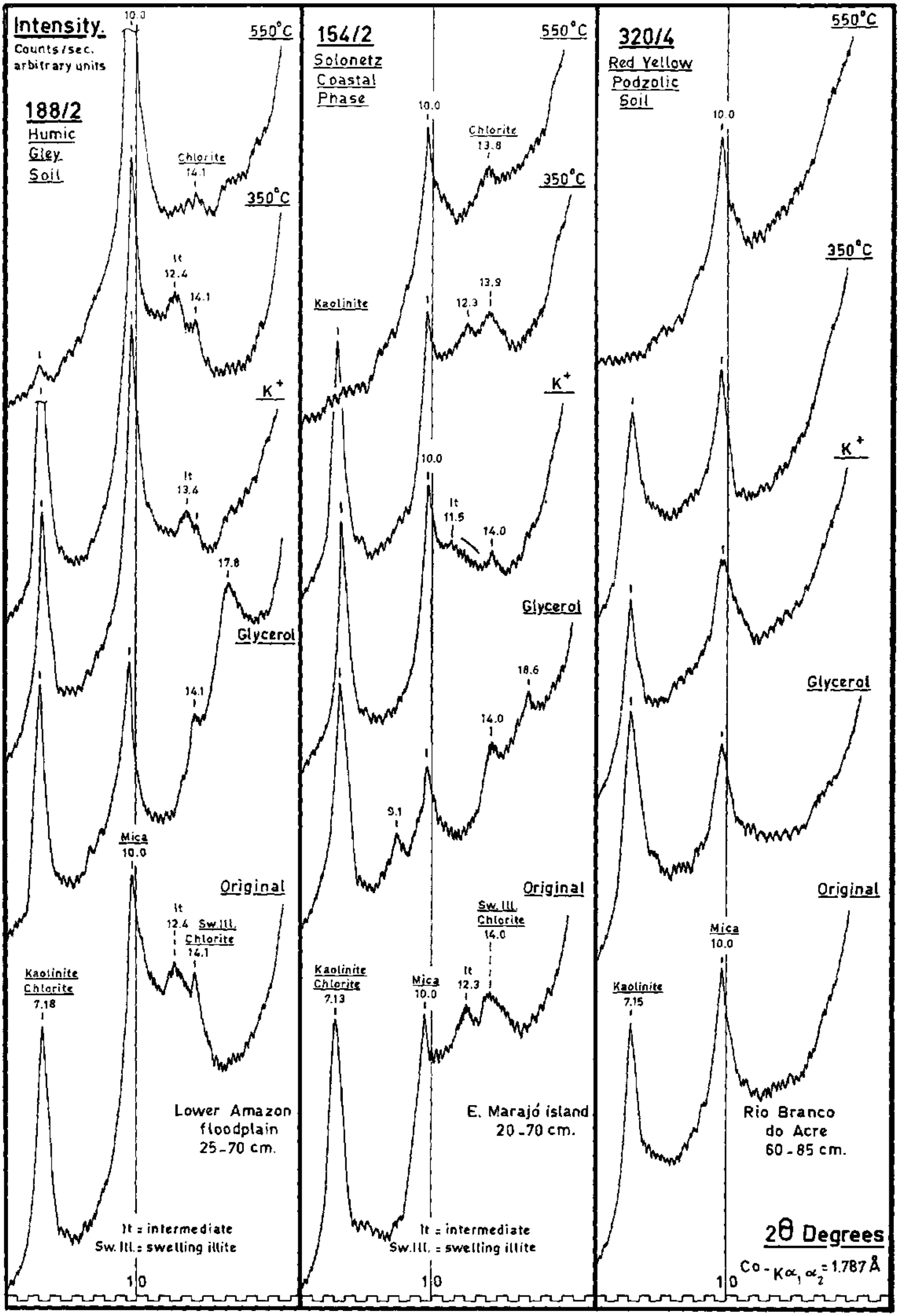


*Foto 9 Micrografia eletrónica da fração de argila ($< 2 \mu$) de Latosolo Amarelo Caolinítico (,Orto) de textura muito pesada (amostra 303–4; Curuá-una)**

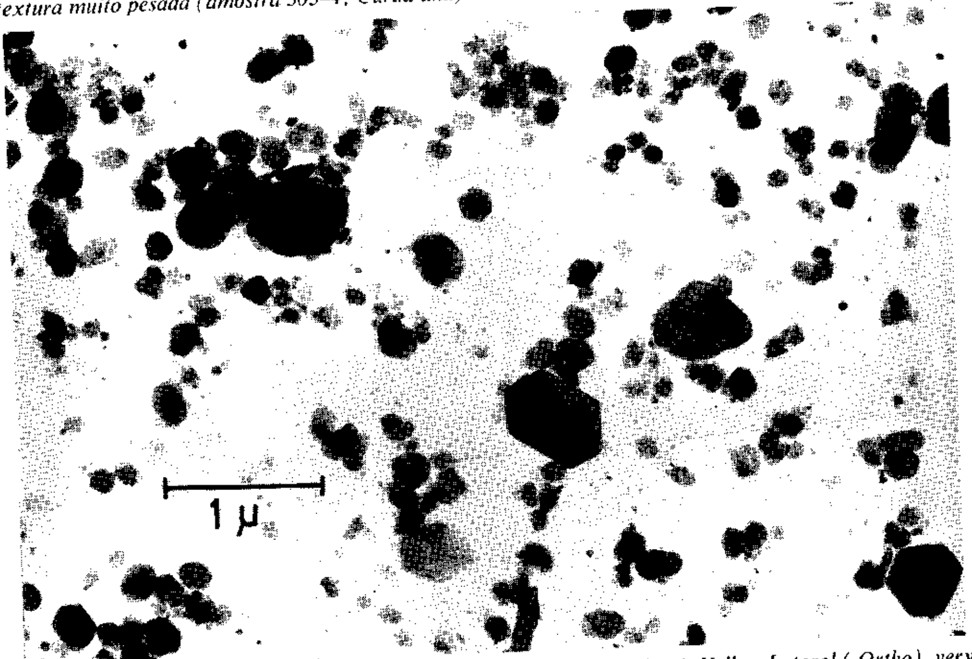


*Photo 9 Electron micrograph of the clay separate ($< 2 \mu$) of a Kaolinitic Yellow Latosol (,Ortho), very heavy textured (sample 303–4; Curuá-una)**

*Foto 10 Micrografia eletrónica da fração de argila ($< 2 \mu$) de Solo Laterita Hidromórfica (amostra 96–5; Caeté-Maracassumé)**

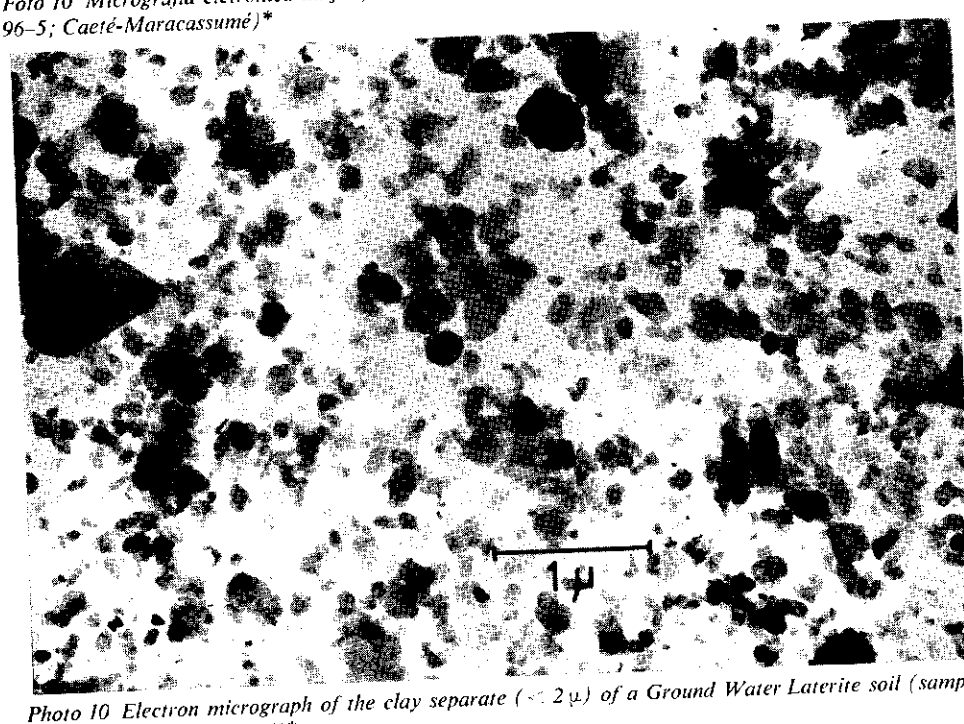


*Photo 10 Electron micrograph of the clay separate ($< 2 \mu$) of a Ground Water Laterite soil (sample 96–5; Caeté-Maracassumé)**

*Foto 11 Micrografia eletrónica da fração de argila (< 2 μ) de Solo Glei Húmico (amostra 188-2; Várzea do Baixo Amazonas**

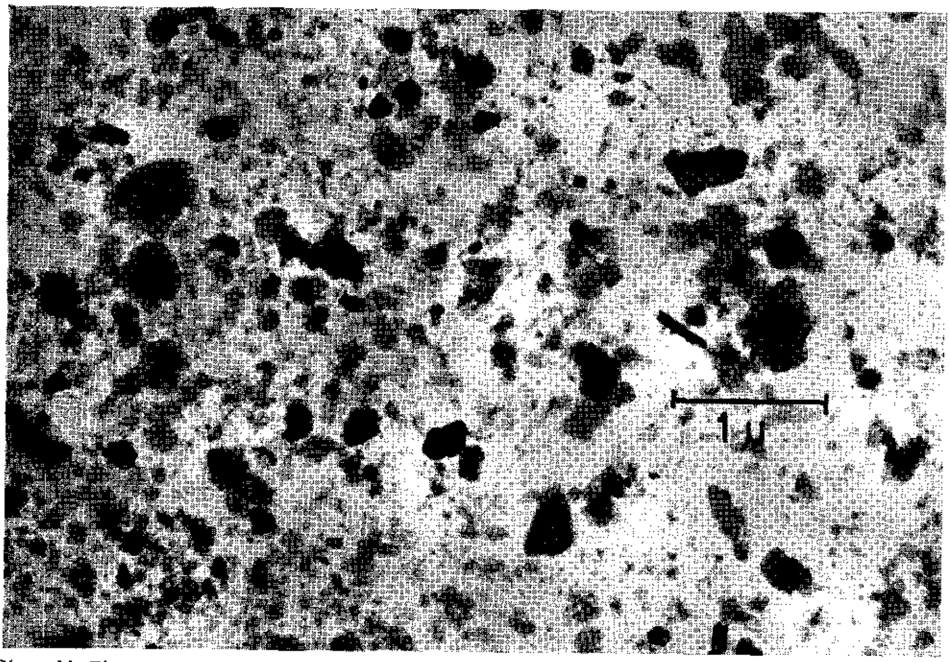


*Photo 11 Electron micrograph of the clay separate (< 2 μ) of a Humic Gley soil (sample 188-2; Lower Amazon floodplain)**

*Foto 12 Micrografia eletrónica da fração de argila (< 2 μ) de Solonetz, fase Costeira (amostra 154-2; Leste da ilha de Marajó)**

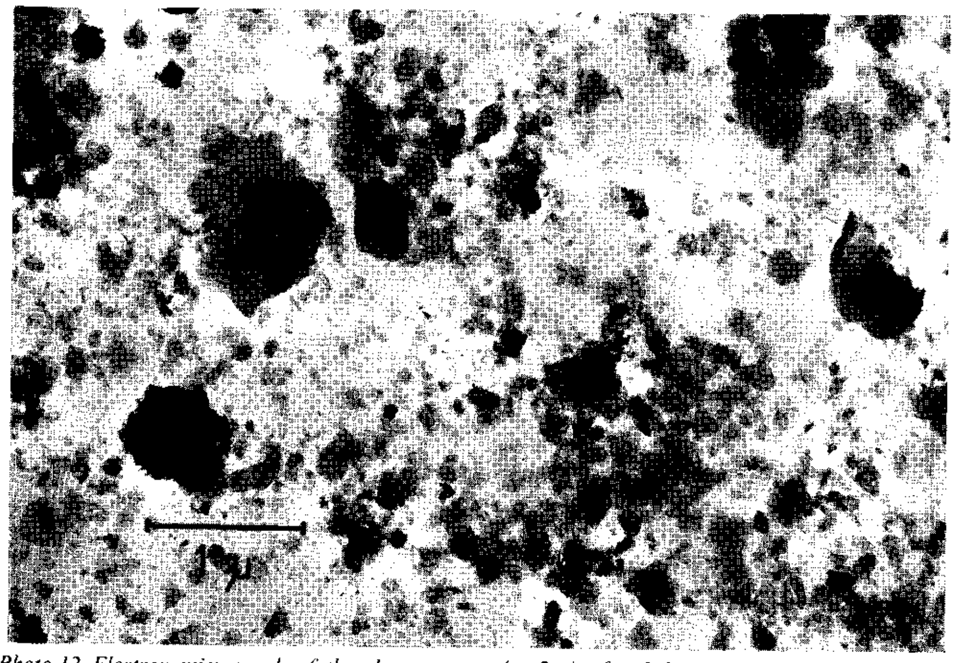


*Photo 12 Electron micrograph of the clay separate (< 2 μ) of a Solonetz, Coastal phase (sample 154-2; Eastern Marajó island)**

* By courtesy of Dr. H. Beutelspacher, Braunschweig, W-Germany.
Por obséquio do Dr. H. Beutelspacher, Braunschweig, Alemanha.

Table 7 Classification, location and general analytical data of samples with special analysis

Classification *classificação*		Location *localização*	Sample[1] *amostra*[1]	Deptl *profun didad* (cm)
Humic Gley soil *Solo Glei Húmico*	HG	Lower Amazon floodplain *Várzea do Baixo Amazonas*	188–2***	20–7(
Low Humic Gley soil, Carbonate subsoil phase *Solo Glei Pouco Húmico, fase subsolo com Carbonato*	LHG, C	Lower Amazon floodplain *Várzea do Baixo Amazonas*	190–2*	15–5(
Solonetz, Coastal phase *Solonetz, fase Costeira*	Sol, C	Eastern Marajó island *Leste da ilha de Marajó*	154–2***	20–7(
Solonetz, Coastal phase *Solonetz, fase Costeira*	Sol, C	Eastern Marajó island *Leste da ilha de Marajó*	175–3*	40–1
Solonetzic Humic Gley soil, intergrade to Ground Water Laterite soil *Solo Glei Húmico solonétzico, 'intergrade' para solo Laterita Hidromórfica*		Southern Marajó island *Sul da ilha de Marajó*	178–4*	55–1(
Hydromorphic Grey Podzolic soil, high base saturation, Ortho *Solo 'Hydromorphic Grey Podzolic', saturação de bases alta, Orto*	HP_{hb}, O	Araguaia Mahogany area *Area Araguaiana de Mogno*	290–2** 290–4	7–2 52–1
Red Yellow Podzolic soil, low base sat. *Solo Podzólico Vermelho-Amarelo, saturação de bases baixa*	RP_{lb}	Rio Branco do Acre *Rio Branco do Acre*	320–2 320–4**	3–2 60–8
Ground Water Laterite soil *Solo Laterita Hidromórfica*	GL	Caeté-Maracassumé area *Area Caeté-Maracassumé*	96–2 96–5***	15–7 150–1
Red Yellow Podzolic soil, int. to Kaolinitic Yellow Latosol, Concretionary phase *Solo Podzólico Verm.-Am., int. para Latosolo Amarelo Caol., fase Concrecionária*	RP-KYL, CR	Guamá-Imperatriz area *Area Guamá-Imperatriz*	302–4**	500–6
Kaol. Yellow Latosol, medium textured *Latosolo Amarelo Caol., textura média*	KYL_m	Guamá-Imperatriz area *Area Guamá-Imperatriz*	233–3**	70–1
Kaol. Yellow Latosol, very heavy textured *Latosolo Am. Caol., textura muito pesada*	KYL_{vh}	Curuá-una centre *Centro Curuá-una*	303–2 303–4***	22–6 95–1
Kaol. Yellow Latosol, medium textured *Latosolo Amarelo Caol., textura média*	KYL_m	Belém *Belém*	300–2 300–4*	32–7 150–2
Kaol. Yellow Latosol, very heavy textured *Latosolo Am. Caol., textura muito pesada*	KYL_{vh}	Guamá-Imperatriz area *Area Guamá-Imperatriz*	210–4**	60–1

[1]) Number of field description and of horizon/*número da descrição de campo e do horizonte do perfil*
tr. = traces/*traços* (< 0.1 m.e./100 g)

bela 7 Classificação, localização e dados analíticos gerais de amostras com análise especial

lori- zon *ori- onte*	Granulometric separate *fracão granulo- métrica* < 16μ (%)	16–80μ (%)	> 80μ (%)	C org. (%)	pH H_2O	Exchangeable cations *cations trocáveis* Ca^{++} (m.e./100 g)	Mg^{++}	K^+	Na^+	Cation exchange capacity *capacidade total de troca* (Na-acet. pH = 8.2) < 2000 μ (m.e./100 g)	< 2 μ	Specific surface *superfície específica* < 2000 μ (m^2/g)	< 2 μ
$_{1g}$	82.6	16.5	0.9	0.62	5.7	9.3	7.8	0.3	0.5	20.7	40.3	111	185
$_{1g}$	63.9	35.0	1.1	0.80	5.2	8.4	6.3	0.5	1.7	20.5	40.3	93	178
$_{2g}$	81.7	16.5	1.8	0.70	6.8	4.0	16.5	0.4	3.3	26.7	43.6	126	175
$_{22g}$	79.2	19.5	1.3	0.26	7.7	3.4	11.2	0.6	9.6	26.6	43.8	109	188
$_{21g}$	71.7	27.2	1.1	0.52	4.3	0.3	tr.	0.3	0.3	19.0	34.3	100	168
$_{2}$	10.2	52.4	37.4	2.03	5.0					6.1		38	
$_{2g}$				0.27	5.0	4.9	1.5	0.2	0.2	11.3		72	
$_{2}$				1.22	4.5					8.9		51	
$_{2}$	69.6	21.7	8.4	0.65	4.5					15.0		78	
$_{2}$	20.5	16.9	62.6	0.75	4.6					2.6		26	
$_{22g}$	65.8	5.3	28.9	0.23	4.5	0.1	tr.	0.1	0.1	5.9		45	90
C	59.1	16.7	24.2	0.05	4.7					3.0	4.6	35	59
$_{1}$	25.3	2.4	72.3	0.32	4.6					1.8	6.5	22	73
$_{3}$				2.04	4.7					6.7		65	
$_{22}$	77.5	18.2	4.3	1.06	4.7	tr.	tr.	0.2	tr.	5.3	4.8	50	54
$_{3}$				0.39	5.0					1.6		22	
$_{22}$	18.6	5.5	75.9	0.13						1.2		18	
$_{3}$	70.6	26.5	2.9	0.76	4.7					2.9	4.8	48	81

* Mineralogical analysis only (*cf.* Table 8)/*sòmente análise mineralógica (cf. Tabela 8)*
** also X-ray curves (*cf.* Fig. 14a–e)/*também curvas de Roentgengramas (cf. Fig. 14a–e)*
*** also Electron micrographs (*cf.* Photos 9–12)/*também micrografias eletrónicas (cf. Fotos 9–12)*

Table 8 Mineralogical composition of the various granulometric separates

Sample[1] *amostra*[1]	Symbol *símbolo*	Depth *profundidade* (cm)	Horizon *horizonte*	Separate/*fração* > 80 μ						Separate/*fração* 16–80 μ							
				Q	K	L	Ht	M	Ch	Q	K	L	Ht	Hd	F	M	Ch
188–2	HG	20–70	C_{1g}	73	10			12	5	47	10				16	15	12
190–2	LHG, c	15–50	C_{1g}	64	7	F=10		16	3	60	10				12	10	8
154–2	Sol, c	20–70	B_{2g}	60	10	12		15	3	67	7				10	8	8
175–3	Sol, c	40–140	B_{22g}	71	10	8		8	3	64	8				10	10	8
178–4		55–100	B_{21g}	20	4		76			88	4				4	4	
290–2	HP_{hb}, o	7–25	A_2	95			5			94			6				
320–4	RP_{lb}	60–85	B_2	90			10			92			8				
96–5	GL	150–170	B_{22g}	89	3		8			62	15		15			8	
302–4	RP-KYL, CR	500–600	C	30	35		35			18	45		30			7	
233–3	KYL_m	70–140	B_1	88	4		8			86	5		6		3		
303–4	KYL_{vh}	95–150	B_{22}	65	23		7	Hd=5		10	77		5	8			
300–4	KYL_m	150–250	B_{22}	97			3			100							
210–4	KYL_{vh}	60–150	B_3	75	18		7			17	69		6	8			

Amorphous matter and heavy minerals (maximum 1%) were neglected in the calculation of the minerals (mentioned in %)/*Material amorfo e minerais pesados (máximo 1%) foram desprezados no cálculo dos minerais, cujo resultado é dado em %*

[1]) *cf.* Table 7/*cf. Tabela 7*

Reference is made to the publication of CATE (1960). He studied, with both X-ray and DTA, samples of all horizons of a very heavy textured and a very light textured specimen of the soils under discussion, collected at Curuá-una centre. This author also arrived at about 80–85% kaolinite in the subsurface and subsoil horizons, when calculated on the clay fraction.

This description shows that the majority of the well-drained soils of the Amazon Planície have a subsoil horizon which constitutes a latosolic-B as described in II.2.1. The main Amazon Latosols fall into group *IIIc* of the tentative scheme of Table 6 elaborated by the national Brazilian Soils Commission. This, because of the relatively rather weak macro-structure of the soils, the slightly hard, to hard consistence in part of the profile when dry, the textural differentiation within the profile, and especially the composition of the clay fraction as expressed in the $SiO_2:Al_2O_3:Fe_2O_3$ molecular ratios.

The name 'Rego-latosol' might be applied for this subgroup of Latosols. This name is however misleading, because it implies relatively young age, without development of definite genetic horizons. The soils under consideration, however, have a distinctly zonal character. They are mature soils, because they are deeply and strongly weathered and show definite profile development, although the transitions between the horizons are diffuse or gradual (*cf.* DAY, 1961). In discussions within the Soils Commission, it *bela 8 Composição mineralógica das várias frações granulométricas*

Separate/*fração* 2–16 μ								Separate/*fração* < 2 μ									
Q	K	L	Ht	Hd	F	M	Ch	Q	K	L	Ht	Hd	F	M	It	Sw	Ch
35	15				15	20	15*	20	22				3	30	10	8	7
35	15				15	23	12*	20	26				3	20	16	8	7
35	15				15	20	15*	20	25				3	20	10	15	7
37	14				17	17	15*	20	25				3	15	6	24	7
59	13	2	2		3	18	3	25	35	6	3	2		10	16		3
92						3	5	30	30					15	25		
62	12		8		8	7	3	24	24	4	8	7		33			
15	56		12	It=5		10	2	2	92		6						
8	55		30			7		3	85	4	8						
73	20				7			3	84	5	5	3					
15	71	4		10				2	85	3	5	5					
68	14	3	3		12			6	84	5		5					
20	63			12	5			3	80	7	5	5					

= quartz/*quartzo;* K = kaolinite/*caolinita;* L = limonite (goethite)/*limonita (goethita);* Ht = hematite/*natita;* Hd = hydrargillite/*hidrargilita;* F = felspar/*feldspato;* M = mica (illite)/*mica (ilita);* It = ermediate (between kaolinite and illite)/*intermediário (entre caolinita e ilita);* Sw = swelling illite *a expansível;* Ch = chlorite/*clorita*

Some swelling illite included/*incluso alguma ilita expansível*

has already been agreed upon that such a term should be rejected. 'Rego-latosol' will not therefore be used, and a new term is proposed in view of the extent of these Latosols.

For full characterisation it is considered the best plan to use the term *Kaolinitic Yellow Latosol* (KYL), since apparently the most common colour of the subsoil horizon is of a yellow hue.

As mentioned, in transition areas to arid regions the colour tends to be of reddish hue, and the base saturation may be medium. For the time being, the term *Kaolinitic Red Latosol* (KRL) is applied in this case. Another name might however fit better.

The light and very light textured profiles must fall outside the Latosols, and belong to the Acid Sands. Such profiles, as far as they occur on the Amazon Planície, are otherwise very similar to the Kaolinitic Yellow Latosols. Therefore, the term *Kaolinitic Latosolic Sand* (KLS) is applied for those profiles that have less than 15% clay in the B horizon.

Besides the typical Kaolinitic Latosols, there are in the Amazon Planície comparable soils, in which however several of the characteristics of a textural-B horizon (*cf.* II.2.1) are present. In this instance the names to be applied will be 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 (for details *cf.* III.2).

II.2.3. Comparison with other Classification Systems

Important other systems for classification of red and yellow soils of tropical and subtropical uplands have been developed for Africa.
A. The classification for French speaking African countries (AUBERT and DUCHAUFOUR, 1956).
B. The classification for Angola, developed by Portuguese soil scientists (BOTELHO DA COSTA *et al.*, 1959).
C. The classification for Congo, developed by Belgian soil scientists (SYS *et al.*, 1961).
D. The classification for the soil map of Africa south of the Sahara (D'HOORE, 1959).

No attempt will be made to give a full comparison between the classification system as developed in the U.S.A. and in Brazil, and those mentioned above. Over-all correlations are in execution, for instance by FAO for its 'Soil map of the World' program. Reference is made to the many comparative notes given by LEMOS, BENNEMA, SANTOS *et al.* (1960) on the classification applied for São Paulo State.
In this publication, an attempt is only made to establish the place of the Brazilian 'Latosols', and more in particular of the Kaolinitic Yellow Latosol and the Kaolinitic Latosolic Sand, in the African systems:

A. AUBERT and DUCHAUFOUR (1956) distinguish *Sols rouges méditerranés, Sols ferrugineux tropicaux (ou fersiallitiques)* and *Sols ferralitiques.* The latter are characterised by a 'ferralitic' B horizon, with individualisation of iron and aluminum, and are about identical with the Brazilian concept of 'Latosols'. Within the *Sols ferralitiques* the following subgroups are distinguished:
1. *Sols faiblement ferralitiques:* Ki[1] 1.7–2.0
2. *Sols ferralitiques typiques:* Ki$<$1.7
3. *Sols ferralitiques humiques (ou humifères):* more than 5% organic matter in the A horizon
4. *Sols ferralitiques à cuirasse en place:* with hardpan of hard plinthite, formed in flat terrain
5. *Sols ferralitiques à cuirasse de bas de pente:* with hardpan of hard plinthite, formed at the foot of slopes

The *sols faiblement ferralitiques* are comparable with the Kaolinitic Yellow Latosol, and perhaps also parts of groups 4 and 5. No special classification is given for the sandy ferralitic soils.

B. The classification of BOTELHO DA COSTA *et al.* (1959) is comparable with the French one. Distinguished are *Solos tropicais semi-áridos, Solos fersialíticos tropicais* and *Solos ferralíticos.* The latter are approximately identical with the Brazilian concept on 'Latosols'. An exception to this is formed by a subgroup of the *Solos ferralíticos*

[1]) SiO_2: Al_2O_3 ratio – see before.

which contains weatherable primary minerals, and is also called *Solos pára-sialíticos*. The subdivision of the *Solos ferralíticos* proper is as follows:

1. *Solo psamo-ferralítico: sandy*
2. *Solo fortemente ferralítico* or *levi-ferralítico:* not sandy, Ki <1.33
3. *Solo mediamente ferralítico:* not sandy, Ki <1.7
4. *Solo fracamente ferralítico:* not sandy, Ki 1.7–2.0

Presence or absence of hard plinthite, and possible humic character, appears only in the lower categories of the classification.

It is apparent that the Kaolinitic Yellow Latosol is comparable with the *Solo fracamente ferralítico*, and the Kaolinitic Latosolic Sand with part of the *Solo psamo-ferralítico*.

C. The classification of SYS *et al.* (1961) is rather different from the two mentioned above. For his classification he discerns *B textural*, *B structural* and *B de consistence*, which are defined as follows:

B textural: horizon of clay illuviation, which is at least one fifth heavier in texture than the A and the C horizons, and has clay skins.

B structural: horizon which has no clay illuviation but nevertheless clay skins on an appreciable part of the structure elements, and which has a firmer consistence than the A and the C horizons.

B de consistence: horizon without clay illuviation or clay skins, but only with a firmer consistence than the A and C horizons. It has a granular or weak to moderate subangular blocky structure, and contains often round pseudo-concretions of clay.

This *B de consistence* is not identical with the 'latosolic-B' as described in II.2.1; the Latosols proper of the Congo are for a part described as A–C profiles. The *B de consistence* seems to be identical with the transitional zone between the A and the B horizon (A_3, B_1), with stronger consistence, of some of the Brazilian Latosols (*cf. ad IIIc* of Table 6 of II.2.1, and II.2.2).

Recently, SYS (1962) defined also a *B ferralitique* for the Congo. This one is almost, if not quite identical with the latosolic-B of Brazil. In the same publication it is stated that the *B de consistence* forms the upper part of some ferralitic-B horizons, and that the Congolese 'C' horizon may form the lower part of this ferralitic-B horizon. The *B de consistence poudreux* applied to the soil survey of Rwanda-Burundi (FRANKART, HERBILLON and VERHOEVEN, 1962) is believed to be identical with the latosolic-B.

The Congo soils fall into two large groups, namely *(1)* soils from recent materials, and *(2)* soils from non-consolidated kaolinitic materials. The second group, called *Sols climatiques*, is divided into *Kaolisols* and *Kaolisols lessivés*. The former have a *B structural* or *B de consistence*, the latter a *B textural*. The well-drained *Kaolisols* are subdivided in *hygro-*, *hygro-xero-*, and *xero-kaolisols*. The *hygro-kaolisols* are found under tropical forest, in regions with less than two dry months. The *hygro-xero-kaolisols* are found under tropical savannah, in regions with more than two dry months. Both groups are *ferralitiques* (largely kaolinite and sesquioxides in the clay fraction), and have a base saturation that is below 40–50%; in part, they are humic *(humifères)*[1]. The *xero-kaolisols* occur in dryer regions. They are *fersialitiques* (besides kaolinite also appreciable amounts of silicate clay minerals of 2:1 lattice occur), have a *B structural*, and a base saturation that is above 40–50%.

The subdivision of the *hygro-* and *hygro-xero-kaolisols* is according to the degree of weathering of the kaolinitic material, and the texture. The subsoil horizon can be *ferrisolique* or *ferralsolique*. Contrary to the *ferralsolique* horizon, the former has either:

1. an appreciable amount of clay skins (more than 25%) on the horizontal and vertical aggregate units, *i.e.* a *B structural* or
2. a silt/clay ratio larger than 0.2 or 0.15 (for sedimentary rocks and alluvia, respectively igneous and metamorphic rock), or
3. more than 10% weatherable minerals in the fraction 50–250 micron.

Three main groups within the *hygro-* and *hygro-xero kaolisols* emerge, namely:
1. *Ferrisols.* These are *ferrisolique;* gibbsite may be present in small amounts; amorphic gels of silica and aluminum are present in appreciable amounts.
2. *Ferralsols.* These are *ferralsolique*, and have more than 20% clay in one of the horizons above 1 m depth. Gibbsite is often present; small amounts of amorphic gels of silica and aluminum only in a few cases.
3. *Arenoferrals.* These are *ferralsolique* and have less than 20% clay in the horizons above 1 m depth.

It is evident that of the *hygro-* and *hygro-xero-kaolisols* the ones that are *ferrisolique* fall outside the concept of soils with a 'latosolic-B' horizon (*cf.* II.2.1). The *Ferralsols* are however comparable with the Brazilian Latosols, and the greater part of the *Arenoferrals* is comparable with the Latosolic Sands. The *Ferralsols* and *Arenoferrals* are not subdivided systematically according to the composition of the clay fraction (no data on the SiO_2: Al_2O_3: Fe_2O_3 molecular ratios). Among the various *Ferralsols* (*e.g.* JONGEN and JAMAGNE, 1959; SYS, 1960; in the latter publication all the *Ferralsols* described have a *B de consistence*, and the *Arenoferrals* A–C profiles), the Kaolinitic Yellow Latosol is most similar to the *Ferralsols des plateaux du type Yangambi* and the *Ferralsols des bas-plateaux de la Cuvette Congolaise*. The Kaolinitic Latosolic Sand is similar to the *Arenoferrals des plateaux du type Salonga.*

The similarity in morphometric field characteristics between the Amazon Kaolinitic Yellow Latosol and the *Ferralsols* of Congo, more in particular those of Yangambi, was already noted by D'HOORE and TAVERNIER on recent visits to Amazonia. The Fe_2O_3/clay ratios of the Yangambi soils are approximately identical with those of the

[1]) Recently, the *kaolisols humifères*, occurring in mountain areas, have been set apart from, and placed at the same level as the *hygro-kaolisols*, the *hygro-xero-kaolisols* and the *xero-kaolisols* (SYS, 1962).

Kaolinitic Yellow Latosol and the Kaolinitic Latosolic Sand, but their cation exchange capacity seems to be considerably higher (10–15 m.e./100 g clay; *cf.* DE LEENHEER, D'HOORE and SYS, 1952, p. 37–41, and SYS, 1960, p. 74).

D. Recently, several drafts have been prepared for a general soil map of Africa, by the Inter-African Pedological Service of the Commission for Technical Co-operation in Africa south of the Sahara (C.C.T.A.). D'HOORE (1960), in explaining the legend of the third draft of this map, distinguishes: 'ferruginous tropical soils' (or fersialitic soils), 'ferrisols' and 'ferralitic soils.' The classifications mentioned above are therefore combined to a degree.

His ferralitic soils, which closely resemble the *sols ferralitiques* of AUBERT and DUCHAUFOUR, the *solos ferralíticos* of BOTELHO DA COSTA, and the *Ferralsols* + *Arenoferrals* of SYS, are comparable with the Brazilian Latosols. D'HOORE's criteria for subdivision of the ferralitic soils are not specifically the composition of the clay fraction, but more the colour of the soil and the parent material.

The Kaolinitic Yellow Latosol is believed to compare most closely with his mapping unit *Kb*: 'ferralitic soils with yellow-yellowish brown as dominant colour, and developed on unconsolidated, more or less clayey sediments'. The Kaolinitic Latosolic Sand is the most like the mapping unit *Ka*: 'ferralitic soils, with yellow-yellowish brown as dominant colour, and developed on unconsolidated sandy sediments'.

II.3 Plinthitic Soils

II.3.1 Origin of Plinthite

For the benefit of the following discussion plinthite will be subvivided into two groups, namely:

Soft plinthite (mottled clay, *Fleckenzone*, *argile tacheté*, *horizon bariolé*):
A layer of soft (*i.e.* cuttable with knife), dense, usually clayey, humus-poor mineral material with many, coarse, prominent mottles. The mottles are red or purple[1], often with admixture of some yellow, and occur in a white or light grey matrix. In case of predominance of the reddish, the situation may be described as the occurrence of white and some yellow mottles in a red or purple matrix. The pattern of mottling is varying. It may be reticulate (polygonal), prismatic (vesicular) or platy (laminar). The centres of the red or purple parts are often indurated to some extent.

Hard plinthite (iron concretions, *Eisenkruste*, laterite, *cuirasse*, ferruginous quartzite, *canga*, *piçarra*): A slag-like (*i.e.* only breakable with hammer), humus-poor mineral

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

material, apparently largely consisting of indurated iron oxides; as well as the earth between this material, if present. The indurated elements vary in colour (red to black), size (from fine gravel to enormous boulders and crusts), shape (pisolithic, platy, prismatic, massive, vesicular), grainage (fine to very coarse elements, usually of quartz, around which the sesquioxides are cemented), and arrangement (vertical, horizontal, irregular).

These two names will also be placed, between square brackets, after relevant terms in the literature referred to below.

According to HARRASSOWITZ (1926, 1930), a fully developed 'laterite profile' should consist of the following sequence:

1. *Eisenkruste (Zellenlaterit):* ironstone crust, *i.e.* indurated, slag-like, porous sesquioxide [hard plinthite]
2. *Anreicherungszone (Fleckenzone):* enrichment zone, mottled zone [soft plinthite]
3. *Zersatzzone (Bleichzone):* dissolution zone, grey zone
4. *Frisches Gestein:* parent material

As already mentioned in II.1, HARRASSOWITZ took it as proven that the concentration of iron and aluminum occurs at the soil surface, due to evaporation after transport of sesquioxide-rich soil water by capillary rise from the grey zone. He therefore assumed that laterite [plinthite] formation does not, at least not fully, take place under tropical rain climate or even monsoon climate, but requires a savannah climate. The laterite [plinthite] would not even be able to support tropical forest, due to the crust formation *(Waldfeindlichkeit)*.

MARBUT (1932), however, observed in the Amazon valley that the HARRASSOWITZ sequence, if occurring, is found below soil material. He noted the following succession:

nr. 1: soil, nr. 2: iron oxide layer, porous and slag-like [hard plinthite], nr. 3: mottled layer [soft plinthite], nr. 4: grey layer, nr. 5: unconsolidated clay and sand.

The second[1] layer is often lacking. The soil above the zone of iron concentration is always 'podzolized', in the sense that it has a relatively light coloured and light textured surface layer (A horizon), rich in SiO_2. MARBUT concluded from extensive field observations throughout the valley that the HARRASSOWITZ profile is due to a process of segregation which takes place at shallow depth *below* the surface, under the influence of ground water, and may be followed by the erosion of the overlying soil material. The layers of sesquioxide accumulation and induration: mottled zone [soft plinthite] and crust [hard plinthite], constitute essentially one horizon which develops at the surface of the ground water. The thickness of the horizon depends largely on the width of the zone over which the ground water surface fluctuates during the year.

[1]) In the publication concerned actually is written *fourth*. From its context it becomes, however, apparent that MARBUT must have meant the *second* layer. Writing or printing errors are common in that paper. They may have contributed considerably to the confusion which subsequently arose on the subject.

According to MARBUT, if the zone of fluctuation is deep no sesquioxide accumulation takes place, because of a restriction in the access of atmospheric oxygen. The crust [hard plinthite] develops in the top of the horizon where the mottled material [soft plinthite] outcrops owing to erosion of the surface layer or at escarpments, or where the material occurs below a shallow layer of sandy soil material. Crusts [hard plinthite] on dissected plateaux which nowadays have no shallow ground water level, are considered to be fossil, and the relics of a mottled zone [soft plinthite] which developed before relative raising of the terrain.

With his observations made in regions with a tropical rain climate, and in agreement with this concept of the development of the crust, MARBUT found no reason to believe that a climate with alternate wet and dry seasons was a requisite. Moreover, he argued, with the help of field observations, that formation of such a crust through capillary rise and evaporation at the surface in any case is highly improbable. That such a process is also difficult to assume for purely physical reasons, was afterwards discussed by MOHR and VAN BAREN (1954, p. 371). MARBUT concedes that 'the horizon of iron oxide accumulation and induration may develop at the surface, but only in the evidently rare case when the ground water surface lies at the earth's surface'.

Since MARBUT's observations, many field and laboratory studies have been published on the subject. Many of them are in agreement with MARBUT's conclusions. THORP and BALDWIN (1940), for instance, adducing evidence from China and Thailand, are convinced that the BUCHANAN's laterite [soft plinthite] develops in the lower part of a soil called 'Ground Water Laterite'. This soil evoluates under intermittently shallow ground water level, by transport of iron compounds from superficial horizons (A horizon) downward to the subsoil (B horizon) where they form reddish mottles that harden on exposure. They give a picture of how bleaching of the superficial horizon occurs in such soils ('podzolisation', 'lixiviation'). They also state that 'erosion and exposure of the laterite [soft plinthite] horizon is the true explanation of the origin of the much discussed laterite crusts [hard plinthite]'.

PRESCOTT and PENDLETON (1952), basing their conclusions mainly upon Australian occurrences, state: 'the evidence, therefore, is that laterite [hard plinthite] is essentially the exposed illuvial horizon of an ancient soil'. They consider it likely that the concentration of iron in the zone of fluctuating ground water is due to both downward movement from eluvial surface horizons, and the carrying upwards with a rising water table from the grey zone (for which latter they prefer the term 'pallid' zone). Practically all laterite crusts [hard plinthite] in Australia are considered to be fossil and of Late Tertiary age. They are believed to have been formed when climatic and geomorphologic conditions were different from the present day ones.

As regards Africa, a very extensive study of plinthitic materials (*zones de accumulation de sesquioxides*), their different mode of formation, and their classification in a genetic system, is given by D'HOORE (1954). According to him, the accumulation of sesquioxides followed by hardening can be *relative* or *absolue*. The former is a carrying off (leaching) of other constituents, principally of Si, from the horizon concerned, whilst the latter is an addition of sesquioxides into the horizon. The addition of sesquioxides at the absolute accumulation is believed to take place predominantly downward, by soil solutions that pass vertically (in the profile) or laterally (along slopes), while sometimes Fe is added by flooding water. The first movement gives the *cuirasse de l'horizon B et l'horizon gleyifié*, the second the *cuirasse de basse pente* or *cuirasse de nappe*. The flooding gives the *cuirasse de galerie*.

A similar classification is applied by MAIGNIEN (1958). He supposes that Al accumulation horizons (bauxite horizons) generally belong to the relative ones, since Al is considered to be principally a residual material, and that Fe (and Mn) accumulation horizons are usually absolute. For West Africa, plinthite formation is thought to be greatest in the transition zone between tropical rain forest and desert, where it is practically independent of the parent rock. MAIGNIEN states also '*les cuirasses* [hard plinthite] *s'édifient normalement à l'interieur des profils. La mise à l'affleurement se fait par érosion hydrique qui décape les horizons meubles de surface. Une cuirasse affleurante est la partie supérieure d'un profil tronqué. Elle représente un stade senil d'évolution.*'

The most recent publication on plinthite is the review by SIVARAJASINGHAM, ALEXANDER, CADY and CLINE (1962). They give also a picture on the chemistry and the mineralogy of sesquioxide concentration and hardening.

II.3.2. Plinthite in Amazonia

Since the observations of MARBUT, a few geographers' descriptions have been published, in Portuguese, on lateritic crusts [hard plinthite] in Northern and Central Brazil (for instance GUERRA, 1953, 1954). But there has been no large-scale checking or elaboration of MARBUT's findings. A detailed report on the widespread occurrence of plinthitic materials in Amazonia, and a discussion in relation to soil classification, is therefore thought to be useful, also in view of the fact that around the world still relatively few complete data about 'Ground Water Laterite' soil are reported.

The formation of plinthite in Amazonia takes place predominantly on flat land surfaces with a cover of unconsolidated sediments of Tertiary or Quaternary age. There are also a number of areas with Paleozoic-Mesozoic outcrops or peneplained Pre-Cambrian crystalline basement which show formation of the material. As will be demonstrated in the following, the Amazon plinthite formation is, with few exceptions, of the type called *accumulation absolue* by D'HOORE (1954), more especially the formation of *cuirasses de l'horizon B et l'horizon gleyifié*. A fluctuating ground water level, or pseudo ground water level, is indeed essential for the formation of by far the majority of the plinthitic materials of Amazonia.

Only a few instances were encountered in which a fluctuating ground water level may not be an essential factor in plinthite formation. This concerns consolidated sediments (*cf.* Profile descriptions 35 and 41, and the notes on Non Calcic Brown-like soil, Gravelly phase and Acid Brown Forest-like soil, Gravelly phase in III.2.). The plinthite formation in these instances, which will not be further discussed, probably falls under D'HOORE's *accumulation relative*. It may be a feature of a general weathering process in the tropics under conditions of good drainage.

The possibility of accretion, without a fluctuating ground water table proper, of fossil plinthite layers in areas of unconsolidated sediments was suggested in one instance (*cf.* page 115).

II.3.2.1 *Plinthite-in-formation*

The presence of a relatively shallow and fluctuating ground water level, or pseudo ground water level or saturation zone, is frequent in Amazonia because of various factors. There is a large expanse of flat land surfaces, which are moreover low lying with regard to the local drainage levels: areas belonging to the Early Tertiary (?) peneplanation surface, sections of the Plio-Pleistocene planalto, portions of the Late Pleistocene terraces, and the Early Holocene terrains. There are, in many places, temporary difficulties in the discharge of the rain water, due to seasonally high water level of many of the rivers and yearly peaks in rainfall distribution in a large part of the region. It may be noted that fluctuations of the ground water level are not necessarily linked to the occurrence of wet and dry seasons. Such fluctuations are also governed by differences in lateral drainage possibilities that are linked with seasonal differences in water discharge of the river system in the area. In many parts of Amazonia, this discharge is determined more by the amount of water drained from the Andes and Central Brazil, which has a large seasonal variation, than by the rain falling in the region itself. Another factor which favours the occurrence of shallow ground water levels is the presence, at a number of places, of shallow-lying impervious layers, for instance hard sand stone or fossil hard plinthite (*cf.* I.4.5).

The absence of any enrichment of the above mentioned flat land surfaces through the deposition of sediments of flooding, of volcanic ashes or of other windborne material is noteworthy (*cf.* SAKAMOTO, 1960). This absence is another condition favouring the formation of plinthite, which is essentially a highly weathered material.

FORMATION OF PLINTHITE BELOW OR IN THE LOWEST PART OF THE SOLUM

At several places, notably where light textured, loose sediments form the cover of the land, it was observed that plinthite is formed in a zone of fluctuating ground water level which is relatively deep below the surface (arbitrarily deeper than two metres). In these instances, the solum proper of the soil profile is normally not affected by this formation. The soil is well or moderately well drained, and constitutes for instance a Kaolinitic Yellow Latosol. The zone of fluctuating ground water level is, apparently, too deep to hamper full activity of roots and soil fauna, which should help to form and maintain the latosolic profile as it is.

Such a situation was observed in several parts of the relatively low uplands that may be found in the Estuary region (predominantly Epi- and Late Monastirian terrace levels, *cf.* I.4.3). The fluctuations in the ground water level in these parts are largely determined by tidal movements, which take place at 2 to 5 m below the surface. On cliff faces, the soft plinthite formed in the fluctuation zone becomes exposed at low tide. The hardening relics, which *in loco* usually have a vesicular-reticulate form, are often found on the beaches. They have a black surface due to the action of the estuary water (*pedra preta* of Soure, Mosqueiro and other places; Amapá town; *cf.* the notes of MARBUT and MANIFOLD, 1926, p. 434). The following short profile description illustrates such a situation:

Profile 1. (KAOLINITIC YELLOW LATOSOL, medium textured – over plinthite-in-formation)
Field description 185A (Sombroek)
Marajó-island, Soure, river cliff
Terrace 2–3 m above high water level (fluctuations in water level are 2–3 m, largely due to tides).

A_1 *0–25 cm:* Dark brown (10YR 3/3) light sandy loam. Many roots, many pores. Transition gradual.

A_3 *25–70 cm:* Yellowish brown (10YR 5/6) sandy loam. Many roots, many pores. Transition gradual to diffuse.

B_{21} *70–150 cm:* Brownish yellow (10YR 5/8) light sandy clay loam. Common roots, many pores. Transition diffuse.

B_{22} *150–210 cm:* Reddish yellow (7.5YR 7/8) sandy clay loam. Common roots, many pores. Transition gradual.

C_{1g} *210–260 cm:* Pale yellow (2.5Y 8/4) light sandy clay loam, with common medium sized distinct mottles of white (2.5Y 8/2) and red (2.5YR 5/8), especially in the lower part. Transition gradual.

C_{2g} *260–350 + cm:* White (10YR 8/1) light sandy clay, with many coarse prominent mottles of red (10R 4/6) and some yellow (10YR 7/8) and pink (5YR 7/4), the latter especially in the lower part; mottling is in a vesicular to coarse prismatic pattern. On the cliff face itself the red parts are hard (hard plinthite), but in from the bank the whole horizon is soft except for some tiny centres in the red (soft plinthite).

In this case, the plinthite formation is more a geological than pedolgiocal process. Most probably, there is no transport of sesquioxides and/or clay sized particles from the upper 200 cm. to the horizon of plinthite formation.

Similar horizons of soft plinthite are reported to occur sometimes in the B_3 and C horizons of a few soils of Rio de Janeiro and São Paulo States which are comparable to the Kaolinitic Yellow Latosol (*cf.* BARROS, DRUMOND, CAMARGO *et al.*, 1958, p. 289; LEMOS, BENNEMA, SANTOS *et al.*, 1960, p. 389).

FORMATION OF PLINTHITE WITHIN THE SOLUM: GROUND WATER LATERITE SOILS

The formation of plinthite nearer the surface was observed in many places. These are terrains with an imperfect drainage, on which the zone of fluctuating ground water level is shallow (arbitrarily at less than two metres depth). In these instances this zone is shallow enough to restrict the activity of roots and soil fauna. No full homogenisation, which usually would result in Latosol formation, is therefore possible. Clay-sized particles and sesquioxides are carried downward to the horizon of plinthite formation. The latter, in effect, now forms the B horizon of a pedological profile. The *Ground Water Laterite soil* profile proper, as defined by MARBUT and successors, develops.

The first large expanse of these soils was observed by DAY (1959)in the Caeté-Maracassumé area. Afterwards, Ground Water Laterite soils were found to occur also in many parts of the Lower Amazon region and on the Island of Marajó (DAY, 1961;

SOMBROEK, 1962b). Scattered observations elsewhere led to the conclusion that the soil is very common throughout Amazonia, often associated with areas of natural savannah or savannah-forest (*cf.* IV.1.2.2). Several phases of the soil, and intergrades of it to other soils, have been distinguished to date. A picture about the variability in the profile characteristics may be obtained from the following short descriptions, partly based on profile pits and partly on augerings. Most of these profiles were analysed. The analytical data that are thought to be of importance for the classification of the soils are given in Appendix 9.

Above each profile description the provisional classification, as used in the survey reports, is printed between brackets. In this publication, no attempt will be made to give an elaborate scheme for classification of the various Ground Water Laterite soils. It is evident, however, that the described profiles all come outside the Latosol or the Oxisol Order, because the plinthitic horizon has many of the characteristics of the 'textural-B', *c.q.* the 'argillic horizon'. The soils seem to constitute, in fact, a kind of imperfectly drained phase of the Red Yellow Podzolic soils. Many of them probably come under

Foto 13 O perfil de um solo Laterita Hidromórfica. Claremente visíveis são o horizonte-A_1 colorido de humo, o horizonte A_2 arenoso branco e o horizonte B densa e de textura pesada de 'plinthite' macio, com seus numerosos mosqueados grossos e prominentes de matiz vermelha numa matriz de cinzento claro. Neste perfil os mosqueados têm padrão reticular. Por causa do caráter muito alvejado de horizonte A_2, o perfil classifica-se entre o chamado solo Laterita Hidromórfica, fase Baixa (fotografia Mr. Th. H. Day)

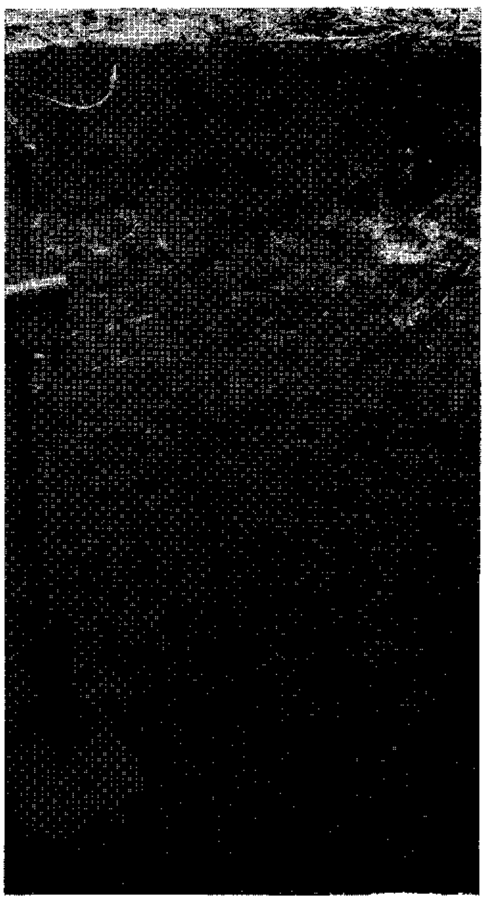


Photo 13 The profile of a ground Water Laterite soil. Clearly visible are the humus stained A_1 horizon, the white sandy A_2 horizon, and the dense, heavy textured B horizon of soft plinthite, with its many coarse and prominent mottles of red hue in a light grey matrix. The mottles have a reticulate pattern in this profile. Because of the strongly bleached character of the A_2 horizon, the profile falls under the so-called Ground Water Laterite soil, Low phase (Photo by Mr. Th. H. Day)

the 'Ultisols' of the VIIth Approximation, more especially the *Ochraquultic Plintaquults* (SOIL SURVEY STAFF, 1960, p. 226–227). The Ground Water Laterite soil, Low phase seems to be identical to the 'Gray Ferruginous soil' as defined in the Multilingual Vocabulary of Soil Science (JACKS, TAVERNIER and BOALCH, 1960).

Profile 2 (GROUND WATER LATERITE soil, medium textured phase)
Field description 124 (Day, Sombroek)
Lower Amazon region, 20 km NNW of Prainha (Lat. 1°.48'S; Long. 53°.40'W)
Flat; remnant of terrace *ca.* 50 m above local rivulet. Imperfectly drained because of impervious layer of fossil plinthite at shallow depth (outcropping at sides); upper phreatic level – ? m, lowest phreatic level below —1.1 m. Early Pleistocene sediments. Grasses and scattered shrubs; yearly burned. Surface strewn with platy slabs of hard plinthite, stratified coarse and fine grained.

A_1 *0–10 cm:* Yellowish brown (10YR 5/4) light fine sandy loam.
A_2 *10–30 cm:* Brownish yellow (10YR 6/6) fine sandy loam.
B_{1g} *30–60 cm:* Reddish yellow (5YR 6/8) fine sandy clay loam, with few to common medium sized prominent mottles of weak red (7.5R 4/4); also some white spots. About 15% small (2–3 cm) coarse grained plinthite concretions.
B_{2g} *60–110 + cm:* Light reddish brown (5YR 6/4) clay, with many coarse prominent mottles of dusky red (7.5R 3/4), strong brown (7.5YR 5/8) and light grey (N7/0).

Profile 3 (GROUND WATER LATERITE soil, medium textured phase)
Field description 136 (Day, Sombroek)
Lower Amazon region, 5 km E of Terra Santa (Lat. 2°.07'S; Long. 56°. 27'W)
Extensive flat terrain, 1–2 m above local river high water level. Imperfectly drained; upper phreatic level – ? m, lowest phreatic level below —2.3 m. Early Holocene sediments. Grasses and patches of low trees; yearly burned.

A_1 *0–10 cm:* Dark grey brown (10YR 4/2) very friable fine sandy loam, with a few fine faint mottles of strong brown (7.5YR 5/8). Transition clear.
A_2 *10–40 cm:* Brownish yellow (10YR 6/8) friable fine sandy clay loam, with a few fine distinct mottles of grey (10YR 5/1). Transition clear.
B_{21g} *40–150 cm:* Reddish yellow (5YR 6/8) firm fine sandy clay, with many coarse prominent mottles of red (2.5YR 5/8). Within the red some dusky red hardening centres. Transition diffuse.
B_{22g} *150–225 + cm:* Light red (2.5YR 6/8) firm fine sandy clay, with many coarse prominent mottles of light grey (N 7/0). Within the light red several dusky red, hardening centres.

Profile 4 (GROUND WATER LATERITE soil, Low phase)
Field description 269 (Sampaio)
Lower Tocantins, 2 km E of Curuçambaba (Lat. 2°.9'S; Long. 49°.17'W)
Extensively flat; terrace, 8 m *ca.* above local river level. Imperfectly drained; upper phreatic level +0.2 m ca. (rain water), lowest phreatic level below —3.3 m. Late Pleistocene sediments. Grasses and scattered low trees and palms; yearly burned.

A_1 *0–40 cm:* Very dark grey (N 3/0) very friable light sandy loam. Transition gradual.
A_2 *40–100 cm:* White (10YR 8/1) friable sandy loam. Transition clear.
AB_g *100–150 cm:* White (10YR 8/1) friable light sandy clay loam, with few to common medium sized distinct mottles of strong brown (7.5YR 5/8). Transition gradual.
B_{21g} *150–220 cm:* White (10YR 8/1) firm clay loam, with many fine distinct mottles of yellowish red (5YR 4/8) and reddish yellow (7.5YR 6/8). Within the red very small hardened nodules. Transition gradual.
B_{22g} *220–330 + cm:* Red (2.5YR 4/8) firm light clay loam, with many medium sized prominent mottles of white (10YR 8/1) and reddish yellow (7.5YR 7/8). Within the red small hardened nodules.

Profile 5 (GROUND WATER LATERITE soil)
Field description 96 (Day)
Caeté-Maracassumé area, Piria river (Lat. 1°.32'S; Long. 46°.27'W)
Flat terrace, some metres above local river level. Imperfectly drained; upper phreatic level – ? m, lowest phreatic level below —3.0 m. Pleistocene sediments. Young secondary forest.

A_p *0–15 cm:* Very dark brown (10YR 2/2) very friable loamy sand. Structureless, or weak medium sized granular. Transition gradual and smooth.
A_1 *15–70 cm:* Dark greyish brown (10YR 4/2) friable sandy loam, with a few fine faint mottles of brown (10YR 6/8). Weak coarse angular blocky. Transition gradual and smooth.
A_3 *70–110 cm:* Yellowish brown (10YR 5/6) friable sandy loam, with common medium sized faint mottles of light yellowish brown (2.5Y 6/4) and reddish yellow (7.5YR 7/8). Very weak coarse angular blocky.
AB *110–120 cm:* Heavy sandy loam. Transition zone.
B_{21g} *120–140 cm:* Yellow (2.5Y 7/6) firm light sandy clay loam, with many medium sized distinct mottles of red (2.5YR 5/8). Weak very coarse subangular blocky. Transition abrupt and smooth.
B_{2ug} *140–150 cm:* Gravelly light sandy clay loam, with same colours as B_{21g}. 50–75% quartz pebbles (1–3 cm diam.). Transition abrupt and smooth.
II B_{22g} *150–170 + cm:* White (10YR 8/1) firm heavy sandy clay loam, with many coarse prominent mottles of red (10R 4/6). In the red some dusky red hardening nodules.

Profile 6 (GROUND WATER LATERITE soil, intergrade to GREY HYDROMORPHIC soil)
Field description 83 (Day)
Caeté-Maracassumé area, Maracassumé river (Lat. 1°.40'S; Long. 45°.52'W)
Flat; terrace, some metres above local river level. Imperfectly drained; upper phreatic level probably + 0.2 m *ca.*, (rain water), lowest phreatic level probably —2.0 m. Shallow Pleistocene sediments over Pre-Cambrian granitic rock. Grasses.

A_1 *0–5 cm:* Pale brown (10YR 6/3) loose sand. Single grains. Transition abrupt and wavy.
A_{21} *5–15 cm:* White (10YR 8/2) loose sand. Single grains. Transition clear and wavy.
A_{22} *15–30 cm:* Yellow (10YR 8/6) very friable to loose sand, with common fine distinct mottles of reddish yellow (7.5YR 6/8). Weak coarse angular blocky. Transition clear and wavy.
(II)B_{1g} *30–40 cm:* Pale yellow (2.5Y 8/4) firm sandy loam, with many coarse distinct mottles of reddish yellow (7.5YR 6/8). Weak to moderate coarse subangular blocky. About 5% small (1–2 cm diam) plinthite concretions. Transition clear and irregular.
(II)B_{2g} *40–100 cm:* White (N 8/0) firm heavy sandy clay loam, with common coarse prominent mottles of red (2.5YR 4/8). Moderate to strong medium sized columnar.
(II)B_{3g} *100–140 + cm:* White (N 8/0) firm light loam, with many coarse prominent mottles of reddish yellow (7.5YR 7/8). Throughout the B horizon a few medium sized (3–5 cm diam.) angular stones of quartz and grano-diorite (?).

Profile 7 (GROUND WATER LATERITE soil)
Field description 162/173 (Day, Sombroek)
Cf. III.2, Profile 43.

Profile 8. (GROUND WATER LATERITE soil)
Field description 199 (Day, Sombroek)
Guamá-Imperatriz area, km 129 E (Lat. 2°.45'S, Long. 47°.25'W)
Slightly dipping part of extensive terrace, 50 m *ca.* above local rivulet level. Micro-relief of *kauwfoetoes*[1]. Imperfectly drained; upper phreatic level +0.5 m ca. (rain water), lowest phreatic level below

[1]) Also called 'pocket' micro-relief (DAY, 1961), or *canaletes* (SOMBROEK and SAMPAIO, 1962).

—1.5 m. Plio-Pleistocene lacustrine sediments (Belterra clay), reworked during Early Pleistocene. Shrubby low forest.

A_1 *0–3 cm:* Light grey (10YR 6/1) friable clay. Moderate fine subangular blocky. Transition clear.

A_{2g} *3–20 cm:* White (10YR 8/2) friable to firm heavy clay, with many fine faint mottles of brownish yellow (10YR 6/8). Moderate to weak medium sized subangular blocky. Transition gradual.

B_{21g} *20–100 cm:* White (10YR 8/1) firm heavy clay, with many medium sized prominent mottles of red (2.5YR 4/8) and some yellow (10YR 7/8). Moderate to weak medium sized subangular and some angular blocky; tendency to platy. A few faint clay skins. Transition gradual.

B_{22g} *100–130 + cm:* Red (2.5YR 6/8) very firm heavy clay, with many medium sized prominent mottles of white (10YR 8/1) and some yellow (10YR 7/8).

Profile 9 (Ground Water Laterite soil)
Field description 214 (Sombroek, Sampaio)
Guamá-Imperatriz area, km 252 (Lat. 3.42'S; Long. 47°.29'W)
Slightly dipping part in almost flat terrain; terrace 5 m *ca.* above local river level. Imperfectly drained; upper phreatic level –? m, lowest phreatic level below —1.5 m. Late Pleistocene sediments. High forest, of low timber volume.

A_1 *0–5 cm:* Brown (10YR 5/3) very friable fine sandy loam. Weak medium to fine subangular blocky. Transition clear.

A_2 *5–40 cm:* Very pale brown (10YR 7/4) firm fine sandy clay loam, with common – in lower part many – fine distinct mottles of strong brown (7.5YR 5/8). Moderate medium sized subangular blocky. Transition clear.

B_{1g} *40–80 cm:* White (10YR 8/2) very firm clay, with many fine to medium sized distinct mottles of strong brown (7.5YR 5/8) and light red (2.5YR 6/8). Weak to moderate coarse angular blocky. Common faint clay skins. About 10% rather soft, only partly loose plinthite concretions, small (0.5–2 cm diam.), rather fine grained and dark reddish brown (2.5YR 3/4) or red (2.5YR 4/8). Transition gradual.

B_{2g} *80–150 + cm:* White (2.5YR 8/2) very firm clay, with many coarse distinct to prominent mottles of light red (2.5YR 6/8) and some yellow (10YR 7/8). Massive, to weak coarse angular blocky.

Profile 10 (Ground Water Laterite soil, light textured phase – intergrade to Kaolinitic Latosolic Sand); (Sandy Ground Water Laterite soil)
Field description 151 (Sombroek)
Marajó island, 40 km N of Muaná (Lat. 1°.09'S, Long. 49°.11'W)
Ridge-like terrain *(teso)*, 1–2 m above submergeable lowland. Imperfectly to moderately well-drained; upper phreatic level –1.7 m *ca.*, lowest phreatic level —2.5 m *ca.* Late Pleistocene sediments. Grasses and scattered low trees and palms; yearly burned; fertilized.

A_{11} *0–20 cm:* Grey (10YR 6/1) loose fine sand. Single grains. Transition gradual.

A_{12} *20–70 cm:* Dark grey brown (10YR 4/2) very friable fine sand. Structureless, to weak fine crumbly. Transition gradual.

A_2 *70–140 cm:* Pale yellow (2.5Y 7/4) loose loamy fine sand. Transition gradual.

B_{1g} *140–170 cm:* Brownish yellow (10YR 6/8) loose loamy fine sand, with common medium sized distinct mottles of red (10R 5/8). A few small hard plinthite concretions. Transition gradual.

B_{21g} *170–200 cm:* Red (2.5YR 4/8) loose loamy fine sand, with many coarse distinct mottles of brownish yellow (10YR 6/8). Transition gradual.

B_{22g} *200–230 cm:* White (N 8/0) loose loamy fine sand, with many medium sized distinct mottles of light red (2.5YR 6/8) and yellow (10YR 7/8). Transition gradual.

C_g *230–325 + cm:* White (N 8/0) loose fine sand.

Profile 11 (GROUND WATER LATERITE soil, heavy textured phase); (GROUND WATER LATERITE soil, Humic phase)
Field description 157 (Sombroek)
Marajó island, 40 km N of Muaná (Lat. 1°.09'S; Long. 49°.11'W)
Flat terrain. Imperfectly to poorly drained; upper phreatic level +0.5 m (rain water), lowest phreatic level -3.0 m *ca*. Early Holocene (?) sediments. Grasses, scattered low trees and palms.

A_1 *0–30 cm:* Black (N 2/0), very friable humic clay loam. Strong fine granular. Transition gradual.
A_2 *30–60 cm:* Light grey (10YR 7/1) firm clay, with a few fine distinct mottles of reddish yellow (7.5YR 6/8). Transition gradual.
B_{2g} *60–270 cm:* White (N 8/0) very firm clay, with many coarse prominent mottles of dark red (7.5R 3/6) and some yellow (10YR 7/8). Throughout the horizon in the dark red many small, dusky red and half hard nodules.
Note: A similar profile in the neighbourhood showed in the B_2 the following structure: Weak to moderate coarse prismatic, breaking into strong coarse subangular blocky. Presence of clay skins.

Profile 12 (GROUND WATER LATERITE soil, intergrade to KAOLINITIC YELLOW LATOSOL, or reverse)
Field description 317 (Sombroek, Falesi)
Porto Velho, km 72 of BR-29.
Extensive flat terrace, 10 m above local rivulet level. Imperfectly to moderately well-drained; upper phreatic level -1.0 m *ca*., lowest phreatic level below —2.0 m. Plio-Pleistocene lacustrine sediments (Belterra clay). Low forest with many creepers.

A_1 *0–10 cm:* Greyish brown (10YR 5/2) friable light clay. Moderate fine to medium sized subangular blocky. Transition clear.
A_2 *10–60 cm:* Light olive brown (2.5Y 5/4) friable clay. Moderate medium sized subangular blocky. Transition diffuse.
B_1 *60–100 cm:* Light yellowish brown (10YR 6/4) friable to firm clay. Weak to moderate medium sized subangular blocky. Transition gradual.
B_{21} *100–150 cm:* Light yellowish brown (10YR 6/4) firm clay. Weak to moderate medium sized subangular and angular blocky. Common faint clay skins. Scattered (2%) small (1 cm diam.) fine grained dark reddish brown (2.5YR 3/4) rather soft plinthite concretions. Transition gradual.
B_{22g} *150–200 + cm:* Pale yellow (2.5Y 7/4) firm clay, with many medium sized prominent mottles of dusky red (10R 3/4) and some dark reddish brown (2.5YR 3/4), yellowish brown (10YR 5/8) and white (N 8/0). Moderate medium sized to coarse angular and subangular blocky, with tendency to prismatic. Common faint clay skins.

Profile 13 (GROUND WATER LATERITE soil, intergrade to LOW HUMIC GLEY soil)
Field description 146 (Sombroek)
Lower Amazon region, 20 km S of Prainha (Lat. 2°.02'S; Long. 53°.30'W)
Patch of low upland *(teso)*, 0.5 m above high water level, within floodplain. Imperfectly drained; upper phreatic level 0.0 m *ca*., lowest phreatic level about -3.0 m *ca*. Early Holocene (?) sediments. Grasses, scattered high trees.

A_1 *0–10 cm:* Dark grey (10YR 4/1) loamy fine sand. Transition clear.
A_2 *10–25 cm:* Light grey (10YR 6/1) loamy fine sand, with few fine faint mottles of reddish yellow (7.5 YR 6/8). Transition clear.
AB_g *25–60 cm:* Light grey (10YR 6/1) fine sandy loam, with many medium sized distinct to prominent mottles of yellowish red (5YR 5/8). Transition gradual.
B_{2g} *60–225 + cm:* White (N 8/0) firm fine sandy clay loam, with many coarse prominent mottles of red (2.5YR 4/8), partly bounded with yellow (10YR 7/6). From 120–150 cm also some weak red (10R 4/3) mottles with hardening centres.

Profile 14 (GROUND WATER LATERITE soil, intergrade to HYDROMORPHIC GREY PODZOLIC soil, Deep phase)
Field description 289 (Sombroek, Sampaio)
Araguaia Mahogany area, Bloco Piranha (Lat. 6°.01'S; Long. 48°.10'W)
Almost flat terrain, 1 m *ca.* above level of local intermittent rivulet. Micro-relief of *kauwfoetoes.* Imperfectly drained; upper phreatic level +0.3 m *ca.* (rain water), lowest phreatic level below —4.0 m. Triassic fine sand-stone (?). Low forest with many creepers.

A_1 *0–50 cm:* Very dark grey (10YR 3/1) loose light sandy loam. Single grains. Transition gradual.
A_2 *50–140 cm:* White (10YR 8/1) loose light sandy loam. Transition clear.
AB_g *140–175 cm:* White (10YR 8/1) friable sandy loam, with common medium sized faint mottles of brownish yellow (10YR 6/8). Transition clear.
B_{2g} *175–250 cm:* White (5Y 8/1) firm light clay loam, with many coarse prominent mottles of dark red (7.5R 3/8) and reddish yellow (7.5YR 6/8). Central parts of dark red half hardened. Transition gradual.
B_{3g} *250–420 cm:* (Sampled 250–320 cm). White (5Y 8/1) firm heavy loam, with many very coarse prominent mottles of dark red (7.5R 3/8), reddish yellow (7.5YR 6/8) and some pale red (10R 6/4). Central parts of dark red somewhat hardened.

Profile 15 (GROUND WATER LATERITE soil, intergrade to HYDROMORPHIC GREY PODZOLIC soil, Clay stone substratum phase – partly truncated?)
Field description 287 (Sombroek, Sampaio)
Araguaia Mahogany area, near Bloco Piranha (Lat. 6°.02'S; Long. 48°.11'W)
Almost flat terrain, about 2 m above level of local intermittent rivulet. Imperfectly drained; upper phreatic level +0.1 m (rain water), lowest phreatic level below -1.2 m. Jurassic-Triassic silty claystones. Low forest with many creepers.

A_1 *0–5 cm:* Pale brown (10YR 6/3) very friable light loam, with many fine faint mottles of yellowish brown (10YR 5/8). Weak to moderate fine subangular blocky. Transition gradual.
A_{2g} *5–30 cm:* Light grey (10YR 7/2) very friable loam, with many fine distinct mottles of yellowish brown (10YR 5/8). Weak medium to fine subangular blocky. About 80% small (<1 cm diam.) hard, fine grained dark red (7.5R 3/8) plinthite concretions. Transition clear.
B_{1g} *30–50 cm:* Light grey (10YR 7/1) friable clay loam, with many medium sized faint mottles of yellowish red (5YR 4–5/6). Moderate fine subangular blocky. A few faint clay skins. Transition gradual.
B_{2g} *50–80 cm:* Very pale brown (10YR 7/4) friable to firm silty clay loam, with many medium sized prominent mottles of red (10R 4/6) and white (10YR 8/2). Moderate fine angular to subangular blocky, compsing weak medium prismatic. Common faint clay skins. The centres of the red parts somewhat hardened. Transition gradual.
B_{3g} *80–100 cm:* White (10YR 8/1) friable to firm silty clay loam with many medium sized prominent mottles of red (7.5R 4/8) and yellow (10YR 7/6). Moderate fine to medium sized angular to subangular blocky, composing weak medium prismatic. Common distinct clay skins. Transition gradual.
C_g *100–120 + cm:* White (N 8/0) friable silty clay loam, with many medium to coarse prominent mottles of dark red (7.5R 3/8) and yellow (10YR 7/6). Weak medium angular to subangular blocky structure. A few faint clay skins.

Profile 16 (GROUND WATER LATERITE soil, intergrade to HYDROMORPHIC GREY PODZOLIC soil, Micaceous phase)
Field description 274 (Sombroek, Sampaio)
Araguaia Mahogany area, opposite Xambioá (Lat.6°.29'S; Long. 40°14'W)
Narrow strip of lowland along intermittent rivulet. Imperfectly to poorly drained; upper phreatic level +0.5 m *ca.* (rivulet water), lowest phreatic level below —1.5 m. Colluvium-alluvium from surrounding Pre-Cambrian micaceous schists. High forest.

A_1 *0-4 cm:* Dark grey (10YR 4/1) very friable sandy loam. Fine crumbly, composing very weak fine subangular blocky. Some tiny flakes of mica. Transition clear.

A_{2g} *4-20 cm:* Light grey (10YR 6/1) friable heavy sandy loam, with common fine distinct mottles of brownish yellow (10YR 6/8). Weak medium subangular blocky. Transition gradual.

B_{2g} *20-90 cm:* Light grey (N 7/0) firm clay, with many fine to medium sized distinct mottles of red (2.5YR 5/8) and yellowish red (5YR 5/8). Moderate medium subangular to angular blocky. Common very faint clay skins. Transition gradual.

B_{3g} *90-130 + cm:* Light grey (N 7/0) firm light clay, with many fine to medium sized distinct mottles of yellowish brown (10-7.5YR 5/8).

Profile 17 (GROUND WATER LATERITE soil, intergrade to LITHOSOL – partly truncated?)
Field description 145 (Sombroek)
Lower Amazon region, Monte Alegre, centre of Dome (Lat. 1°.57'S, Long. 54°.10'W)
Low part of gentle undulating terrain. Imperfectly drained; upper phreatic level 0.0 m *ca.*, lowest phreatic level —1.0 m *ca.* Devonian fine sand-stone. Grasses and many shrubs, locally cacti.

A_1-A_2 *0-15 cm:* Grey brown (10YR 5/2) friable fine sandy loam, with common fine faint mottles of yellow (10YR 7/6). Transition abrupt.

B_1 *15-30 cm:* Reddish yellow (7.5YR 6/8) friable clay loam. About 80% loose and hard small (0.5-2 cm diam.) fine grained very dusky red plinthite concretions. Transition abrupt.

B-C_g *30-80 cm:* White (N 8/0) very firm clay loam, with many medium sized prominent mottles of dusky red (7.5R 3/4) and some yellow (10YR 8/6). Transition abrupt.

R *80 + cm:* Stratified hard sand-stone; upper part broken and ferruginous.

Profile 18 (Solonetzic HUMIC GLEY soil, intergrade to GROUND WATER LATERITE soil); (GROUND WATER LATERITE soil, Humic phase)
Field description 178 (Day, Sombroek)
Marajó island, 8 km NW of Arariuna (Lat. 0°.59'S; Long. 49°.60'W)
Flat lowland. Imperfectly to poorly drained; upper phreatic level +1.0 m *ca.* (river water, almost without load), lowest phreatic level —4.0 m ca. Early Holocene marine-deltaic (?) sediments. Grasses and occasional shrubs.

A_1 *0-15 cm:* Very dark grey brown (10YR 3/2) firm clay with some strong brown (7.5YR 5/8). Moderate medium sized prismatic, breaking into moderate coarse subangular blocky. Transition abrupt and smooth.

A_{2g} *15-20 cm:* Grey brown (10YR 5/2) friable clay loam, with common fine distinct mottles of yellowish red (5YR 5/8). Moderate medium sized subangular blocky. Transition abrupt and smooth.

B_{1g}-C *20-55 cm:* Dark grey (10YR 4/1) firm clay, with many fine distinct mottles of red (2.5YR 4/6). Weak fine prismatic, breaking into strong fine subangular blocky. Transition clear and smooth.

B_{21g}-C *55-100 cm:* Light grey (10YR 6/1) very firm clay, with many fine distinct mottles of red (2.5YR 5/6) and reddish yellow (7.5YR 6/8). Strong very coarse prismatic. Clay skins prominent on horizontal ped surfaces, faint to distinct on vertical ped surfaces. Transition diffuse and smooth.

B_{22g}-C *100-180 + cm:* Light grey (N 6/0) firm clay, with many coarse prominent mottles of dark red (10R 5/6) and reddish yellow (7.5YR 6/8). Weak to moderate coarse prismatic, composed of strong coarse angular blocky. Clay skins prominent on both horizontal and vertical ped surfaces.

The main factors that cause the variations, as illustrated in the profile descriptions, are the following:

1. the character of the fluctuation of the ground water level (or pseudo ground water level, or saturation zone), which fluctuation may vary in depth and frequency.
2. the texture of the parent material.
3. the degree of pre-weathering of the parent material.

Ad 1. The plinthite formation may take place at relatively shallow depth (the Profiles 6, 8, 15), or relatively deep (Profiles 4, 10, 12, 14). In the latter case, little influence of the ground water fluctuation may be felt in the upper horizons; the A_2 of the Ground Water Laterite profile might then be taken as for instance the A_3 or the B_1 horizon of a shallow Kaolinitic Yellow Latosol *c.q.* Kaolinitic Latosolic Sand (Profiles 10, 12).

The thickness of the layer of soft plinthite (the B horizon) depends on the thickness of the zone of fluctuation. The lower boundary was established only in a few instances (Profile 10); in the other cases no 'pallid zone' proper was reached during the field studies. It is evident however, that the upper boundary does not coincide with the upper level of the ground water. At places where this level reaches the surface tempo-

Foto 14 Solo Laterita Hidromórfica, desenvolvido em sedimentos arenosos. Nêste perfil, os mosqueados vermelhos do horizonte B de 'plinthite' macio, ocorrem como faixas verticalmente arranjadas. O horizonte A arenoso lixiviado tem côr relativamente escura em sua secção central, devida a alguma cumulação de humo naquêle lugar (fase inicial de formação de Podzol Hidromórfico dentro do horizonte A de solo Laterita Hidromórfica)

Photo 14 A Ground Water Laterite soil, developed on sandy sediments. In this profile, the red mottles of the soft plinthitic B horizon occur as vertically arranged stripes. The leached sandy A horizon is relatively dark coloured especially in its central section, due to some humus accumulation there (initial stage of Ground Water Podzol formation within the A horizon of a Ground Water Laterite soil) rarily, or the terrain is even shallowly covered with rain water for a part of the year (Profiles 2, 4, 6, 8, 11, 14, 16, 18), the soft plinthite layer nevertheless only starts from some depth on (0.5–1.5 m). One may expect the thickest layers of soft plinthite upstream of the main rivers, where seasonal differences in river level are greatest (Solimões, Madeira, Araguaia). Also, since near rivers the fluctuation of the phreatic level is generally larger than on watershed parts, one might find thicker layers at the former locations. Apparently however Ground Water Laterite soils predominate in watershed regions (*cf.* IV.1.2.2). Near the rivers the zone of fluctuation is probably usually too deep to cause plinthite formation (good drainage), or the sesquioxides are carried off to the river.

Ad 2. Understandably, the textural differentiation between the A and the plinthitic B horizon, as expressed in the textural ratio B/A, depends on the texture of the parent material. If this texture was light throughout, then the plinthitic B horizon of the genetically ultimate profile would be rather light textured (Profile 10). If the parent material was a clay, then also the ultimate A horizon would be at least rather heavy textured[1] (Profile 8). It seems that the upper boundary of the plinthite layer, with the same drainage condition (for instance the ground water level temporarily at the surface, or standing rain water), depends on the texture of the parent material. If this is sandy, then the plinthite develops relatively deep (Profiles 4 and 14 *versus* 8). The pattern of mottling seems to depend on both texture and structure of the soil material *in situ* (*cf.* II.3.2.2).

Ad 3. Per definition, the 'modal' Ground Water Laterite soil is a strongly weathered soil and its clay minerals are 'lateritic', by consisting only of silicate clay minerals with 1:1 lattice structure (kaolinite), and sesquioxides (gibbsite, goethite, hematite). Such a 'lateritic' character of the clay fraction shows up in the SiO_2:Al_2O_3 ratios (Ki values), which should be about or below 2.

The parent material can be strongly pre-weathered ('rego-genetic' material), the only mineral constituents being quartz, kaolinite and sesquioxides. In this instance, the 'modal' Ground Water Laterite soil can be established relatively rapidly, since only the concentration of the kaolinite and the sesquioxides in the B horizon is involved. This is likely to be the case with all the Ground Water Laterite soils of the Planície. They have a Ki value of about or below 2, a low silt/clay ratio in the B horizon and a low cation exchange capacity (Profiles 2, 4, 7, 8, 9, 10, 12).

Profile 5 can also be called a 'modal' Ground Water Laterite soil. X-ray diffraction was applied to the lower part of the B horizon of this profile (*cf.* sample 96-5 of Tables 7 and 8, and Fig. 14 a–e). The clay fraction of this sample is practically completely kaolinitic (92%), with only 6% hematite and 2% quartz present. The percentage of sesquioxides is understandably larger in the coarser fractions. They consist however only of iron oxides (hematite 8–15%), not aluminum oxides. That in the fractions 2–16

[1]) The texture of the plinthitic B horizon is often estimated too heavy in the field, due to the denseness of the horizon.

micron and 16–80 micron also some other minerals, notably mica, are present is probably related with the fact that, in the area of the profile, the crystalline basement (mica schists) is often almost outcropping. The composition of the clay fraction of the sample is comparable, to a large extent, with that of the B horizons of the Kaolinitic Yellow Latosol profiles (samples 233-3, 303-4, 300-4 and 210-4 of Table 8). An electron micrograph (Photo 10) however shows that the kaolinite crystals are less well developed than in these latter. The difference in crystallisation also shows up in the different values for specific surface of the clay fraction of samples 96-5 and 303-4 respectively (Table 7).

When the parent material is relatively rich, easily weatherable primary minerals and silicate clay minerals of 2:1 lattice structure forming part of it, then the formation of the 'modal' Ground Water Laterite profile requires both a weathering to kaolinite and sesquioxides, and a regrouping in the profile. This is likely to take more time. Apparently, the modal type is not therefore reached on the Holocene sediments nor on some Paleozoic-Mesozoic deposits. Lowlands which are still being enriched (flooding by river water with a load of sediments, *água branca*, *cf.* I.4.4) usually have Low Humic Gley or Humic Gley soils. On the following sites, however, the formation of plinthite was invariably observed:

1. The lowlands intermittently covered with only rain water (except for those in eastern-central Marajó island which are alkaline).
2. The lowlands flooded with river water without load of sediments (*água preta*, *água limpa*, *cf.* I.4.4).
3. The terrains, along rivers, only slightly above high water level (*massapés*, *cf.* I.4.4).

Examples are the Profiles 3, 11, 13 and 18. The weathering in these profiles is often not yet very strong. Ki values are still above 2.0, which indicates that also non-kaolinitic silicate clay minerals are present. This is substantiated by a sample of Profile 18, to which X-ray diffraction was applied (sample 178-4 of the Tables 7 and 8). In addition to kaolinite (35%) and sesquioxides (11%), the clay fraction contains also mica (illite, 10%), intermediate (16%) and some chlorite (3%). In the coarser fractions moreover some felspar is present. The specific surface of the sample is still high (Table 7).

That the weathering in the profiles under discussion is still not very strong is also shown by the fact that often no pronounced textural difference between the A and the B horizons has developed as yet (Profiles 3, 11), and that textural differences within the parent material, due to stratification, are often not yet quite erased (Profile 18).

The Ground Water Laterite soils on relatively rich deposits of Paleozoic-Mesozoic age, and on peneplained Pre-Cambrian basement have a large textural difference between A and B horizons. Ki values are, however, still considerably above 2 (Profiles 6, 14, 15, 16, 17). Also the silt/clay ratios are usually still high (Profiles 14, 15).

Whatever the parent material, the ultimate stage of Ground Water Laterite soil formation is believed to be represented by the following profiles (*cf.* GL in Fig. 15): A thick, bleached and very sandy A horizon, grading sharply into a thick, relatively heavy textured, dense, slowly permeable B horizon of soft plinthite. At the transition zone of the two horizons, some plinthitic material occurs that has already hardened. Such profiles, in this publication called Ground Water Laterite, Low phase, generally have a poor vegetative cover (*cf.* IV.1.2). Any lowering of the drainage base and change in climate will result in erosion of the A horizon, followed by hardening of the truncated soft plinthite of the B horizon.

II.3.2.2 *Fossil Plinthite*

INTRODUCTION

In Amazonia, it is common to encounter layers of hard or soft plinthite on well drained sites, where the phreatic level occurs at many metres depth, and a shallow pseudo ground water level does not exist. In view of the above described present day formation of plinthite in Amazonia, and in agreement with the majority of the recent literature on the subject, such plinthite is considered to be fossil. It was formed in times when there existed, *in situ* or in the surroundings, a land surface with a fluctuating ground water level at shallow depth.

Fossil hard plinthite may occur underlain by fossil soft plinthite, or as an unconformable layer on top, or between non-concretionary sediments without any mottling. Fossil soft plinthite without a distinct capping of fossil hard plinthite was rarely found.

Layers of fossil hard plinthite occurring alone, as crusts on top of, or as stone-lines of varying thickness within, non-concretionary sediments without any mottling, were not formed *in situ*, but carried along, alluvially or colluvially, from other places. Absence of a regularity in the arrangement of the concretionary elements, and a more or less rounded form of the elements, are complementary in establishing their alluvial-colluvial origin.

However, the apparently most frequent situation is that a layer of fossil hard plinthite is underlain by a layer of fossil soft plinthite. In these instances, it is likely that both plinthitic layers constitute the relics of a Ground Water Laterite soil – or of its geologic relative, if the formation had taken place below the solum. After the conditions of imperfect drainage ceased to exist the profile was eroded geologically to the point that all the light textured and loose A horizon, and possibly part of the heavy textured plinthitic B horizon, was stripped off. Whilst the lower part of the plinthitic B (and the C) horizon has remained soft, the upper part has become hard plinthite. The red mottles changed and became stony elements (pisolithic pieces, vesicular blocks or massive plates, depending upon the original pattern of mottling), by dessication through alternate wetting and drying at the surface. The white and yellow parts of the dense material changed, under influence of roots and soil fauna, to become friable homogeneous yellowish or reddish earth. It is normally only a lack of contact with the atmosphere which prevents the hardening of that section of the plinthitic layer which is below the present day crust. This was verified at many deep cuts excavated for the BR-14 highway, which were examined during the construction of the road, as well as at intervals

Foto 15 O processo de endurecimento de 'plinthite'. Após ser exposto por menos de dois anos, o sub-solo original de 'plinthite' macio do corte de estrada tem endurecido consideràvelmente. Foi levado pela água o material caolinítico da matriz de côr branca, enquanto os mosqueados vermelhos endurecentes – aqui em padrão laminar – ressaltam do corte. Na parte superior do corte pode ver-se o 'plinthite' duro como era antes da excavação. Partes deste 'plinthite' duro ainda mantêm um arranjo laminar (Tipo de concreções Mãe do Rio; BR-14, km 40 m. ou m.)

Photo 15 The hardening process of plinthite. After being exposed for less than two years, the original soft plinthitic subsoil of this road embankment has hardened to a considerable extent. The kaolinitic material of the white coloured matrix has been washed away, while the hardening red mottles – here in a platy pattern – protrude from the face of the embankment. At the uppermost part of the embankment, the hard plinthite can be seen as it existed before excavation. Parts of this hard plinthite still have a platy arrangement (Mãe do Rio type of concretions, BR-14, km 40 ca.)

during the 2-3 years afterwards. While the plinthite was soft during the excavating, the wands of the cuts became gradually hard as stone[1] (*cf.* Photo 15).

The sequence: fossil hard plinthite – fossil soft plinthite, normally indicates that the material was formed *in situ*. But it is of course possible that the hard plinthite, or part of it, was carried along and deposited on top of the plinthite which was formed *in situ*. Certainty is obtained about the *in situ* origination of layers of fossil hard plinthite overlying soft plinthite if the sequence has the following features:

1. The character of the concretionary elements (size, form, grainage) is related to the character of the red parts of the soft plinthite
2. The arrangement of these elements in the lower part of the hard plinthite layer is similar to the pattern of mottling in the soft plinthite
3. The transition between hard plinthite and soft plinthite is gradual.

A frequently occurring situation is that fossil soft plinthite is capped by related fossil hard plinthite which in its turn is overlain by non-concretionary sediments of varying thickness. Such a situation might be confused with present-day Ground Water Laterite formation, especially if the hard plinthite forms a layer near to and parallel with

[1]) It is likely however, that the types of soft plinthite which have relatively high Ki values, for instance those constituting the *Zersatzzone* of consolidated sediments and rocks, need considerably more than a few years time for hardening, if they harden at all.

the surface. But, as stated above, layers of hard plinthite are infrequent in present-day Amazon Ground Water Laterite soils and are then always thin. One can establish the fossil character of the plinthite from the absence, directly above the hard plinthite, of a relatively light textured layer with colours of little chroma and high value, and/or mottling (pedologically an A_2 horizon).

Such an arrangement of: sediments – fossil hard plinthite – fossil soft plinthite, can be explained by assuming that after truncation and hardening of a former Ground Water Laterite soil profile, the stony surface was buried with sediments. A disturbance of an original arrangement of the concretionary elements in the upper section of the hard plinthite layer is also a sign of truncation and subsequent burying.

It may still be noted that, with the sequence: sediments – hard plinthite – soft plinthite, there is a good possibility for new Ground Water Laterite soil formation in the covering sediments. This is the case when the layers of fossil plinthite are impervious, thereby causing a pseudo ground water level. This new soil, in its turn, may become truncated, resulting in another sequence of fossil plinthite above the earlier one (*cf.* I.4.5). If the zone of fluctuating ground water level is located within the layer of fossil hard plinthite, then the conditions for the formation of plinthitic conglomerates are present.

The above considerations on the origin of the sequence sediments – hard plinthite – soft plinthite holds for Amazon conditions. It is quite conceivable that in semi-arid regions, for instance in North-Eastern Brazil, the sequence may constitute the whole of a non-eroded fossil Ground Water Laterite profile, because there the soil may frequently dry out to a great depth, and the original A_2 may lose its aspect of lixiviation. Amazon fossil plinthite not truncated at some time in the past, and consequently not hardened over more than a few decimetres, is apparently uncommon. In the central part of the Guamá-Imperatriz area however, a well-drained soil was found which may be a fossil full Ground Water Laterite soil profile. The soil, classified under *Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol* (*cf.* for instance Profile 39), is found on terraces that are 30–10 m above the level of local rivulets. The soil has a yellowish (hue 10YR) and friable A horizon and a reddish (hue 5 YR or 2.5YR), rather firm and heavier textured B horizon. Between these, a transitional horizon (AB) occurs, 20–50 cm thick, of which the upper part has rather often small (1–2 cm diam.), hard, round plinthite concretions which comprise about 5–20% of the soil mass. The lower part of the transitional horizon has, within a matrix of yellowish hue, common, medium sized and distinct mottles of yellowish red or red (5YR, 2.5YR). The indications are that the parent material of the A, AB and B is identical. The features described therefore make it likely that an originally plinthitic horizon has hardened in its upper part, while in the lower part the mottling has been diminished by oxidation. Genetically speaking, the profile is likely to constitute a 'raised', but not truncated Ground Water Laterite soil profile, in which the formation of plinthite was limited.

In the foregoing discussion it was assumed that the soft plinthite[1] below a capping of

[1]) The chromas and values of the matrix of soft plinthite well above the ground water level are usually less low and less high respectively than those of the matrix of soft plinthite in the B horizon of present-day Ground Water Laterite soils.

fossil hard plinthite is all of fossil character. However, the layer of soft plinthite is sometimes of ten and more metres thickness. The lowest section of such thick layers has only a concentration of sesquioxides into mottles (the form of which is often directly related to the stratification of the parent material; *cf.* Photo 16), not a concentration of silicate clay minerals. This lowest part, after exposure, maintains also a rather soft consistence. It is improbable that at the time of Ground Water Laterite soil formation the fluctuation of the ground water level was so great that all of the layer

Foto 16 A seqüência de 'plinthite' duro fóssil e 'plinthite' macio fóssil que constitui o solo Podzólico Vermelho-Amarelo, 'intergrade' para Latosolo Amarelo Caolinítico, fase Concrecionária. A camada de 'plinthite' duro que forma a parte superior do perfil se compõe de elementos concrecionários discretos em terra friável não mosqueada. A camada de 'plinthite' macio que constitui a parte inferior do perfil, se compõe de material argiloso firme e denso com mosqueados prominentes e grossos de matiz vermelho numa matriz branca ou cinzento claro. Neste perfil os mosqueados têm um padrão vesicular-prismático e os elementos concrecionários são do tipo Ipixuna. As separações ovais dentro do horizonte de 'plinthite' macio são compostas de terra não mosqueada friável sem concreções. Provàvelmente resultam de homogenização local do 'plinthite' macio por cupins (BR-14, km 115 m. ou m.)

Photo 16 The sequence of fossil hard plinthite and fossil soft plinthite that constitutes a Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol, Concretionary phase. The layer of hard plintite which makes up the upper part of the profile, consists of discrete concretionary elements in unmottled friable earth. The layer of soft plinthite which makes up the lower part of the profile, consists of dense and firm clayey material with a prominent coarse mottling of red hue in a white or light grey matrix. In this profile, the mottling has a vesicular-prismatic pattern and the concretionary elements are of the Ipixuna type. The pockets and pipes that are visible in the layer of soft plinthite consist of unmottled, friable earth without concretions. They are probably the result of local homogenisation of the soft plinthite by termites (BR-14, km 115 ca.)

was then formed. The thickness of the soft plinthite layer may be due to a very gradual lowering of the ground water level, related to a very gradual lowering of the drainage base. In view of the fact that the layer seems to be thickest at the rims of crust-capped plateau land (*cf.* I.4.5, note on page 44), it is however more probable that, once a sequence of hard and soft plinthite is present in a well drained position, the soft plinthite may enlarge itself in a downward direction under influence of obliquely downward moving ground water. For such present-day accretion of fossil plinthite a fluctuating phreatic level proper would therefore not be necessary.

From the descriptions in I.4.5, it can be concluded that the fossil hard plinthite of Amazonia rarely constitutes massive, impenetrable and thick slabs (hardpans, *carapaçes*), as reported for many areas in Africa, for instance N. Nigeria. Usually there are only concretionary elements between loose earth. This general weakness of the development of the Amazon plinthitic crusts is believed to be related, in part, to a general low Fe content of the main Amazon sediments, which also accounts for the low iron oxide content of the main Amazon Latosol (*cf.* II.2.2). The variation in the characteristics of the concretionary elements of fossil hard plinthite, as shown in I.4.5, is related to a variation of patterns of mottling of the original soft plinthite. The latter is believed to have depended upon differences in texture and in stratification of the sediments, or upon differences in structure of the superficial layers (*i.e.* the soil) before, or during, the time when conditions of imperfect drainage caused the plinthite formation. It was discussed in I.4.5 that the Paragominas type of concretions is very likely connected with the structural constitution of the Belterra clay. The reticulate-prismatic pattern of the Ipixuna type may be due to a blocky to prismatic structure of the B horizon of the original soil, before or at the time when conditions of imperfect drainage occurred, or to action of roots and soil fauna in this layer during the plinthite formation. For the Mãe do Rio type, an origin in non-homogenized stratified sediments is plausible, especially for those elements that are platy and alternating coarse and fine grained, or coarse grained throughout. The more massive aspect, compared with other types, may indicate a formation below the solum, lateral enrichment with sesquioxides, or both.

FOSSIL PLINTHITE BELOW THE SOLUM

Fossil plinthite occurring only deep below the surface, arbitrarily below 1.50 m, is not diagnostic for classification of the soil at the spot, unless at a very low categorical level. At several places such a situation was observed. At the town of Belém fossil hard plinthite is found from about 5 m depth on, under sandy sediments that constitute a Pleistocene terrace. Near Itacoatiara, thin bands (30 cm) of fossil hard plinthite, in part underlain with fossil soft plinthite (150 cm), are found at a local depth of 8 m below the surface (ETA-54 *seringal*, near river Urubú). On the planalto terrace in the region south and southeast of Santarém, fossil hard plinthite is found at about 15 m below the level of the flat central sections. Also in the Guamá-Imperatriz area such situations are common.

In these instances the solum is usually a *Kaolinitic Yellow Latosol* (KYL), which

Fig. 15 Esbôço de alguns solos amazônicos com 'plinthite' (para os símbolos, veja Tabela 9)

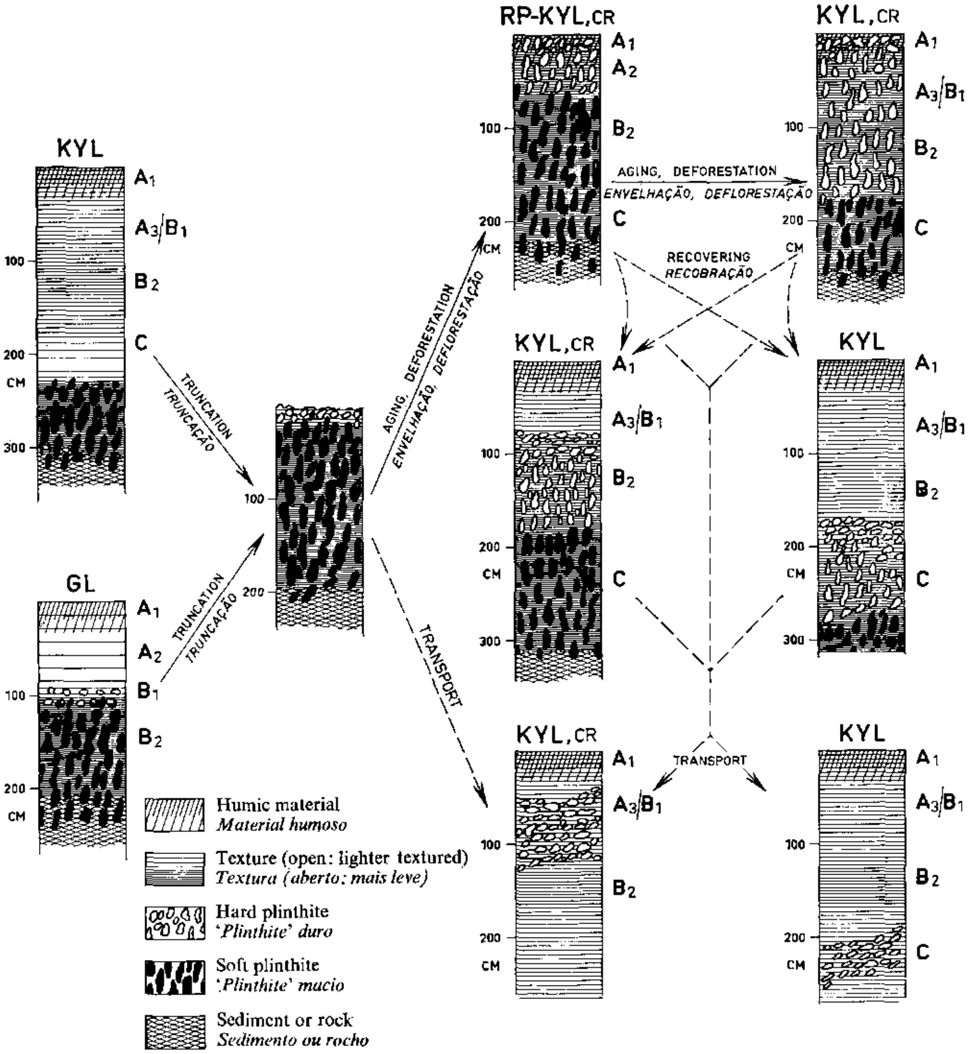


Fig. 15 Sketch of some Amazon plinthitic soils (see for symbols Table 9)

developed on the overlying sediments. Imperfectly drained soils may however occur, also where the land surface is well above the level of the local rivers, due to the fact that the fossil plinthite can form an almost impervious substratum. In that case the profile constitutes normally a recent Ground Water Laterite soil (*cf.* Profile 8 of II.3.2.1).

FOSSIL PLINTHITE WITHIN THE SOLUM

Fossil plinthite at the surface or at a shallow depth (less than 1.50 m arbitrarily) is, of course, an important characteristic of the soil *in situ*. In fact, the plinthite now acts as parent material for a soil. The characteristics of the soil depend on the degree of weathering of the original soft plinthite. As discussed before, the final product of this weathering is the hard plinthite, which in Amazonia consists, with few exceptions, of a mixture of hard, concretionary elements, and loose, friable earth. The concretionary elements are inactive, whilst the earth is, in fact, similar to that of latosolic profiles on non-concretionary sediments in the surrounding area (kaolinitic character of the clay fraction; $SiO_2:Al_2O_3$ molecular ratios = Ki values around, or slightly below 2).

This weathering may be only relatively shallow, *i.e.* the dense layer of soft plinthite is still present near to the surface (arbitrarily less than 1 m). In that case the actual solum consiscs of a friable, concretionary topsoil (A horizon) with subangular blocky or granular structure, and a dense, firm subsoil (B horizon) with predominantly angular blocky structure and presence of a few clay skins. Because of the morphometric field characteristics of the B horizon the soil cannot be called a Latosol, although Ki values are around or slightly below 2. Such soils are classified as *Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol, Concretionary phase* (RP-KYL, CR).

If the weathering of the soft plinthite has progressed to a greater depth from the surface (arbitrarily to more than 1 m), then practically the whole solum, both the A and the B horizons, consists of friable, concretionary earth. Therefore, the soil can be classified as a Latosol: *Kaolinitic Yellow Latosol, Concretionary phase* (KYL, CR). This classification has to be given, of course, also to those concretionary and friable soils, in which soft plinthite is completely lacking and the concretions were not formed *in situ*, but are of colluvial-alluvial origin (stone-lines). A thickness of the stone-line of minimally 30 cm above 1 m depth is taken as a criterion for a Concretionary phase.

Profile 19 (RED YELLOW PODZOLIC soil, intergrade to KAOLINITIC YELLOW LATOSOL, Concretionary phase – type of concretions: Ipixuna)
Field description 202 (Sombroek)
Guamá-Imperatriz area, km 109.6 (Lat. 2°.35'S; Long. 47°.28'W)
Approx. flat terrain; terrace, 55 m above level of local rivulet. Slightly imperfect drainage. Pliocene sediments, probably formerly covered with Belterra clay. High forest, with rather high timber volume.

A_1 *0–10 cm:* Brown (10YR 5/3) friable clay. Moderate fine subangular blocky. About 25% loose hard plinthite concretions, medium to small sized (10–0.5 cm diam.), prismatic, predominantly fine grained, dusky red (10R 3/4) and locally light red (10R 6/6). Transition clear to gradual.

A_2 *10–70 cm:* Brownish yellow (10YR 6/6–8) friable heavy clay. Moderate fine subangular blocky and locally angular blocky. A few faint clay skins, largely at the surfaces of the concretions. About 75% loose hard plinthite concretions, similar to those in A_1. Transition gradual.

B_1 *70–120 cm:* Reddish yellow (7.5YR 7/6) firm heavy clay, with many medium sized to fine distinct mottles of red (2.5YR 5/6) and yellow (10YR 7/8) in a reticulate pattern; the red parts are rather hard. Weak medium prismatic, composed of moderate medium to fine subangular blocky. Common faint clay skins. About 25% half loose, vertically arranged, hard or rather hard plinthite concretions, similar to those in A_1. Transition gradual and irregular.

B_2-B_3 *120–350 cm:* Reddish yellow (5YR 7/8) very firm heavy clay, with many coarse prominent mottles of dusky red (7.3R 3/4), white (N 8/0) and yellow (10YR 7/8); the dark red occurs predominantly as vertical pipes, about 5–20 cm long, which are rather hard. Weak medium to coarse prismatic, falling apart into moderate fine subangular and angular blocky. A few faint clay skins. Transition gradual.

C *350–550 + cm:* Reddish yellow (7.5YR 8/6) firm to very firm heavy clay, with many coarse prominent mottles of pale red (7.5YR 6/6), white (N 8/0) and yellow (10 YR 8/8).

Profile 20 (RED YELLOW PODZOLIC soil, intergrade to KAOLINITIC YELLOW LATOSOL, Concretionary phase – type of concretions: Mãe do Rio)
Field description 238 (Sombroek, Sampaio)
Cf. III.2, Profile 40.

Profile 21 (RED YELLOW PODZOLIC soil, intergrade to KAOLINITIC YELLOW LATOSOL, Concretionary phase – type of concretions: Paragôminas)
Field description 205 (Sombroek, Sampaio)
Guamá-Imperatriz area, km 175.6 (Lat. 3°.06'S; Long. 47°.18'W)
Side of low hill in very gently undulating terrain. Slightly imperfect drainage. Plio-Pleistocene lacustrine (Belterra clay) and older sediments; upper part of profile probably colluvial. High forest, of low timber volume.

A_1 *0–5 cm:* Brownish yellow (10YR 4/2) very friable heavy sandy loam. Weak fine subangular blocky. About 60% loose, hard plinthite concretions, very small sized (0.5–1.0 cm diam.), subangular blocky, fine grained, dusky red (7.5R 3/4). Transition clear.

A_2 *5–80 cm:* Brownish yellow (10YR 6/6) friable heavy fine sandy clay. Weak medium to fine subangular blocky. About 80% loose, hard plinthite concretions, similar to those in A_1, but somewhat larger (0.5–2.0 cm diam.). Transition gradual.

B_1 *80–120 cm:* Reddish yellow (7.5YR 6/8) friable to firm clay with common medium sized distinct mottles of red (2.5YR 5/8), predominantly in a fine polygonal pattern. Moderate medium sized subangular and angular blocky. Common faint clay skins, largely at the surface of the concretions. About 80% loose, hard concretions similar to those of A_1, but somewhat larger (0.5–2.5 cm diam.).

B_2 *120–220 cm:* Light red (2.5YR 6/8) firm clay, with common to many medium sized faint mottles of light red (7.5YR 6/6) in a fine polygonal pattern, and half hard. Weak medium sized subangular and angular blocky. About 50% half loose, hard or half hard plinthite concretions, similar to those in the A_1, but somewhat larger (0.5–2.5 cm diam.). Transition clear.

B_3 *220–280 + cm:* Light red (2.5YR 6/8) friable to firm clay, with common coarse distinct mottles of pale red (7.5R 6/4), and white (N 8/0). Massive, to weak medium sized subangular and angular blocky.

Profile 22 (KAOLINITIC YELLOW LATOSOL, Concretionary phase)
Field description 114 (Day)
Cf. III.2, Profile 28.

Profile 23 (KAOLINITIC YELLOW LATOSOL, medium textured – over bank of fossil plinthite)
Field description 337 (Commissão de Solos)
Amapá Territory, along road Macapá-Fazendinha (Lat. 0°.0'; Long. 51°.08'W)
Flat terrain, about 4 m above local river level. Well-drained. Pleistocene sediments. Grasses and scattered shrubs; yearly burned.

A_1 *0–15 cm:* Very dark greyish brown (2.5Y 3/2) friable sandy clay loam. Weak very fine to coarse granular. Transition clear and smooth.

A_3 *15–30 cm:* Olive brown (2.5Y 4/4) friable heavy sandy clay loam, with many fine faint mottles of very dark grey brown (2.5Y 3/2). Weak very fine subangular blocky. Transition diffuse and smooth.

B_1 *30–50 cm:* Yellowish brown (10YR 6/5) friable sandy clay. Little coherent massive, easily falling apart into fine earth. Transition diffuse and smooth.

B_{21} *50–75 cm:* Olive yellow (7.5Y 6/5) friable light clay. Structure as in B_1. Transition diffuse and smooth.

B_{22} *75–110 cm:* Brownish yellow (10YR 6/6) friable light clay. Structure as in B_1. Transition abrupt and irregular.

B_{2u} *110–190 cm:* Same material as B_{22} but with about 80% loose, large (up to 20 cm diam.), somewhat rounded, vesicular plinthite concretions, fine and medium grained and variegated reddish coloured.

The foregoing profile descriptions, and their analytical data (Appendix 9), illustrate the variation in the characteristics of well or moderately well-drained soils with fossil plinthite.

Another profile of Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol, Concretionary phase (RP-KYL, CR), located at km 30 of the Guamá-Imperatriz area, was also studied. A sample of the soft plinthite of the deep subsoil, beneath two separate layers of fossil hard plinthite, was analysed by X-ray diffraction (*cf.* sample 302-4 of Tables 7 and 8, and the Figs. 14 a-e). The clay fraction was found to be predominantly kaolinite (85 %), iron oxides comprising only 12 % and clay sized quartz 3 %. In the coarser fractions more sesquioxides are present (30–35 %), but they are only hematite. This mineral apparently kept enclosed much kaolinite (35–55 %). In the 2–16 micron and 16–80 micron fractions moreover some mica (7 %) occurs. The specific surface of both the whole soil and the clay fraction is very low. The clay fraction is in fact quite comparable, also in its chemical activity, to that of B horizons of Kaolinitic Yellow Latosol profiles (samples 233-3, 303-4, 300-4, and 210-4 of Table 7).

In the Guamá-Imperatriz area practically all concretionary soils contain soft plinthite at shallow depth. They therefore have been grouped as RP-KYL, CR. The impression is that the same situation exists in the majority of the concretionary soils elsewhere in Amazonia. However, those near Belém (Bragantina area) and Amapá (Savannah area) are, for a part, deeply friable: KYL, CR. It is often difficult, during surveys, to establish the upper level of the soft plinthite, because of the stoniness of the surface. It can only be easely done where recent deep road cuts are present, as was the case in the Guamá-Imperatriz area. Besides, for actual land use the degree of stoniness may be more important than the morphometric-genetic characteristics of the subsoil which determine the classification.

The genetic relationship between the Ground Water Laterite soils and the above described concretionary soils of Amazonia was the reason why the latter were provisionally termed 'Ground Water Laterite soil, Truncated phase' (*cf.* DAY, 1961: SOMBROEK, 1962b). Such a term however refers to the genesis of the *parent material* of the soils, not that of the present-day soils. Moreover, it suggests a drainage condition inherent into the Ground Water Laterite soil profile, *i.e.* intermittently imperfect drainage. The soils concerned are however well or moderately well-drained. Also, the differences in thickness of the layer with friable earth cannot be indicated as decisive as is secured by the distinction between Latosol and Red Yellow Podzolic soil.

The concretionary soils are, in fact, intergrading to Lithosols. When practically no earth occurs between the mass of concretionary elements, or the fossil plinthite forms a slab-like hardpan, a classification of the soil as 'Concretionary Lithosol' may be the most appropriate (*cf.* CAMARGO and BENNEMA, 1962). Such senile soils are, however, rare in Amazonia.

A general scheme for the different soils that can be distinguished with the formation, respectively the truncation and the burying of Amazon plinthite is given in Fig. 15.

III. The Soils Classified, and their Geographic Occurrence

III.1 The Methods of Study

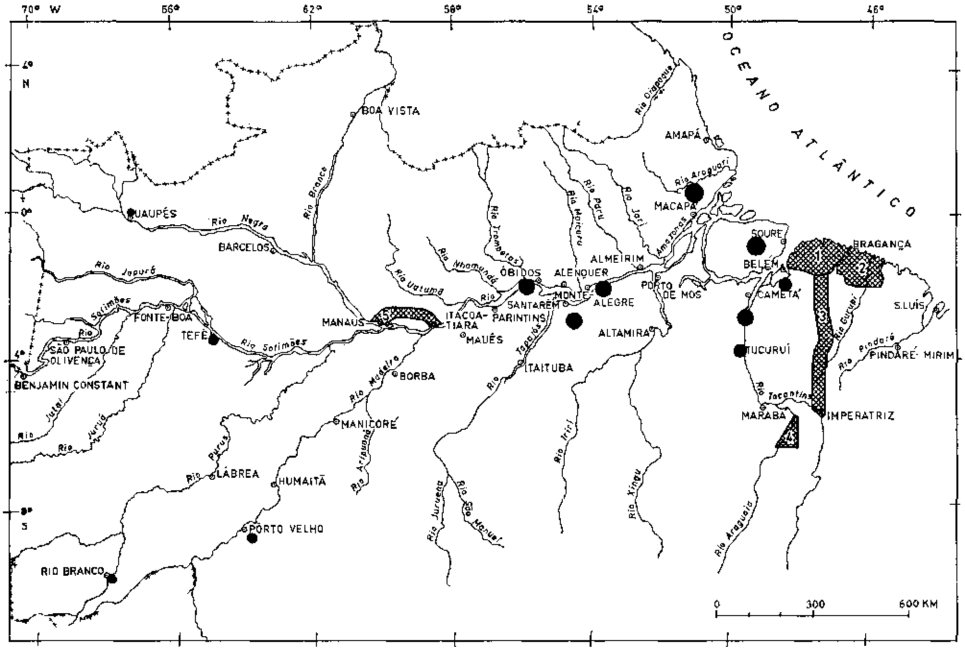
III.1.1 Field Studies

The soil data compiled in this publication were obtained from field studies by FAO soil scientists during the years 1957–1962, partly in cooperation with members of the Soils Section of the Instituto Agronômico do Norte (IAN) at Belém. During this time, several reconnaissance soil surveys were executed, largely in the eastern half of the region. Also many observations scattered throughout the region were made (*cf.* Fig. 16). Together with the data of the surveys, they enabled a picture to be obtained of the soils of Amazonia, and their relative importance. A total of about 350 full profile descriptions was assembled.

The reconnaissance soil surveys of the Caeté-Maracassumé area, the Guamá-Imperatriz area and the Araguaia Mahogany area (2, 3 and 4 of Fig. 16) were executed in cooperation with an FAO/SPVEA Forest Inventory Team, which made forest inventories of the same areas at the same time. Aerial photographs were used for these surveys. They were only partly verticals with full coverage of the terrain (Araguaia Mahogany area). The majority were trimetrogon photographs of poor quality. Moreover, they left gaps in the coverage. For the one area mentioned, aerial photograph interpretation was very helpful for soil mapping. For the other areas however, where vegetational differences were hardly noticeable, the photographs could only be used to produce little more than topographic-planimetric maps, as prepared by the Forest Inventory Team. It was therefore necessary to make comparatively many field observations. This was economically and technically possible because of the cooperation with the Forest Inventory Team, which cut, for its measurements, a network of ten-kilometres transects all over the area concerned. Details on the location of these transects may be found on the maps of Glerum (1960) and Glerum and Smit (1962a, 1962b).

The field studies were partly done on profile pits and partly on borings with a Dutch soil auger, the *Edelman auger*. The profile descriptions were made according to the standards established in the Soil Survey Manual (1951). The pH of the soil in the field was estimated with adapted fluids (Soil-tex pH kit, La Motte-Morgan pH kit, or Hellige pH kit). The Munsell Soil Color Charts were used to establish soil colours. Unless stated otherwise, the colour noted are those of the soil in a moist condition.

Fig. 16 Os estudos de campo utilizados para base desta publicação



Reconnaissance soil surveys
Levantamentos de reconhecimento dos solos

● Concentration of other field studies
Concentração dos outros estudos de campo

1. Bragantina (Filho *et al.*, 1963); 2. Caeté-Maracassumé (Day, 1959); 3. Guamá-Imperatriz (Sombroek, 1962a); 4. Araguaia Mahogany (Sombroek and Sampaio, 1962); 5. Manaus-Itacoatiara (Santos *et al.*, in execution/*em execução*)

Fig. 16 The field studies of Amazon soils which were used as a basis for this publication

III.1.2 Laboratory studies

Samples of about 100 of the studied soil profiles were analysed in the laboratory. The analysis of most samples was carried out at the Instituto de Química Agrícola (IQA) in Rio de Janeiro, Brasil, under the supervision of the chemist Dr. Leandro Vettori. The methods employed (IQA, 1949) are the same as those used for the laboratory analysis of the studies of the national Brazilian Soils Commission (*cf.* Barros, Drumond, Camargo *et al.*, 1958; Lemos, Bennema, Santos *et al.*, 1960), and are as follows:

Physical analysis

1. *Apparent bulk density:* Weighing of 100 ml earth, compacted in a metal cylinder of the same capacity.
2. *Real bulk density:* A known weight of fine earth (< 2.0 mm), dried at 105 °C, is put in a receiver of 50 ml, which is then filled up with absolute ethyl alcohol.

3. *Mechanical analysis:* Sedimentation in a Koettgen cylinder, using NaOH as the dispersion agent. In the samples with more than 1 % C, the organic material is first destroyed by H_2O_2.

For a portion of the samples, the separation is made in four fractions according to the classification of the U.S. Department of Agriculture (fractions 2.0–0.2 mm, 0.2–0.05 mm, 0.05–0.002 mm and $<$ 0.002 mm) and for the other samples according to the International Classification (2.0–0.2 mm, 0.2–0.02 mm, 0.02–0.002 mm and $<$ 0.002 mm). The textural class names generally used in the field are based on the subdivision of the U.S. system. In case the data are provided according the International Classification, the percentages of the 0.02–0.05 mm fraction are therefore estimated, by graphical interpolation on a summation curve.

4. *Textural relation B/A:* The mean of the clay percentages of the subhorizons of the B (exclusive B_3), divided by the mean of the clay percentages of the subhorizons of the A.

5. *'Natural' clay:* The percentage of clay obtained by shaking with distilled water.

6. *Index of structure:* Obtained by comparing 'natural' clay content with clay content after dispersion with NaOH. Index of structure $= 100 \times (1 - \text{natural clay/total clay})$

7. *Moisture equivalent, M.E.:* Determination according to the process of BRIGGS and MAC-LANE, centrifuging the moistened earth at 1000 g during 40 minutes.

CHEMICAL ANALYSIS

8. *Organic carbon, C:* Oxidation of the organic material with potassium bichromate 0.4 N (method of TIURIN).

9. *Total nitrogen, N:* Digestion with sulphuric acid, catalized with copper and potassium sulphate. After transformation of all N into ammonia salt, this is decomposed by NaOH and the distilled ammonia collected in a solution of boric acid 4% which is titrated with H_2SO_4, 0.02 N.

10. *Ratio C/N:* Dividing organic carbon by total nitrogen.

11. *pH–H_2O and pH–KCl:* Determination with potentiometer in a soil paste with ratio of soil to water approximately 1:1, using glass electrode.

12. *Available phosphorus, P_2O_5:* Extraction according to the TRUOG method, (H_2SO_4, 0.01 — 0.001 N + $(NH_4)_2SO_4$, 0.05 M) using the 'Unicam' colorimeter, or according to the BRAY method (HCl, 0.1 N + NH_4F, 0.5 M).

13. *Attack by H_2SO_4 ($d = 1.47$):* Under a reflux cooler, 2 g of fine earth are boiled for an hour with 50 ml H_2SO_4, $d = 1.47$. After boiling, the material is cooled, diluted and filtered into a receiver of 250 ml capacity.

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

b. *Al_2O_3, total aluminum:* In 50 ml of the filtrate of the sulphuric acid attack, the other heavy metals are separated with an excess of NaOH, 30%. A measured part of the new filtrate is gradually neutralized with HCl and the aluminum determined volumetrically with EDTA.

c. *Fe_2O_3, total iron:* Determination on 50 ml of the filtrate of the sulphuric acid attack by the bichromate method, using diphenilamine as the indicator and tinchloride as the reducer.

d. *TiO_2:* Determination in the filtrate of the sulphuric acid attack by the colorimetric method of H_2O_2, after elimination of the organic material by heating with some drops of concentrated $KMnO_4$.

e. *P_2O_5, total phosphorus:* Colorimetric determination on the filtrate of the sulphuric acid attack, using ascorbic acid as the reducer, in the presence of ammonium molybdate, sulphuric acid, and bismuth salt.

14. *Values Ki (SiO_2:Al_2O_3 ratio) and Kr (SiO_2:(Al_2O_3 + Fe_2O_3) ratio):* Calculation on molecular basis from the data obtained under 13. It is assumed that Al and Fe are determined totally with the sulphuric acid attack as described under 13. The data for these two constituents therefore represent the sums of the portions of Fe and Al occurring in exchangeable form, the portions occurring as free sesquioxides – including concretions – and the portions that are constituents of the silicate clay minerals. The determined Si comprises all that of the silicate clay minerals and also that which is present in free colloidal form. Quartz and other primary minerals are not, however, attacked, even when of clay-size.

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

15. *Exchangeable metallic cations:*

a. *The sum of exchangeable metallic cations, S:* Determination by percolation of 12.5 g fine earth with 250 ml normal ammonium acetate at pH 7. 100 grams of the percolate are evaporated,[1] calcinated, the residue dissolved in a measured excess of HCl, 0.1 N, and the excess determined with NaOH, 0.1 N. The value S represents also the sum of the separately determined Ca^{++}, Mg^{++}, K^+ and Na^+.

b. *Exchangeable calcium, Ca^{++}, and magnesium, Mg^{++}:* A measured part of the solution prepared for direct determination of S (*cf.* 15 a) is used for determination of Ca^{++} + Mg^{++} by EDTA, applying Eriochrome as the indicator. In another measured part of the solution, Ca^{++} is likewise determined by application of the indicator Murexide. With this analysis method, the Ca of possibly present free carbonates is included in the value for Ca^{++}.

c. *Exchangeable potassium, K^+, and sodium, Na^+:* Direct determination in the percolate of ammonium acetate with a flame photometer (see, however, 16).

16. *Soluble salts:* If the amount of Na^+, determined under 15c, is rather high, then the presence of free salts in the soil solution is suspected. In that case, the quantity of free anions, referred to as 'soluble salts' or 'Cl', is determined by measuring the conductivity of the saturation extract.

In the presence of soluble salts, the sum of the metallic cations as determined under 15*a* represents the exchangeable metallic cations together with the soluble metallic cations. It is assumed that the latter are normally Na^+ for a large proportion. In this case therefore, the Na^+ in the saturation extract is determined separately. This amount of Na^+ is subtracted from the amount determined under 15*c*, to obtain the real amount of exchangeable Na^+ on the adsorption complex. The value S, as determined under 15*a*, is also diminished with the amount of Na^+ in the saturation extract, to obtain the approximately correct sum of exchangeable metallic cations on the adsorption complex.

17. *Exchangeable aluminum, $(Al)^+$:* Determination by shaking 10 g fine earth with 200 ml KCl, 1 N, followed by decantation, and titration with NaOH, 0.1 N, in the presence of brome-thymol blue.

In fact, this determination gives the 'active acidity'. Experience at IQA has however shown that the data for exchangeable $(Al)^+$, determined colorimetrically with aluminon after extraction with KCl, 1 N, are practically always equal to the data for active acidity.

18. *Potential acidity, $H^+ + (Al)^+$:* Determination by extraction with normal calcium acetate at pH 7.

This value represents the 'potential acidity'. Its includes the 'active acidity', or the exchangeable $(Al)^+$ (see 17). H^+ alone represents the pH-dependent acidity.

19. *Potential cation exchange capacity, T:* Not determined separately but obtained by the addition of S (see 15 a) and $H^+ + (Al)^+$ (see 18). As such, it is equivalent to the potential cation exchange capacity according the NH_4OAc method at pH 7.

20. *Base saturation, V:* Obtained by comparing S with T. $V = 100\ S/T$.

The value represents the base saturation percentage of the potential cation exchange capacity.

Mineralogical analysis

Mineralogic analysis by IQA involves only a few selected samples, of which only the coarse sand fraction is studied. After separation of the minerals in groups with the Brögger funnel, using bromoform and a mixture of bromoform and chloroform as a separation fluid, the material is analysed under the binocular loupe and the polarizing microscope. Amounts less than 0.5 % weight are indicated as 'traces'.

Samples of a few selected profiles were analysed in laboratories elsewhere, namely that of UNSF British Guiana Soil Survey at Georgetown, British Guiana, that of the Royal Tropical Institute at Amsterdam, Holland, and that of the Netherlands Soil

Survey Institute (STIBOKA) at Wageningen, Holland. For a description of their analysis methods *cf.* PLAISANCE and VAN DER MAREL (1960); DAY *et al.* (1964).

III.2 The Soils Classified

The soils described in this publication are classified according to an international system, so as to permit comparison of the Amazon soils with those of other tropical regions. The classification system followed is that applied until recently in the USA, as described first by BALDWIN, KELLOGG and THORP (1938), and revised by THORP and SMITH (1949). The details of the classification of the zonal tropical soils agree with the adaptations and elaborations made on the USA system by the national Brazilian Soils Commission (*cf.* II.2). The 'Guide to the classification of the Late Tertiary and Quaternary soils of the Lower Amazon valley' (DAY, 1961) is followed as closely as possible, the said guide also being based on the USA system. However, DAY's classifying had to be done practically only on morphometrical field studies. Laboratory data afterwards becoming available, expansion of the field studies, and more definite correlation with the findings in other regions of Brazil, made it necessary to elaborate, and in part deviate from, this Guide.

The levels of classification are those of the 'Great Soil Group', its subgroups, and phases of these. For practical soil mapping, the soil texture is often included in the nomenclature.

In the following, the soil units found to date in Amazonia are described systematically. A full description of the concept and the range in characteristics of a unit is given only for those ones of which frequent occurrence was established, for instance those mapped in survey areas. Further details are given in direct survey reports (DAY, 1959; SOMBROEK, 1962a; SOMBROEK, 1962b; SOMBROEK and SAMPAIO, 1962). The listing of the soils discussed is given in Table 9. For analytical data on most individual profiles, *cf.* Appendix 10.

(I) KAOLINITIC LATOSOLS AND KAOLINITIC LATOSOLIC SANDS (KL and KLS)

A general discussion of the characteristics of this most important group of Amazon soils is given in II.2.2. Their qualities are dealt with in V.3.

(Ia) Kaolinitic Yellow Latosol (KYL)

General concept: This unit comprises deeply and strongly weathered soils, well-drained and permeable, predominantly with colour of yellowish hue, and of varying texture, but with at least 15% clay in the B horizon. The soils are very strongly or extremely acid, having a base saturation below 40%.

The profiles are well developed, having ABC sequence of horizons; the boundaries between these horizons are gradual or diffuse. The soils have a latosolic-B horizon (*cf.* II.2.1); the clay-sized particles consist very predominantly of silicate clay minerals of

Table 9 Listing of the described Amazon soils

	Soil name *nome de solo*	Symbol *símbolo*	Profile no. and detailed symbol *número do perfil e símbolo detalhado*
(I)	KAOLINITIC LATOSOLS AND KAOLINITIC LATOSOLIC SANDS *Latosolos Caoliníticos e Areias Latosólicas Cauliníticas*	KL + KLS	
	(Ia) Kaolinitic Yellow Latosol *Latosolo Amarelo Caolinítico*	KYL	
	(Ia.1) *Kaolinitic Yellow Latosol (,Ortho)* *Latosolo Amarelo Caolinítico (,Orto)*	KYL	*24* KYL_{vh} *25* KYL_{m}
	(Ia.2) *Kaolinitic Yellow Latosol, Compact phase* *Latosolo Amarelo Caolinítico, fase Compacta*	KYL, C	*26* KYL, C_{vh} *27* KYL, C_{rh}
	(Ia.3) *Kaolinitic Yellow Latosol, Concretionary phase* *Latosolo Amarelo Caolinítico, fase Concrecionária*	KYL, CR	*28* KYL, CR
	(Ia.4) *Kaolinitic Yellow Latosol, intergrade to Yellow Podzolic soil* *Latosolo Amarelo Caolinitico, 'intergrade' para solo Podzólico Vermelho-Amarelo*	KYL-RP	*29* $KYL\text{-}RP_{rh}$
	(Ia.5) *Kaolinitic Yellow Latosol, intergrade to Dark Horizon Latosol* *Latosolo Amarelo Caolinítico, 'intergrade' para Latosolo de Horizonte Escuro*	KYL-DHL	*30* $KYL\text{-}DHL_{h}$
	(Ia.6) *Kaolinitic Yellow Latosol, intergrade to Ground Water Laterite soil* *Latosolo Amarelo Caolinítico, 'intergrade' para solo Laterita Hidromórfica*	KYL-GL	
	(Ib) Kaolinitic Red Latosol *Latosolo Vermelho Caolinítico*	KRL	*31* KRL_{m}
	(Ic) Kaolinitic Latosolic Sand *Areia Latosólica Caolinítica*	KLS	*32* KLS, F *33* KLS, S
(II)	RED YELLOW LATOSOLS *Latosolos Vermelho-Amarelo*	RL	*34* RL?
(III)	DARK RED LATOSOLS *Latosolos Vermelho Escuro*	DL	*35* DL, S
(IV)	RED YELLOW PODZOLIC SOILS *Solos Podzólicos Vermelho-Amarelo*	RP	
	(IV.1) *Red Yellow Podzolic soil (,Ortho)* *Solo Podzólico Vermelho-Amarelo (,Orto)*	RP	*36* RP_{lb} *37* RP_{rhb}
	(IV.2) *Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol* *Solo Podzólico Vermelho-Amarelo, 'intergrade' para Latosolo Amarelo Caolinitico*	RP-KYL	*38* $RP\text{-}KYL_{vh}$ *39* $RP\text{-}KYL_{rh}$
	(IV.3) *Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol, Concretionary phase* *Solo Podzólico Vermelho-Amarelo, 'intergrade' para Latosolo Amarelo Caolinitico, fase Concrecionária*	RP-KYL, CR	*40* RP-KYL, CR
(V)	RED YELLOW MEDITERRANEAN SOILS *Solos Mediterránicos Vermelho-Amarelo*	RM	*41* RM
(VI)	LITHOSOLS *Litosolos*	L	*42* L

	Soil name *nome de solo*	Symbol *símbolo*	Profile no. and detailed symbol *número do perfil e símbolo detalhado*
(VII)	GROUND WATER LATERITE SOILS *Solos Laterita Hidromórfica*	GL	*43* GL
(VIII)	HYDROMORPHIC GREY PODZOLIC SOILS *Solos 'Hydromorphic Grey Podzolic'*	HP	*44* HP_{hb}, O *45* HP_{hb}, D *46* HP_{hb}, S
(IX)	GROUND WATER PODZOLS AND WHITE SAND REGOSOLS *Podzols Hidromórficos e Regosolos de Areia Branca*	GP WSR	*47* GP *48* WSR
(X)	LOW HUMIC GLEY AND HUMIC GLEY SOILS *Solos Glei Húmico e Glei Pouco Húmico*	LHG HG	*49* LHG *50* HG *51* HG, U
(XI)	SALINE AND ALKALI SOILS *Solos Salinos e Alcalinos*		*52* Sol, C
(XII)	'TERRA PRETA' SOIL *Terra Preta*	TP	*53* TP_t
(XIII)	'TERRA ROXA LEGÍTIMA' AND 'TERRA ROXA ESTRUTURADA'; GRUMOSOL; NON CALCIC BROWN-LIKE SOIL, GRAVELLY PHASE (NB, G); ACID BROWN FOREST-LIKE SOIL, GRAVELLY PHASE (AF, G); ALLUVIAL SOIL; 'PARÁ' PODZOL; GREY HYDROMORPHIC SOIL; HALF BOG SOIL AND BOG SOIL *Terra Roxa Legítima e Terra Roxa Estruturada; Grumosolo; Solo parecido com 'Non Calcic Brown', fase Cascalhenta; Solo parecido com 'Acid Brown Forest', fase Cascalhenta; Solo Aluvial; Podzol de Pará; Solo 'Grey Hydromorphic'; Solos Orgânicos*		

Applied soil textural classes *aplicadas classes texturais de solo*		
clay (%) *argila (%)*	class *classe*	symbol *símbolo*
< 5%	very light textured *textura muito leve*	*vl*
15–15%	light textured *textura leve*	*l*
15–35%	medium textured *textura média*	*m*
35–50%	rather heavy textured *textura meio pesada*	*rh*
50-70%	heavy textured *textura pesada*	*h*
>70%	very heavy textured *textura muito pesada*	*vh*

Applied base saturation classes *classes de saturação de bases*		
V(%)	class *classe*	symbol *símbolo*
<50	low *baixa*	*lb*
50–70	rather high *meio-alta*	*rhb*
70–100	high *alta*	*hb*

If the textural class is applied for the soil as a whole, the texture of the B_2 horizon is taken as the criterion

Se a classe textural é aplicada ao solo como um todo, então a textura do horizonte B_2 é a que prevalece

In generalisations, the first three classes are grouped together as 'relatively light textured', and the latter three as 'relatively heavy textured'. The terms 'sandy' and 'clayey' for these two groups are normally avoided

Ao se fazerem generalizações, as três primeiras classes são agrupadas como 'textura relativamente leve' e as últimas três como 'textura relativamente pesada'. Os têrmos 'arenoso' e 'argiloso', para êstes dois grupos, são geralmente evitados

Tabela 9 Os solos amazônicos descritos the 1:1 lattice structure, being kaolinite. The soils have a rather weak macro-structure, at least in the subsurface horizon. When dry they are slightly hard, or hard. The B horizon is generally somewhat heavier than the A horizon, a fact which is also noticeable in the field, except where very heavy textured profiles are met.

Within the Kaolinitic Yellow Latosol group, various subgroups are distinguished. For practical mapping purposes, these subgroups are, for the most part, further subdivided according to the texture of the B horizon (*cf.* Table 9).

(Ia.1) *Kaolinitic Yellow Latosol (,Ortho)* (KYL)

The profiles of the Ortho type are characterized by the following features:

1. The transitions, both as regards colour and texture, between the horizons are diffuse, or gradual, except the transition from the A_1 to the A_3. From top to bottom of the profile, the colour gradually obtains more value, more chroma, and a redder hue; mottles are absent.
2. The B horizon is neither compact nor firm.
3. The soils are deeply porous and deeply rooted, to the C horizon.
4. Hard plinthitic gravel is absent or nearly absent. If occurring scattered in the profile, it comprises maximally 5% of the soil mass; if concentrated in a layer, then this layer is less than 30 cm thick above 1 m depth.

The range in characteristics of the *very heavy textured* profiles is given below:

The profiles have heavy clay texture in all horizons. The A horizon, consisting of an A_1 and an A_3, is between 20 and 45 cm thick; the B horizon, consisting of a B_2 and often a B_3, is 80 to 150 cm thick; the C horizon is of varying and often difficult to determine, thickness.

The A_1 subhorizon varies considerably in thickness (from 2 to 30 cm). The colour is predominantly dark yellowish brown (10 YR 4/4) or dark brown to brown (10 YR 4/3 or 5/3). The structure is usually moderate, medium to fine subangular blocky, with often weak to moderate, very fine granules present. The superficial part may be crusted and clodded (*cf.* IV.1.1.2).

The A_3 subhorizon is 15–40 cm thick. The colour is predominantly yellowish brown (10 YR 5/6 or 5/4) or light yellowish brown (10 YR 6/4). It has usually a weak to moderate fine subangular blocky and moderate to weak, very fine granular structure. On a considerable part of the insect and root channels, coatings may be present.

The subhorizons of the B horizon are normally strong brown (7.5 YR 5/6), less frequently yellowish brown (10 YR 5/6) or reddish yellow (7.5 YR 6/6 or 6/8). The structure is weak to moderate, mostly medium subangular blocky, with weak, very fine granular elements present in varying frequency. A portion of the channels may have coatings.

The C-horizon is reddish yellow (7.5 YR 6/6 or 6/8, 5 YR 6/8), or yellowish red (5 YR 5/8), and massive or with a weak, medium subangular blocky structure.

The characteristics of the *heavy, rather heavy,* and *medium textured* profiles have the following range:

The profiles have heavy sandy loam, sandy clay loam, sandy clay, or clay texture in the B horizon. The A horizon, consisting of an A_1 and A_3, is 35 to 75 cm thick. The B horizon, consisting of a B_2 and B_3, and often a B_1, is 100 to 250 cm thick. The C horizon is of varying and not easily determined thickness.

The A_1 subhorizon ranges from 5 to 30 cm in thickness. The texture varies from sand to sandy clay. The colour has values of 3 to 5, a chroma of 3 or 4, and a hue of 10 YR, less frequently 7.5 YR or 5 YR; most common are brown (10 YR 4/3 or 5/3) and dark yellowish brown (10 YR 4/4). In the lightest textures the horizon may be structureless (single grains), but more often there is a structure of weak to moderate, fine subangular blocky and very fine granules. Both under a cover of primeval forest, and under cultivation, the upper section of the A_1 often consists of a layer of loose, bleached sand (pepper and salt colour), ranging in thickness from 0.1 to 5 cm ('micro-podzol').

The A_3 subhorizon is normally between 20 and 50 cm thick. The texture varies from sandy loam to light clay. The colour value is usually 5 or 6, the chroma varies from 4 to 8, and the hue is generally 10 YR; most common are yellowish brown (10 YR 5/6) and light yellowish brown (10 YR 6/4). The structure is mostly weak to moderate, medium to fine subangular blocky, with very fine granules present in varying frequency.

The B_1 subhorizon, when present, is 50 to 80 cm thick. The texture is usually heavy sandy loam or light sandy clay loam. The colour is brownish yellow (10 YR 6/6) or yellow (10 YR 7/6), less frequently reddish yellow (7.5 YR 6/6 or 7/6). The structure is normally the same as that of the A_3.

The B_2 subhorizon, 70 to 150 cm thick, varies in texture from heavy sandy loam to clay; the texture is always noticeably heavier than that of the A horizon. The colour is normally reddish yellow (7.5 YR 6/6 or 6/8) or brownish yellow (10 YR 6/6 or 6/8). The structure is normally a slightly coherent porous soil mass, falling apart into weak, medium to fine subangular blocky elements and some very fine granules.

The B_3 horizon is commonly slightly lighter textured than the B_2, with the other characteristics approximately identical.

The C horizon, in texture varying from sandy loam to sandy clay, is usually reddish yellow (5 YR 6/8) or yellowish red (5 YR 5/8). The horizon is massive, but has mostly a large number of fine pores.

Profile 24. KAOLINITIC YELLOW LATOSOL (,ORTHO), very heavy textured (KYL_{vh}).
Field description 210 (Sombroek)
Location: Along highway BR-14, km 247, S of São Miguel do Guamá.
Relief and drainage: Totally flat top of rather small section of high terrace (planalto). Alt. 200 m. Well-drained.
Parent material: Plio-Pleistocene lacustrine sediments (Belterra clay).
Vegetative cover: Primeval tropical forest. Rather low timber volume (100 m^3/ha *ca.*); rather few, but thick trees; dense undergrowth, of thick creepers and climbers.

O_1 *8–5 cm:* Undecomposed plant residues.

O_2 *5–0 cm:* Partly decomposed plant residues with many fine roots.

A_1 *0–2 cm:* Dark yellowish brown (10 YR 4/4) heavy clay. Moderate, medium to fine subangular blocky and weak, very fine granular structure. Moist, friable. Sticky and plastic when wet. Locally the horizon is crusty, due to intense activity of insects, especially termites. Many pores. Very many, mostly fine, roots. Transition clear.

A_3 *2–20 cm:* Yellowish brown (10 YR 5/6) heavy clay. Moderate, fine subangular blocky and weak, very fine granular structure. Moist, friable. Sticky and plastic when wet. Soft when dry. Many pores. Very many roots. Transition gradual.

B_2 *20–60 cm:* Strong brown (7.5 YR 5/6) heavy clay. Weak to moderate, medium to fine subangular blocky and weak, very fine granular structure. A few, faint clay skins. Moist, friable. Sticky and plastic when wet. Slightly hard when dry. Many pores. Many roots. Transition diffuse.

B_3 *60–150 cm:* Strong brown (7.5 YR 5/6) heavy clay. Weak, medium sized subangular blocky and weak, very fine granular structure. A few, very faint clay skins. Moist, friable to firm. Sticky and plastic when wet. Slightly hard when dry. Common pores. Many roots. Transition diffuse.

C *150–250 cm:* Yellowish red (5 YR 5/8) heavy clay. Massive to weak, medium sized subangular blocky structure. Moist, firm. Sticky and plastic when wet. Few pores. Very few roots.

For full mineralogical analysis and specific surface data of the A_3 and B_2 horizons of a comparable profile: see sample 303-2 and 303-4 of the Tables 7 and 8, Fig. 14a-e and Photo 9. For pF-curves of the B_2 of comparable profiles: see samples 219-3 and 303-3 of Fig. 37.

Profile 25. KAOLINITIC YELLOW LATOSOL (,ORTHO), medium textured (KYL$_m$).
Field description 233 (Sombroek-Sampaio)
Location: Along highway BR-14, km 12.7 S of São Miguel do Guamá.
Relief and drainage: Flat top of terrace, about 55 cm above nearby river. Well-drained. Alt. 65 m.
Parent material: Pleistocene fluviatile (?) sediments.
Vegetative cover: Tropical forest with medium timber volume (150 m^3/ha *ca.*). At the spot probably once or twice attacked by fire.

O_1 *6–1 cm:* Undecomposed plant residues.

O_2 *1–0 cm:* Partly decomposed plant residues, with very fine roots.

A_{11} *0–2 cm:* Loose bleached sand.

A_{12} *2–20 cm:* Brown (10 YR 4/3) coarse sand. Single grains and a few, weak, fine crumbs. Moist, loose. Not sticky and not plastic when wet. Soft when dry. Very many, mainly fine roots. Transition gradual.

A_3 *20–70 cm:* Yellowish brown (10 YR 5/4) light coarse sandy loam. Little coherent massive, to weak, medium to fine subangular blocky structure. Moist, very friable. Not sticky and not plastic when wet. Slightly hard when dry. Slightly more resistant to penetration than other horizons. Common pores. Many roots. Some pieces of charcoal. Transition diffuse.

B_1 *70–140 cm:* Brownish yellow (10 YR 6/6) coarse sandy loam. Weak, medium to fine subangular blocky structure. Moist, very friable. Not sticky and not plastic when wet. Slightly hard, to hard when dry. Common pores. Many roots. Transition diffuse.

B_{21} *140–220 cm:* Reddish yellow (7.5 YR 6/6) heavy coarse sandy loam. Little coherent massive, to weak, medium to fine subangular blocky structure. Moist, very friable. Not sticky and slightly plastic when wet. Slightly hard, to hard when dry. Common, to few poers. Few roots. Transition diffuse.

B_{22} *220–320 cm:* Reddish yellow (7.5 YR 6/6) light coarse sandy clay loam. Little coherent massive. Moist, very friable. Not sticky and slightly plastic when wet. Hard when dry. Few pores. Very few roots.

For full mineralogical analysis and specific surface data of the A_3 and B_2 horizons of a comparable profile: see sample 300-2 and 300-4 of Table 7 and 8. For the pF-curve of the B_2 of a comparable profile: see sample 231 of Fig. 37.

(Ia.2) *Kaolinitic Yellow Latosol, Compact phase* (KYL, C)

The profiles of the Compact phase differ from those of the Ortho type in being compact and rather firm, especially in the B horizon. This B horizon is relatively slightly porous; the root development in this horizon is limited. The hue of the profiles is yellower (often 2.5 Y). In the very heavy textured profiles, the A_1 horizon is extremely thin. In the lighter textured profiles the textural difference between the A and the B horizons is fairly great. Some mottling may also be present in the B horizon of the latter profiles.

The very heavy textured and the rather heavy textured profiles were frequently encountered. A range in characteristics can therefore be given.

The range for the *very heavy textured* profiles is as follows:

The A horizon, consisting of an A_1 and an A_3, is 30–50 cm thick. The B horizon, consisting of a B_2 and a B_3, is between 100 and 150 cm thick. The C horizon is of varying thickness.

The A_1 subhorizon rarely comprises more than 2–3 cm. The colour value is 5 or 6, the chroma 3 or 4, the hue 10 YR or 2.5 Y. Light yellowish brown (10 YR 6/4) is the most common. The structure is usually moderate, fine subangular blocky, composing weak, medium subangular blocky. Due to the thinness of the A_1, and the thinness or absence of an O_1 and O_2, the yellowish clay of the A_3 can often be observed bare at the surface. The A_3 subhorizon, varying from 30 to 50 cm in thickness, has colour values of 6 or 7, chromas of 4 or 6, hues of 2.5 Y or 10 YR. Most common are very pale brown (10 YR 7/4) and pale yellow (2.5 Y 7/4). The structure is a moderate, fine subangular blocky and weak very fine granular. The B_2 horizon, varying in thickness from 50 to 100 cm, has colour values of 6 or 7, chromas of 6 or 8, hues of 10 YR or 7.5 YR. Most common is yellow (10 YR 6/7). Mottling does not occur. The structure is commonly weak to moderate, fine subangular blocky and locally weak, very fine granular. The B_3 subhorizon is about 70 cm thick. The colour is generally reddish yellow (7.5 YR 6/8). The structure is usually weak, medium subangular blocky but sometimes a weak, medium sized platy structure occurs. The C-horizon is generally reddish yellow (5 YR 7/6). The horizon is normally massive.

For the *rather heavy textured* profiles the range in characteristics is as follows:

The A horizon, consisting of an A_1 and an A_3, varies between 20 and 60 cm in thickness. The B horizon, consisting of a B_2 and a B_3, is between 100 and 120 cm thick. The C horizon is of varying thickness. The A horizon is often capped with a rather thick (up to 3 cm) layer of loose bleached sand ('micro-podzol').

The A_1 subhorizon varies between 5 and 20 cm in thickness. The texture is predominantly sandy loam. The colour is grey brown (10 YR 5/2), brown (10 YR 5/3) or pale brown (10 YR 6/3). The horizon is structureless, or has a weak, fine subangular blocky structure. The A_3 subhorizon is between 20 and 40 cm thick. The texture is mostly sandy clay loam, sometimes sandy loam or sandy clay. The colour is predominantly very pale brown or pale yellow (10 YR, resp. 2.5 Y 7/4), sometimes pale brown (10 YR 6/3). The structure is usually weak, medium subangular blocky. The B_2 subhorizon is between 20 and 70 cm thick. The texture is predominantly sandy clay, sometimes sandy clay loam, or clay. The colour is commonly brownish yellow (10 YR 6/6), but also colours of less chroma occur (10 YR resp. 2.5 YR 6/3–6/4). The latter is mostly the case if the horizon is of clay texture; then also common and distinct mottles of yellowish red (5 YR 5/8), may be present. The structure is normally weak, medium subangu-ar blocky but sometimes a stronger structure (weak to moderate, medium angular blocky) is present, accompanied by a few faint clay skins. The B_3 subhorizon is between 50 and 100 cm thick. The texture is predominantly a light sandy clay. The colour is commonly reddish yellow (7.5 YR 6/6–6/8), but yellow (10 YR resp. 2.5 Y 7/6) may occur. The horizon is massive, or has a weak, medium sized subangular blocky structure.

The C horizon has normally sandy clay or sandy clay loam textures. Its colour is predominantly reddish yellow (7.5 resp. 5 YR 6/8–7/8).

Profile 26. KAOLINITIC YELLOW LATOSOL, Compact phase, very heavy textured (KYL, c_{vh})
Field description 230 (Sombroek)
Location: Highway BR-14, km 69 of São Miguel do Guamá, 6 km E.
Relief and drainage: Totally flat terrace. Well-drained. Alt. 70 m.
Parent material: Plio-Pleistocene lacustrine sediments, re-worked in early Pleistocene.
Vegetative cover: Primeval tropical forest, with medium (140 m^3/ha *ca.*) timber volume. Scattered thick trees, often in small groups; dense undergrowth, largely consisting of thick creepers and climbers.

- O_1 *4–1 cm:* Undecomposed plant residues.
- O_2 *1–0 cm:* Partly decomposed plant residues with many very fine roots. Surface rough and rather hard, locally bare and then with green cover (*Algae*).
- A_1 *0–3 cm:* Grey brown (2.5 Y–10 YR 5/2) heavy clay. Structure of moderate, fine subangular blocks, composing weak, medium sized subangular blocks. Moist, friable to firm. Sticky and plastic when wet. Hard when dry. Many pores, many large insect channels. Very many, mainly fine roots. Transition clear.
- A_3 *3–40 cm:* Light yellowish brown (2.5 Y 6/4) heavy clay. Moderate, fine subangular blocky and weak, very fine granular structure. Moist, friable. Sticky and plastic when wet. Slightly hard when dry. Rather compact. Many pores. Many roots. Transition gradual.
- B_2 *40–90 cm:* Brownish yellow (10 YR 6/6) heavy clay. Structure of weak to moderate, very fine subangular blocks, composing weak, medium sized subangular blocks. Tendency to platy. A few, faint clay skins. Moist, friable to firm. Sticky and plastic when wet. Slightly hard, to hard when dry. Compact. Very resistant to penetration with hammer. Few pores. Few roots. Transition diffuse.

With Dutch auger:

B_3 *90–130 cm:* Brownish yellow (10 YR –7.5 YR 6/8) heavy clay. Moist, firm. Sticky and plastic when wet. Very difficult to penetrate with soil auger. Transition diffuse.

C *130–180 cm:* Reddish yellow (7.5 YR 7/8) heavy clay. Moist, firm. Sticky and plastic when wet. Very difficult to penetrate with soil auger.

Profile 27. KAOLINITIC YELLOW LATOSOL, Compact phase, rather heavy textured (KYL, C_{rh})
Field description 194 (Sombroek)
Location: Highway BR-14, km 63 S of São Miguel do Guamá, 7 km E.
Relief and drainage: Extensive, completely flat terrace, about 60 m above river level. Somewhat imperfect internal drainage. Alt. 60 m.
Parent material: Early Pleistocene fluviatile (?) sediments.
Vegetative cover: Primeval tropical forest of low timber volume (75 m^3/ha *ca.*). Dense undergrowth, predominantly of thin creepers and climbers.

O_1 *9–2 cm:* Undecomposed plant residues.

O_2 *2–0 cm:* Partly decomposed plant residues with many fine roots.

A_{11} *0–1 cm:* Loose bleached sand.

A_{12} *1–30 cm:* Pale brown (10 YR 6/3) sandy loam. Weak, fine subangular blocky structure. Moist, friable. Not sticky and not plastic when wet. Slightly hard when dry. Slightly compact. Common to few pores. Common roots. Transition diffuse.

A_3 *30–60:* Light yellowish brown (2.5 Y 6/4) heavy sandy clay loam. Weak, medium subangular blocky structure. Moist, firm. Slightly sticky and slightly plastic when wet. Hard when dry. Compact. Very resistant to penetration with hammer. Very few pores. Few roots. Transition diffuse.

B_2 *60–120 cm:* Yellow (2.5 Y 7/6) light sandy clay. Weak to moderate, coarse subangular blocky structure Moist, firm. Slightly sticky and slightly plastic when wet. Hard when dry. Compact. Very resistant to penetration with hammer. Common pores. Few roots. Transition diffuse.

B_3 *120–170 cm:* Yellow (2.5 Y 7/6) sandy clay loam, with few, medium sized, faint mottles of yellow (10 YR 7/6). Massive to weak, medium sized subangular blocky structure. Moist, friable to firm. Slightly sticky and slightly plastic when wet. Hard when dry. Slightly compact. Less resistant to penetration with hammer than B_2. Common pores. No roots.

(Ia.3) *Kaolinitic Yellow Latosol, Concretionary phase* (KYL, CR)

The profiles of the Concretionary phase differ from those of the Ortho type owing to the presence of plinthitic gravel. This includes more than 5% of the soil mass when it occurs scattered in the profile, or constitutes a layer in excess of 30 cm in thickness above a depth of 1 m. Soft plinthite is absent above a depht of 1 m. The colour is often, but not always, somewhat redder than that of the Ortho type. For a general discussion on the genetics of this soil, please refer to II.3.2.2.

Profile 28. KAOLINITIC YELLOW LATOSOL, Concretionary phase (KYL, CR)
Field description 114 (Day)
Location: Near Belém, 3 km S of IAN Headquarters (Lat. 1°.27′ S; Long 48°.26′ W).
Relief and drainage: Undulating terrain (slope 2–5%). Alt. less than 50 m. Well-drained.
Parent material: Mio-Pliocene fluviatile (?) sediments.
Vegetative cover: Cleared from brush. Formerly forest.

A_p *0–25 cm:* Dark reddish brown (5 YR 3/2) gravelly sandy clay loam. Weak, coarse subangular blocky structure, breaking into moderate, medium to fine subangular blocky. Moist, friable. Gravels are coarse grained iron-quartz plinthite fragments, of diameter 0.5–3 cm, occupying about 75% of the soil mass. pH (Soiltex) 4 or below. Transition clear and smooth.

A_3 *25–50 cm:* Gravelly clay. Transitional horizon between A_{1p} and B_{21}. Transition gradual and wavy.

B_{21} *50–100 cm:* Yellowish red (5 YR 5/6) gravelly clay. Weak, coarse subangular blocky structure. Moist, friable. Gravels are plinthite fragments, containing some medium or coarse grained quartz. They are of diameter 1–5 cm and occupy about 75% of the soil mass. pH (Soiltex) 4 or below. Transition diffuse and wavy.

B_{22} *100–170 cm:* Red (2.5 YR 5/8) gravelly clay. Weak, very coarse angular blocky structure, breaking into moderate, fine angular blocky. Moist, friable. Gravels are plinthite fragments, fine, and occupying about 75% of the soil mass. pH (Soiltex) 4 or below. Transition diffuse and wavy.

With Dutch auger:

C_1 *170–230 cm:* Red (2.5 YR 5/8) clay, with common to many, medium sized, prominent mottles of yellow (10 YR 8/8) and dark red (10 R 3/6). Still a few plinthite concretions, fine grained, rather soft.

C_2 *230–290⁺ cm:* Light reddish brown (2.5 YR 6/4) clay, with many, coarse, prominent mottles of pinkish white (7.5 YR 8/2) and dusky red (10 R 3/4).

(Ia.4) *Kaolinitic Yellow Latosol, intergrade to Red Yellow Podzolic soil* (KYL-RP)

The profiles of this group differ from those of the Ortho type in having a distinct colour change from the A to the B horizon. Also, the textural difference between the A and the B horizons is slightly larger than that of profiles of the Ortho type with the same general texture. The change in texture is, however, diffuse to gradual, as in the Ortho type.

Many examples were studied of the *rather heavy textured* profiles. Therefore, a range in characteristics for this textural class can be given:

The A horizon, consisting of an A_1 and an A_3, is between 35 and 60 cm thick. The B-horizon, consisting of a B_2 and a B_3, is 150 to 180 cm thick. The C horizon is of varying thickness. The A horizon is generally capped with only a thin layer ($\leqslant$ 1 mm) of loose sand ('micro-podzol').

The A_1 subhorizon is between 5 and 10 cm thick. The texture is predominantly sandy clay loam, sometimes sandy loam, or sandy clay. The colour is grayish brown or brown (10 YR 5/2 resp. 10 YR 5/3). The structure is weak or moderate, fine subangular blocky. The transition to the A_3 is characteristically clear. The A_3 subhorizon varies between 20 and 50 cm in thickness. The texture is normally sandy clay loam or sandy clay. The colour value is 6 or 7, the chroma 4 or 6, the hue 10 YR, sometimes 2.5 Y. Most frequent is very pale brown (10 YR 7/4). The structure is weak to moderate, medium to fine subangular blocky. The transition to the B horizon is characteristically gradual, not diffuse. Sometimes a transition zone (A + B) occurs, with colours both of A_3 and B_2. The B_2 subhorizon is 60 to 80 cm thick. The texture is commonly a light clay, but sandy clays are also rather frequent. The colour is reddish yellow (7.5 YR 7/6, sometimes 7.5 YR 7/8 or 6/6). The structure is a weak, medium subangular blocky. A few, faint clay skins may occur. The transition to the B_3 is diffuse. The B_3 subhorizon varies between 50 and 100 cm in thickness. The texture is a sandy clay or, less frequently, a light clay. The colour is reddish yellow (5 YR 6/8, 5 YR 7/8). The horizon has a weak, medium subangular blocky structure, if any. The C-horizon has commonly a sandy clay texture. Sandy clay loam or light clay textures also occur. The colour is reddish yellow (5 YR 6/8) or light red (2.5 YR 6/8), often with some mottling of yellow (10 YR 8/6). Sometimes colours of rather yellow hue and little chroma (*e.g.* pink, 7.5 YR 7/4) predominate.

Profile 29. KAOLINITIC YELLOW LATOSOL, intergrade to RED YELLOW PODZOLIC soil, rather heavy textured (KYL-RP_{rh}); the actual profile would come under the heavy texture class

Field description 197 (Sombroek)

Location: Along highway BR-14, km 136 S of São Miguel do Guamá.

Relief and drainage: Edge of flat terrace, 10 m above level of nearby rivulet. Well-drained. Alt. 80 m.

Parent material: Pleistocene fluviatile sediments.

Vegetative cover: Primeval tropical forest of rather high timber volume (200–250 m^3/ha). Erect, open undergrowth, nearly devoid of creepers and climbers.

O_1 *4–0.5 cm:* Undecomposed plant residues.

O_2 *0.5–0 cm:* Partly decomposed plant residues with very fine roots. Surface somewhat irregular and hard, due to intense termite activity. Loose bleached sand grains form a very thin discontinuous cover.

A_{11} *0–5 cm:* Dark brown (7.5 YR 3/2) heavy sandy clay loam. Moderate, very fine subangular blocky structure. Many very fine granular insect outcasts. Moist, friable. Sticky and slightly plastic when wet. Slightly hard when dry. Very many pores and large insect channels. Very many, mainly fine, roots. Transition abrupt.

A_{12} *5–20 cm:* Dark grey brown (10 YR 4/2) sandy clay, with many, fine, faint mottles of pale brown (10 YR 6/3). Weak to moderate, fine subangular blocky and weak, very fine granular structure. Moist, friable. Sticky and plastic when wet. Soft when dry. Many pores. Many roots. Transition clear.

A_3 *15–50 cm:* Very pale brown (10 YR 7/4) clay. Weak to moderate, medium subangular blocky and weak, very fine granular structure. Moist, friable. Sticky and plastic when wet. Slightly hard when dry. Many pores. Many roots. Transition gradual.

A + B *50–70 cm:* Reddish yellow (5 YR 7/8) clay, with many, fine, faint mottles of very pale brown (10 YR 7/4). A transition zone between A_3 and B_2.

B_2 *70–140 cm:* Reddish yellow (5 YR 7/8) clay. Structure weak, coarse subangular blocky, falling apart into weak, fine subangular blocky. A few, very faint clay skins. Moist, friable. Sticky and plastic when wet. Hard when dry. Many pores. Common roots. Transition gradual.

B_3 *140–190 cm:* Reddish yellow (5 YR 7/8) clay, with many fine, faint mottles of pink (7.5 YR 7/4). Massive, to weak, coarse subangular blocky or medium prismatic structure. Moist, friable. Sticky and plastic when wet. Slightly hard when dry. Common pores. Common roots. Transition gradual.

C *190–250 cm:* Pink (7.5 YR 8/4) heavy clay, with many, medium sized, faint to distinct mottles of white (10 YR 8/1). Massive, to weak, medium prismatic structure. Moist, friable. Sticky and plastic when wet. Slightly hard when dry. Few, to common pores. Few roots.

(Ia.5) *Kaolinitic Yellow Latosol, intergrade to Dark Horizon Latosol* (KYL-DHL)

The profiles of this group differ from those of the Ortho type by having in the B horizon a layer of slightly darker colour (lower value) than the earth immediately above and below. The classification is very provisional, awaiting more field studies, and analytical data (for Dark Horizon Latosol *cf.* RUHE and CADY, 1954; SOIL SURVEY STAFF, 1960, p. 241).

Profile 30. KAOLINITIC YELLOW LATOSOL, intergrade to DARK HORIZON LATOSOL, heavy textured (KYL-DHL$_h$)
Field description 319 (Sombroek, Falesi)
Location: 8 km E of Porto Velho; Experimental Station of IAN, 2 km S of Headquarters.
Relief and drainage: Approximately flat terrain, 30 m *ca.* above larger rivulets. Well-drained. Alt. 100 m *ca.*
Parent material: Pleistocene sediments.
Vegetative cover: High secondary forest.

O_1 *7–4 cm:* Undecomposed plant residues.

O_2 *4–0 cm:* Partly decomposed plant residues, and very many very fine roots.

A_1 *0–5 cm:* Dark yellowish brown (10 YR 4/4) fine sandy clay. Moderate, fine subangular blocky structure. Moist, friable. Slightly sticky and slightly plastic, to plastic, when wet. Many coarse and few fine pores. Very many roots. A few pieces of charcoal. Transition clear.

A_3 *5–45 cm:* Yellowish brown (10 YR 5/4) fine sandy clay. Weak, fine subangular blocky and weak to moderate, very fine granular structure. Moist, friable. Slightly sticky and slightly plastic, to plastic, when wet. Few coarse and common fine pores. Many roots. A few pieces of charcoal. Transition gradual.

B_{1h} *45–85 cm:* Dark yellowish brown (10 YR 3/4) fine sandy clay. Weak, fine to medium subangular and weak, very fine granular structure. Moist, very friable. Slightly sticky and slightly plastic, to plastic, when wet. Little resistance to penetration with hammer. Common to many fine pores. Many roots. Transition gradual.

B_2 *85–130 cm:* Strong brown (7.5 YR 5/6) clay. Porous massive, to weak, medium subangular blocky and weak, very fine granular structure. Moist, very friable. Plastic and slightly sticky when wet. Little resistance to penetration with hammer. Many medium sized pores. Many roots. Transition diffuse.

B_3 *130–180+ cm:* Reddish yellow (7.5 YR 6/8) clay. Porous massive, to weak, medium subangular blocky structure. Moist, very friable. Plastic and slightly sticky when wet. Little resistance to penetration with hammer. Common fine pores. Common roots.

(Ia.6) *Kaolinitic Yellow Latosol, intergrade to Ground Water Laterite soil* (KYL-GL)

The profiles of this group differ from those of the Ortho type in having in the lower part of the profile some soft plinthite-in-formation: The B and C horizons have a fair quantity of reddish mottles in a matrix of less chroma than the Ortho type. The B horizon has certain characteristics of a textural-B (*cf.* II.2), *viz.* relatively large textural difference B/A, subangular to angular blocky structure, a few clay skins, and limited porosity. The A_3 subhorizon is often slightly paler (*e.g.* hue 2.5 Y, chroma 4 to 6) than that of the profiles of the other types.

The Kaolinitic Yellow Latosol, intergrade to Ground Water Laterite soil seems to be identical with what is called 'Planosolic Latosol' by the U.S. Soil Conservation Service. This name refers to soils assumed to occupy about 40% of the area in western Amazonia and described by STRIKER as: 'very highly acid, with greyish and yellowish brown silty to silty clay surface horizons over yellow and reddish yellow, mottled, moderately plastic or compacted, slowly drained clay subsoils' (KELLOGG, personal communication). See also Profile 12 (II.3.2.1).

(Ib) Kaolinitic Red Latosol (KRL)

General concept: This unit includes deeply and strongly weathered soils, well-drained and permeable, predominantly of reddish hue and of varying texture but with at least 15% clay in the B horizon. The soils are very strongly to slightly acid, and have a base saturation above 40%.

The profiles are well developed, having an ABC sequence of horizons; the boundaries between these horizons are gradual or diffuse. The soils have a latosolic-B horizon (*cf.* II.2.1); the clay-sized particles consist very predominantly of silicate clay minerals of the 1:1 lattice structure, being kaolinite. The soils have a rather weak macro-structure, at least in the sub-surface horizon. When dry they are slightly hard, to hard. The B horizon is generally slightly heavier than the A horizon.

The only frequently encountered profiles of this unit are of *medium texture*. The range in characteristics within this textural class is given below:

The A horizon, consisting of an A_1 and A_3, is about 70 cm thick. The B horizon, consisting of a B_2 and a B_3, is about 200 cm. The C horizon is of varying thickness. The A horizon is normally capped with a thin ($\leqslant$ 1 cm) layer of loose bleached sand ('micro-podzol').

The A_1 subhorizon is 5–20 cm thick. The texture varies between loamy sand and light sandy clay loam. The colour value is 4 to 5, the chroma 4 to 6, the hue 7.5 YR or 5 YR. Brown (7.5 YR 4/4 or 5/4) is most frequent. The horizon is structureless (single grains) or has a weak, fine subangular blocky structure. The A_3 subhorizon is 40–60 cm thick. The texture is usually sandy loam or sandy clay loam. The colour is predominantly yellowish red (5 YR 4/6 or 4/8). Weak, fine subangular blocky is the predominant structure. The B_2 subhorizon is 50–100 cm thick. The texture is commonly sandy clay loam, sometimes sandy loam, or sandy clay. The predominant colours are yellowish red (5 YR 4/6 or 4/8) and red (2.5 YR 4/6 or 4/8). The structure is a weak, medium to fine subangular blocky. The B_3 subhorizon is about 100 cm thick. The texture is light sandy clay loam or sandy loam. The colour is the same as in the B_2 horizon. The horizon is structureless (little coherent porous massive), or has a weak, medium subangular blocky structure. The C horizon is predominently of sandy loam texture. The colour is generally red (2.5 YR 4/8). The horizon is massive. Rounded quartz pebbles or rounded plinthite concretions commonly occur, in small percentages.

Profile 31. KAOLINITIC RED LATOSOL, medium textured (KRL_m); the actual profile is transitive to the light texture class
Field description 226 (Sombroek, Sampaio)
Location: Along highway BR-14, km 429 S of São Miguel do Guamá.
Relief and drainage: Side of one several small hills in generally flat terrain. Somewhat excessively drained. Alt. 140 m.
Parent material: In Pleistocene reworked sediments of Cretaceous/Tertiary age.
Vegetative cover: Tropical forest, with low timber volume (75 m^3/ha *ca.*). Low, thin trees; many palms of various species. Rather dense undergrowth, in which thin creepers and vines are common.

O_1 *4–1 cm:* Undecomposed plant residues.
O_2 *1–0 cm:* Partly decomposed plant residues.
A_{11} *0–0.5 cm:* Loose bleached sand with many fine roots.
A_{12} *0.5–20 cm:* Dark brown (7.5 YR 4/4) loamy sand. Single grains. Moist, loose. Not sticky and not plastic when wet. Many roots. Transition clear to gradual.
A_3 *20–70 cm:* Yellowish red (5 YR 4/8) fine sandy loam. Weak, fine subangular blocky structure. Moist, very friable. Not sticky and not plastic when wet. Soft when dry. Many pores. Many roots. Transition diffuse.
B_2 *70–180 cm:* Red (2.5 YR 5/8) fine sandy loam. Weak, medium to fine subangular blocky structure. Moist, very friable. Not sticky and not plastic when wet. Slightly hard when dry. Many pores. Many roots. Transition diffuse.
B_3 *180–300 cm:* Red (2.5 YR 5/8) fine sandy loam. Massive to weak, medium subangular blocky structure. Moist, very friable. Not sticky and not plastic when wet. Slightly hard when dry. Many pores. Many roots.
In A_3 and B_2 some quartz pebbles and rounded, black, medium textured plinthite concretions, both partially as stone-lines.

(Ic) Kaolinitic Latosolic Sand (KLS)

General concept: This unit comprises highly and very deeply weathered soils, well or somewhat excessively drained, with colours of yellowish or, less commonly, of reddish hue. The soils are light textured, the percentage of clay-sized particles in the B horizon being *less than 15 %*. They are very highly or extremely acid and have a base saturation of less than 40 %.

The profiles are well developed, having an ABC sequence of horizons; the boundaries between these horizons are gradual or diffuse. The solum is generally very thick (2 m or more). The few clay sized mineral particles consist very predominantly of silicate clay minerals of the 1:1 lattice structure, being kaolinite. The soils are structureless (single grains), or have a very weak structure. The B horizon is slightly less sandy than the A horizon, which is often also noticeable in the field.

Apart from texture and associated characteristics, the soils are comparable to the Kaolinitic Yellow Latosol (,Ortho).

Two main phases are distinguished, namely a Forest phase and a Savannah phase. Many profiles of the *Forest phase* (F) were studied. Therefore, a range in characteristics can be given.

The A horizon, consisting of an A_1 and an A_3, is about 70 cm thick. The B horizon is between 150 and 200 cm thick, and consists normally of a B_1 and a B_2. The C horizon is of varying thickness.

The A_1 subhorizon is 10–40 cm thick. Its texture varies from sand to sandy loam. The colour value is 4 or 5, the chroma 2 or 3, the hue 10 or 7.5 YR; dark brown to brown (10 YR 4/3) is predominant. The structure is usually weak fine subangular blocky. The subhorizon is generally capped with a thin layer of loose bleached sand. The A_3 subhorizon is between 30 and 60 cm thick. Its texture varies from sand to sandy loam. The colour value is 4 to 6, the chroma 3 to 6, the hue is 10 or 7.5 YR, less commonly 5 or 2.5 YR; brown (7.5 YR 5/4) is most common. The structure is weak medium to fine subangular blocky, or little coherent porous massive. The B_1 subhorizon is 70–150 cm thick. Its texture is a loamy sand or light sandy loam. The colour hue is 10 or 7.5 YR, less commonly (for instance in relatively dry regions) 5 or 2.5 YR; value and chroma are 6/6 or 6/8 (brownish yellow, reddish yellow, sometimes light red). The structure is normally little coherent porous massive, to weak medium subangular blocky. The B_2 subhorizon, 50 to 100 cm thick, varies between sand and sandy loam in texture. The colours are predominantly the same as in the B_1, sometimes of slightly redder hue. The structure is usually porous massive. The C horizon is generally somewhat lighter textured than the B_2. It has the same colour or is of slightly redder hue; some mottling, for instance light grey in a reddish yellow matrix, may occur. The horizon is massive. Plinthite concretions or rounded quartz pebbles may occur at varying depth in this horizon.

Only a few profiles were studied of the *Savannah phase* (S). Except for the development of the A_1 horizon and a slightly larger difference in texture between A and B horizons, the phase seems to be largely comparable to the Forest phase.

Profile 32. KAOLINITIC LATOSOLIC SAND, Forest phase (KLS, F)
Field description 296 (Sombroek)
Location: Araguaia Mahogany area, Rio Antonino, transect 6, stake 23 (Lat. 6° 21′ S; Long. 48° 16′ W)
Relief and drainage: Extensive flat terrace, about 10 m above level of nearby rivulet. Somewhat excessively drained. Alt. 200 m. *ca.*
Parent material: Pleistocene sediments.
Vegetative cover: Primeval forest with low timber volume. Closed canopy of rather thin trees, and palms. Open undergrowth, with a few thin climbers. Open field layer of seedlings and scattered clumps of grass.

O_1 *12–2 cm:* Undecomposed plant residues.

O_2 *2–0 cm:* Partly decomposed plant residues, and fine roots. Surface smooth, with scattered outcasts of parasol ants.

A_{11} *0–0.2 cm:* Loose bleached sand.

A_{12} *0.2–10 cm:* Dark brown (10 YR 4/3) light loamy fine sand. Single grains, to weak, fine subangular blocky structure. Moist, very friable. Not sticky and not plastic when wet. Soft when dry. Many, mainly fine roots. Many large, and common fine pores. Transition clear.

A_3 *10–70 cm:* Yellowish brown (10 YR 5/4) loamy fine sand. Little coherent porous massive, to weak, medium to fine subangular blocky structure. Moist, very friable. Not sticky and not plastic when wet. Slightly hard, to hard and somewhat brittle when dry. Many roots. Many large and fine pores. Transition gradual.

B_{11} *70–140 cm:* Reddish yellow (7.5 YR 6/6) loamy fine sand. Little coherent porous massive, to weak medium subangular blocky structure. Moist, very friable. Not sticky and not plastic when wet. Common roots. Common fine pores. Some krotovinas of A_3. Transition diffuse.

With Dutch auger:

B_{12} *140–220 cm:* Reddish yellow (7.5–5 YR 5/8) loamy fine sand. Moist, very friable. Not sticky and not plastic when wet. Few roots. Transition diffuse.

B_2 *220–290 cm:* Reddish yellow (5 YR 6/8) heavy loamy fine sand. Dry. Not sticky and not plastic when wet. A few fine roots. Transition clear.

$B_3(g)$ *290–320+cm:* Reddish yellow (7.5 YR 6/8) light fine sandy loam, with common, medium sized, distinct mottles of very pale brown (10 YR 7/4). Moist, very friable. Not sticky and not plastic when wet.

Profile 33. KAOLINITIC LATOSOLIC SAND, Savannah phase (KLS, s); the actual profile is transitive to the medium texture class of the KAOLINITIC YELLOW LATOSOL

Field description 298 (Sombroek)

Location: Araguaia Mahogany area, Araguatins, 1.5 km E of town (Lat. 5°38′ S; Long. 48° 06′ W)

Relief and drainage: Approximately flat upland, about 15 m above level of rivulets. Excessively drained. Alt. 150 m *ca.*

Parent material: Reworked sand-stones of Sambaiba member of Pastos Bons beds (Jura-Triassic).

Vegetative cover: Savannah. Shrubs and rare low trees. Open field layer: scattered palmlets, some grasses under the shrubs. Formerly frequently (?) burned.

O_1 *2–0 cm:* Locally. Undecomposed plant residues.

O_2 Absent: Most of surface is bare and white sandy.

A_{11} *0–5 cm:* Loose bleached sand.

A_{12} *5–30 cm:* Dark grey brown (10 YR 4/2) coarse sand. Little coherent porous massive, to weak medium subangular blocky. Some white sand around the structure elements. Moist, very friable to loose. Not sticky and not plastic when wet. Hard when dry; the horizon stands out as a bank in long exposed pits. Common roots. Few large, and common to few, fine pores. Transition gradual.

A_3 *30–65 cm:* Light yellowish brown (10 YR 6/4) coarse sand, with krotovinas of brown (10 YR 4/3). Very little coherent porous massive, to weak, medium to fine subangular blocky structure. Moist, very friable to loose. Not sticky and not plastic when wet. Slightly hard when dry. Common roots. Common large and fine pores. Transition gradual.

B_1 *65–130 cm:* Reddish yellow (7.5 YR 6/6) loamy coarse sand. Little coherent porous massive. Consistence as in A_3. Very few large, and common fine pores. Few roots. Scattered pieces of charcoal. Transition diffuse.

With Dutch auger:

B_{21} *130–220 cm:* Reddish yellow (7.5 YR 6/6 –8) light coarse sandy loam. Consistence as in A_3. Common fine roots. Scattered pieces of charcoal. Transition diffuse.

B_{22} *220–320 cm:* Reddish yellow (7.5 YR 6/6 – 8) light coarse sandy loam. Consistence as in A_3. A few fine roots.

(II) RED YELLOW LATOSOLS (RL)

General concept (*cf.* group *IIc* of Table 6): This group includes deeply and strongly weathered soils, well-drained and permeable, with below the surface layer a colour that is commonly of reddish or yellowish hue, high value and high chroma. The soils are of varying texture, but with at least 15% clay in the B horizon. The profiles are well developed, having an ABC sequence of horizons. The boundaries between these horizons are gradual or diffuse. The B horizon is a latosolic-B horizon (*cf.* II.2.1). The clay fraction is composed of intermediate percentage of silicate clay minerals of 1:1 lattice structure, *i.e.* kaolinite, and relatively low percentages of Fe clay minerals. The soils have a moderately strong macro-structure. There may be some difference in texture between the A and the B horizon.

Only a few profiles of this group were encountered. A range of characteristics of the Amazon Red Yellow Latosols cannot therefore be given. The description of only one profile follows. This profile, moreover, does not seem to be a typical one, if only because of its colour.

Profile 34. RED YELLOW LATOSOL (?) (RL?)
Field description 308 (Sombroek)
Location: Serra de Navio, Amapá Territory; top of ICOMI manganese mine.
Relief and drainage: Slope (15%) in hilly upland. Alt. 300 m. *ca.*, well-drained.
Parent material: Undefined rock of crystalline basement.
Vegetative cover: Primeval forest, of rather high timber volume.

A_1 *0–40 cm:* Dark brown to brown (7.5 YR 4/4) light clay. Moderate to strong, very fine subangular blocky, or granular, structure. Moist, very friable. Sticky and plastic when wet. Soft when dry. Many pores. Many roots. Transition diffuse.

A_3 *40–100 cm:* Reddish brown (5 YR 4/4) clay. Moderate, very fine subangular blocky, or granular, structure. Consistence as in A_1. Many pores. Many roots. Transition diffuse.

B_2 *100–200+ cm:* Reddish brown (5 YR 4/4) clay. Moderate, very fine subangular blocky, or granular, structure. Consistence as in A_1. Many pores. Many roots.
In all horizons small (diameter $\leqslant$ 5 cm), hard, round, black concretions of Mn (?), in a quantity of 5–10%.

(III) DARK RED LATOSOLS (DL)

General concept (*cf.* group *IIb* of Table 6): This group includes deeply and strongly weathered soils, well-drained and permeable, with below the surface layer a colour that is commonly of reddish hue, low value and high chroma. The soils are of varying texture, but with at least 15% clay in the B horizon. The profiles are well developed, having an ABC sequence of horizons. The boundaries between these horizons are gradual or diffuse. The B horizon is a latosolic-B horizon (*cf.* II.2.1). The clay fraction is composed of intermediate percentage of silicate clay minerals of the 1:1 lattice structure, being kaolinite, and intermediate percentages of Fe clay minerals. The soils have a moderate to strong macro-structure. There is normally no textural difference between the A and the B horizon.

Only a limited number of profiles with Dark Red Latosol characteristics were encountered. A description of only one profile is given. This profile is moreover not typical for the group, because of its hsallowness, and the considerable percentages of silt present.

Profile 35. DARK RED LATOSOL, Shallow phase (DL, s)
Field description 279 (Sombroek, Sampaio)
Location: Araguaia Mahogany area, Rio Corda, transect 8, stake O (Lat. 6°23′ S; Long. 48°20′ W).
Relief and drainage: Edge of almost flat terrain, about 10–15 m above level of nearby river. Well drained. Alt. 200 m *ca.*
Parent material: Dark shales of Pimenteiras beds (Devonian).
Vegetative cover: Primeval forest. Open canopy of a few thick trees, laden with climbers, and scattered palms. Dense undergrowth, with many creepers and climbers. Dense field layer, consisting largely of a fern species.

O_1 *4–2 cm:* Undecomposed plant residues.

O_2 *2–0 cm:* Partly decomposed plant residues, with many fine roots. At the surface some worm outcasts.

A_1 *0–15 cm:* Dark reddish brown (2.5 YR 3/4) light clay loam. Structure of moderate, very fine granules, composing weak, fine subangular blocks. Moist, very friable. Slightly sticky and slightly plastic when wet. A few, small (diameter $\leq$ 5 cm) plinthite concretions, similar to those in A_3. Very many roots. Transition diffuse.

A_3 *15–40 cm:* Dark reddish brown (2.5 YR 3/4) clay loam. Moderate, very fine granular structure. Moist, very friable. Slightly sticky and slightly plastic when wet. About 20% small (diam. $\leq$ 5 cm), to a degree platy, hard, very fine grained, plinthite concretions, brownish yellow (10 YR 6/8) in their outer parts, black (5 YR 2/1) in their centres. Many roots. Transition gradual.

B_2 *40–80 cm:* Dark red (2.5 YR 3/6) clay loam. Structure of moderate to strong, very fine granules, composing weak, fine subangular blocks. A few, faint clay skins, for a large proportion on the surface of the concretions. Moist, very friable. Plastic and slightly sticky when wet, About 70% plinthite concretions, similar to those in A_3, but slightly larger (diam. $\leq$ 10 cm), less hard, and with more brownish yellow. Many roots. Transition gradual, irregular.

C *80–120 + cm:* Dark red (2.5 YR 3/6) heavy clay loam. Structure and consistence as in B_2. About 95% large (diam. 10–20 cm), platy, rather soft, fine grained, black and yellow concretions (weathering dark shale?).

For the pF curve of the B_2 see Fig. 37.

(IV) Red Yellow Podzolic soils (RP)

General concept: According to Baldwin, Kellogg and Thorp (1938) and Thorp and Smith (1949), the modal Red Yellow Podzolic soils are well-drained soils with a thin organic top over a well developed light textured surface horizon (A horizon) and a heavy textured, blocky or prismatic subsoil (B horizon), with silicate clay skins present. This B horizon often has a red or yellow colour in the upper part and a redder colour in the lower part, while at the transition zone with the C horizon a mottling is often present.

According to the elaboration of this concept as applied in Brazil (*cf.* Lemos, Bennema, Santos *et al.*, 1960) the clay-sized minerals should consist of silicate clay minerals 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. The B horizon should have the characteristics of a textural-B as described in II.2.1. In Brazil, the Red Yellow Podzolic soils are subdivided in those of low base status, and those of medium and high base status.

(IV.1) *Red Yellow Podzolic soil (,Ortho)* (RP)

Under this head are described those Red Yellow Podzolic soils of which the B horizon has about all the characteristics of a textural-B.

Only a few profiles were encountered of those with *low base saturation.* Therefore only a profile description is given.

Many profiles were encountered locally of those with *rather high base saturation.* Therefore the following generalisation can be given:

The A horizon, consisting of an A_1 and an A_2, is about 40 cm thick. The B horizon, consisting of a B_2 and sometimes a B_3, is 40 to 80 cm thick. The C horizon is about 30 cm. Below this, unweathered rock (mica schists) occurs. The A_1 subhorizon is 5–10 cm thick. Its texture is usually a loam. The colour value is about 4, its chroma 2 or 3, its hue 10, 7.5 or 5 YR; most common is dark brown (7.5

YR 4/2). The structure is a moderate, medium to fine subangular blocky and fine granular. The A_3 subhorizon is about 30 cm. Its texture is predominantly clay loam. Its colour value is 4 to 6, its chroma also 4 to 6, its hue 7.5, 5 or 2.5 YR; most common is reddish brown (5 YR 4/4). The structure is usually a moderate, medium subangular blocky (in part composed of moderate, very fine subangular to angular blocks). Clay skins are few and faint. The B_2 subhorizon is about 40 cm. Its texture is a clay, less frequently a clay loam. The colour value is 4 or 5, the chroma usually 6, the hue 5 YR or 2.5 YR; most common is red (2.5 YR 4/6). The structure is normally moderate, medium angular, to subangular blocky (in part composed of very fine angular blocks). Clay skins are common to continuous, and distinct. The B_3 subhorizon, where existent, has usually a clay or clay loam texture. Its colour is approximately identical to that of the B_2. The structure is somewhat weaker. Clay skins are mostly common, and faint to distinct. The C horizon has a loam or clay loam texture. Its colours are variegated red, black and reddish yellow. The horizon is normally massive.

Fine shiny flakes of mica are found in all horizons. Angular quartz stones are often present.

Profile 36. RED YELLOW PODZOLIC SOIL (,Ortho), with low base saturation (RP_{lb})
Field description 320 (Sombroek, Falesi)
Location: Rio Branco do Acre, km 0.5 W of town
Relief and drainage: Low top in gentle undulating terrain, Alt. less than 100 m. Well-drained.
Parent material: Tertiary (?) clay-stone.
Vegetative cover: Secondary shrub.

A_1 *0–3 cm:* Dark brown to brown (10 YR 4/3) loam with common, fine, distinct mottles of strong brown (7.5 YR 5/6). Moderate, medium subangular blocky structure. Moist, friable. Slightly sticky and slightly plastic when wet, slightly hard when dry. Many large, and few fine pores. Many roots. Activity of earth worms. Transition clear and smooth.

A_2 *3–26 cm:* Strong brown (7.5 YR 5/8) loam. Weak, medium subangular blocky structure. Moist, friable. Slightly sticky and slightly plastic when wet, hard when dry. Few large and fine pores. Few roots. Activity of earth worms. Transition clear and wavy.

B_1 *26–60 cm:* Yellowish red (5 YR 5/8) clay loam. Moderate, medium subangular to angular blocky structure. Clay skins continuous, faint. Moist, firm. Sticky and plastic when wet, hard when dry. Common large and fine pores. Few roots. Transition diffuse and smooth.

B_2 *60–85 cm:* Yellowish red (5 YR 5/8) clay. Moderate to strong, medium and fine angular blocky structure. Clay skins continuous, faint to moderate. Moist, firm. Sticky and plastic when wet, hard when dry. Few large, and common fine pores. Few roots. About 2% small (diam. $\leqslant$ 0.5 cm), round, hard, fine grained plinthite concretions. Transition gradual and smooth.

B_{3g} *85–130 cm:* Light grey (2.5 Y 7/2) heavy clay, with many, medium sized, distinct to prominent mottles of dark red (10 R 3/6) and strong brown (7.5 YR 5/8). Weak to moderate, medium subangular, to angular blocky structure. Clay skins common, very faint. Consistence as in B_2. Few pores. No roots. Transition gradual.

C_g *130–300+ cm:* White (2.5 Y 8/2) heavy clay, with many, coarse, prominent mottles of red (2.5 YR 4/8) and yellowish brown (10 YR 5/8). Massive. Consistence as in B_2. Material is used for brick making.

No IQA analysis was executed on this profile, but the Soils Laboratory of the Royal Tropical Institute in Amsterdam (Holland) kindly provided for analytical data.

Full mineralogical analysis was carried out on the B_2 horizon, by the Netherlands Soil Survey Institute, Wageningen (Holland). The data on sample 320-4 in the Tables 7 and 8, and the Figs. 14a-e show that the mineralogical composition is indeed distinctly different from that of latosolic profiles. In the clay fraction even 33% mica (illite) occurs, more than kaolinite (24%); iron oxides comprise 12% and aluminum oxides 7%. The remainder is comprised of clay-sized quartz (24%). In the fraction 2-16 micron some felspar (8%) and chlorite (3%) are present. The coarser fractions contain only quartz (90%) and hematite (10%).

For both the A_2 and the B_2 horizons also the specific surface was determined (samples 320-2 and 320-4 of Table 7). A specific surface of 100 m^2, on whole soil basis, gives about 18 m.e. cation exchange capacity, which is considerably more than in the Latosol profiles (*cf.* II.2.2).

For both the A_2 and B_2 horizons a pF curve was determined on undisturbed samples. The A_2 proved to have 13.5 vol. perc. available moisture (50.1 % moisture at pF 0.4; 32.4 % at pF 2.0; 18.9 % at pF 4.2), the B_2 only 8.6 vol. perc. (50.4 % moisture at pF 0.4 36.9 % at pF 2.0; 28.3 % at pF 4.2); *cf.* V.3.1.1.

Profile 37. RED YELLOW PODZOLIC soil (,Ortho), with rather high base saturation (RP $_{rhb}$)
Field description 282 (Sombroek, Sampaio)
Location: Araguaia Mahogany area, Santa Isabel, transect 10, stake 11 (Lat. 6°08′ S; Long. 48°22′ W).
Relief and drainage: Gentle sloping side of hill in undulating terrain. Well-drained. Alt. 200 m *ca.*
Parent material: Micaceous schists with veins of quartz, of Pre-Cambrian (Arquean) age.
Vegetative cover: Primeval forest of very low timber volume. Open canopy, of only a few trees, and some palms. High undergrowth, consisting largely of a dense network of creepers and climbers. Very dense field layer, consisting predominantly of a fern species.

O_1 *4–2 cm:* Undecomposed plant residues.

O_2 *2–0 cm:* Partly decomposed plant residues, with fine roots and fungi. About half of the surface is covered with very dark grey worm outcasts.

A_1 *0–8 cm:* Dark reddish brown (5 YR 3/3) light loam. Structure of weak to moderate, fine granules, composing moderate, medium to fine subangular blocks. Moist, very friable. Slightly sticky and slightly plastic when wet. Very many large and fine roots. Many pores. Common very fine shiny flakes (mica). Transition gradual, smooth.

A_2 *8–40 cm:* Reddish brown (2.5 YR 4/4) clay loam. Structure of weak to moderate, very fine subangular to angular blocks, composing moderate, medium to fine subangular blocks. Common, faint clay skins. Moist, friable. Sticky and plastic when wet. Many large and fine roots. Common fine pores. Common very fine shiny flakes (mica). Transition gradual, smooth.

B_2 *40–80 cm:* Red to dark red (2.5 YR 4–3/6) clay. Structure of moderate, very fine angular blocks, composing weak to moderate, medium subangular to angular blocks. Continuous, distinct clay skins. Moist, friable to firm. Sticky and plastic when wet. Common roots. Common, fine pores. Common, very fine, shiny flakes (mica). Transition gradual, smooth. From 30 to 70 cm many (75 % *ca.*), small to medium sized (2–20 cm), very hard, angular, milky white stones of quartz, the surfaces of which are coated with clay skins.

B_3 *80–110 cm:* Red (2.5 YR 4/6) clay. Structure of moderate, very fine subangular to angular blocks, composing weak to moderate, medium to coarse, subangular to angular blocks. Continuous, faint to distinct clay skins. Moist, friable. Sticky and plastic when wet. Few roots. Few fine pores. Many fine shiny flakes (mica). A few quartz stones similar to those in B_2. Transition gradual, irregular.

C *110–140+ cm:* Weathering micaceous schist: Dark red (10 R 3/6) and black (N 3/0) soft rock of heavy loam texture, horizontally very finely stratified. Angular milky quartz stones embedded in a scattered way.

For the B_2 horizon a pF curve was determined on a undisturbed sample. The amount of available moisture proved to be 9.0 vol. perc. (51.1 % moisture at pF 0.4; 42.1 % at pF 2.0; 33.1 % at pF 4.2); *cf.* V.3.1.1.

(IV.2) *Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol* (RP-KYL)

Under this heading are described Red Yellow Podzolic soils which have a B horizon whose characteristics mostly belong to those of the textural-B, while a minor part of them are characteristics of the B horizon of the Kaolinitic Yellow Latosol. Those belonging to the textural-B are the following:

1. a gradual to clear boundary between the A and the B horizons,
2. a distinct change in colour from the A to the B horizon or the presence of a transitional horizon that is mottled,
3. a distinct textural difference between the A and the B horizons,
4. compactness and rather firm, to firm consistence of the B horizon,
5. a limited porosity and rooting in the B horizon.

As to the characteristics of the B horizon that belong to those of the latosolic-B, there is in particular an absence of a well developed angular blocky or prismatic structure. Clay skins are weak and discontinuous, when present at all. The mineralogical composition of the clay fraction is largely comparable to that of the Kaolinitic Yellow Latosol.

The base saturation of the soils is low throughout the profiles (< 40%). Plinthite concretions are absent or occur only in minor quantities. The group of soils is subdivided, for practical mapping purposes, according to the texture of the B horizon. The qualities of the soils are dealt with in V.3.

Many examples were encountered and studied of both *very heavy textured* and *rather heavy textured* profiles. For both variants, therefore, a range in characteristics can be given.

The *very heavy textured* profiles have an A horizon of 40–50 cm thick, consisting of an A_1 and an A_3 subhorizon. The B horizon, which consists generally of a B_2 a B_3, varies between 100 and 150 cm in thickness. The thickness of the C horizon is undetermined.

The A horizon lacks a capping with loose bleached sand. The A subhorizon is 2–5 cm thick. The texture is predominantly light clay or heavy sandy clay. The colour is usually dark grey brown (10 YR 4/2). A moderate, fine subangular blocky is the common structure. The transition to the A_2 is generally clear. The A_2 subhorizon is about 40–50 cm thick. The texture is a clay or heavy clay. The colour hue is 10 YR, the value varies between 5 and 7, the chroma between 6 and 8. Most frequent is brownish yellow (10 YR 6/6). The structure is usually moderate, fine subangular blocky and weak, very fine granular. The transition to the B_2 is gradual or clear. Several times a thin (10–20 cm) transition zone occurs, with colours both of the A_2 and the B_2. The B_2 subhorizon is between 50 and 70 cm thick. The texture is a heavy clay. The main colour has a hue of 7.5 YR, a chroma of 8 and a value between 5 and 7. Reddish yellow (7.5 YR 6/8) is most frequent. The profiles have normally common, fine, distinct mottles of red (2.5 YR 5/8). The structure is normally moderate, medium to fine subangular blocky. The presence of a few, faint clay skins is general. The transition to the B_3 is gradual to diffuse. The B_3 subhorizon varies between 40 and 80 cm in thickness. The texture is a heavy clay. The main colour is yellowish red (5 YR 5/8, 5 YR 6/8). Secondary colours are light red (2.5 YR 6/8) and yellow (10 YR 8/6), occurring as few to common, fine, distinct mottles. The structure is moderate, medium subangular to angular blocky. The structure elements are covered with common faint clay skins. The transition to the C is diffuse or gradual. The C horizon has predominantly a clay texture. The colour is red or light red (2.5 YR 5/6 or 5/8, resp. 2.5 YR 6/6 or 6/8). The structure is predominantly weak, medium angular to subangular blocky. Clay skins, when present, are few and very faint.

Rather common is the presence, in small quantities (5% *ca.*), of very small fine grained, red or dark red plinthite concretions. They are hard in the A horizon, half hard in the B horizon. A few larger concretions may occur.

The *rather heavy textured* profiles have an A horizon of 40 to 70 cm thickness which consists of an A_1 and an A_3. The B horizon, consisting of a B_{21} and a B_{22}, is between 100 and 150 cm thick. Between the A and the B horizon a transitional horizon AB, of 20–50 cm thickness, occurs. The C horizon is of undetermined thickness.

The A_1 subhorizon is mostly 5–10 cm, sometimes 10–20 cm thick. The texture is predominantly light sandy clay loam, but sandy loam and even loamy sand textures may be found. The colour hue is 10 YR, the value 4 or 5, the chroma 3, 4 or 6. Yellowish brown (10 YR 5/4) is predominant. The structure is a weak to moderate, fine subangular blocky. The transition to the A_2 is clear. The A_2 subhorizon varies between 20 and 60 cm in thickness. The texture is predominantly a heavy loam clay or light sandy clay, but also sandy loams do occur. The colour hue is 10 YR, the value 5 or 6, rarely 7, the chroma 4 or 6. Brownish yellow (10 YR 6/6) is the most common. The structure is weak to moderate, medium to fine subangular blocky. The transition to the AB is clear. The AB horizon, 20 to 50 cm thick, has predominantly light sandy clay texture, but light clay or sandy clay loam textures also occur. The main colour is normally identical to that of the A_2, namely brownish yellow (10 YR 6/6). Secondary colour is yellowish red (5 YR 4/8, 5/8) or red (2.5 YR 4/6 or 5/6, sometimes 2.5 YR 4/8 or 5/8), occurring as common, medium, distinct mottles. In the upper section of the horizon very small, hard, round plinthite concretions (5–20% of the soil mass) occur rather often. The structure is usually a weak to moderate, medium subangular blocky. The transition to the B_{21} is gradual to clear. The B_{21} subhorizon varies between 40 and 80 cm in thickness. The texture is a sandy clay or clay. The colour hue is 5 YR, sometimes 2.5 YR or 7.5 YR, the value is 5 or 6, the chroma 8. The colour is therefore predominantly yellowish red or reddish yellow. The structure is weak to moderate, medium subangular to angular blocky. Clay skins are few and faint, if present at all. The transition to the B_{22} is diffuse. The B_{22} subhorizon varies between 20 and 70 cm in thickness. The texture is a clay or sandy clay. The colour is red (2.5 YR 4/8 or 5/8). The structure is a weak, medium subangular to angular blocky. Clay skins are normally absent. The transition to the C is diffuse. The C horizon was examined at only a few profiles. There it showed a sandy clay texture, and a massive structure. The colour was red (2.5 YR 5/8) with common, medium sized, distinct mottles of red (10 R 4/8) and yellow (10 YR 7/8).

Included in the unit are profiles with many, rather large plinthite concretions concentrated in the AB horizon, but with otherwise similar characteristics as described above. The concretions are apparently colluvial, in contrast to the rather few, very fine concretions which occur commonly in the AB and which are believed to have been formed *in situ* (*cf.* II.3.2.2).

Profile 38. RED YELLOW PODZOLIC SOIL, intergrade to KAOLINITIC YELLOW LATOSOL, very heavy textured (RP-KYL$_{vh}$)

Field description 236 (Sombroek, Sampaio)

Location: Along highway BR-14, km 232 S of São Miguel do Guamá.

Relief and drainage: Flat stretch of gentle undulating terrain, about 10 m above level of nearby intermittent rivulet. Moderately well-drained. Alt. 140 m.

Parent material: In Pleistocene redeposited material from Plio-Pleistocene lacustrine origin (reworked Belterra clay).

Vegetative cover: Primeval forest, with medium timber volume (150 m³/ha *ca.*). Open undergrowth, nearly devoid of creepers and climbers.

O_1 *12–2 cm:* Undecomposed plant residues.

O_2 *2–0 cm:* Partly decomposed plant residues, with many fine roots. Surface rather irregular and hard, slightly crusted due to intense termite activity.

A_1 *0–2 cm:* Dark grey brown (10 YR 4/2) clay. Moderate, fine subangular blocky structure. Moist, friable to firm. Sticky and plastic when wet. Slightly hard when dry. Many pores, and large insect channels. Very many, mainly fine, roots. A few, very small, fine grained, dark red plinthite concretions. Transition abrupt.

A_2 *2–40 cm:* Yellowish brown (10 YR 5/6) heavy clay. Moderate, fine subangular blocky and weak to moderate, very fine granular structure. Moist, friable. Sticky and plastic when wet. Slightly hard when dry. Many pores. Many roots. A few plinthite concretions, similar to those in A_1. Transition gradual.

B_2 *40–100 cm:* Strong brown (7.5 YR 5/8) heavy clay, with common, fine, distinct mottles of red (2.5 YR 5/8). Weak to moderate, medium to fine subangular blocky and weak, fine granular structure. A few, faint clay skins. Slightly compact, to compact. Moist, friable to firm. Sticky and plastic when wet. Hard when dry. Common pores. Common roots. Transition gradual.

B_3 *100–180 cm:* Yellowish red (5 YR 5/8) heavy clay. Weak to moderate, coarse to medium, subangular and angular blocky structure. Tendency to prismatic. Common, faint clay skins. Compact. Moist, firm. Sticky and plastic when wet. Hard when dry. Few pores. Few roots. Transition diffuse.

C *180–230+cm:* Red (2.5 YR 5/8) heavy clay. Weak, medium sized subangular and angular blocky structure. Slightly compact. Moist, friable to firm. Sticky and plastic when wet. Slightly hard when dry. Common pores. Few roots.

Profile 39. RED YELLOW PODZOLIC SOIL, intergrade to KAOLINITIC YELLOW LATOSOL, rather heavy textured (RP-KYL$_{rh}$)
Field description 237 (Sombroek, Sampaio)
Location: Along highway BR-14, km 205.8 S of São Miguel do Guamá.
Relief and drainage: Nearly flat remnant of terrace, about 30 m above level of nearby stream. Well-drained. Alt. 101 m.
Parent material: Pleistocene fluviatile sediments.
Vegetative cover: Primeval forest, of medium timber volume (130 m^3/ha). Rather dense undergrowth, with several thin creepers and climbers.

O_1 *6–1 cm:* Undecomposed plant residues.

O_2 *1–0 cm:* Partly decomposed plant residues with fine roots, and some loose bleached sand.

A_1 *0–10 cm:* Dark brown (10 YR 3/3) sandy loam. Weak to moderate, fine subangular blocky structure. Moist, very friable. Not plastic and slightly sticky when wet. Soft when dry. Many pores. Very many roots. Transition clear.

A_2 *10–60 cm:* Brownish yellow (2.5 Y–10 YR 6/6) sandy clay loam. Weak to moderate, medium to fine, subangular blocky structure. Moist, friable. Slightly sticky and slightly plastic when wet. Slightly hard, to hard when dry. Scattered (2%) very small, fine textured, dusky red plinthite concretions. Many pores. Many roots. Transition gradual.

AB *60–110 cm:* Yellow (10 YR 7/8) fine sandy clay. Weak to moderate, medium to fine subangular blocky and weak, very fine granular structure. Moist, friable. Slightly sticky and slightly plastic when wet. Slightly hard, to hard when dry. About 20% plinthite concretions, similar to those in A_2. Many pores. Common roots. Transition clear.

B_{21} *110–160 cm:* Reddish yellow (5 YR 6/8) fine sandy clay, with few to common, fine, distinct mottles of yellow (10 YR 7/8). Weak to moderate, medium sized subangular and angular blocky and locally weak, very fine granular structure. A few, faint clay skins. Moist, friable to firm. Slightly sticky and slightly plastic when wet. Hard when dry. Common pores. Few roots. Less than 1% plinthite concretions, similar to those in A_2. Transition gradual.

B_{22} *160–220 +cm:* Light red (2.5 YR 6/8) heavy fine sandy clay. Weak, medium sized subangular and angular blocky structure. Moist, friable to firm. Slightly sticky and slightly plastic when wet. Hard when dry. Few pores. No roots.

For the pF curve of the B_2 horizon of a similar profile: see sample 213-3 of Fig. 37.

(IV.3) *Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol, Concretionary phase* (RP-KYL, CR)

This soil is similar to that of unit **(IV.2)**, except that the A horizon contains considerable amounts of gravelly hard plinthite concretions. Moreover, the B horizon is generally of heavy texture, and has abundant prominent mottling of red, yellow and white, although the soil is well or moderately well-drained. The structural development of the B horizon is normally slightly nearer to that of a textural-B horizon than that of the **(IV.2)** unit. The soil has a low base saturation percentage ($< 40\%$). The plinthite concretions are of varying size, form, colour, grainage and arrangement. The mottling in the B horizon is of varying pattern. Included in the soil unit are profiles in which the concretions start only at some depth below the surface (maximally 50 cm arbitrarely).

The genesis of the soil is discussed in II.3.2.2, in which section additional profile descriptions are given. Reference may be made also to I.4.5. The qualities of the soil are dealt with in V.3. Many profiles of the soil were encountered and studied, enabling the following generalisations to be made:

The A horizon, consisting of an A_1 and an A_2, comprises about 80 cm. The B horizon, consisting normally of a B_1, a B_2 and a B_3, varies in thickness between 200 and 250 cm. The C horizon is often many meters thick.

The A_1 subhorizon, 5–10 cm thick, has commonly a sandy clay loam texture, but also sandy loam, sandy clay or clay textures occur. The colour is predominantly brown (10 YR 5/2). The structure is usually a weak to moderate, fine subangular blocky. Loose, hard plinthite concretions occur in percentages of 25–90% of the total soil mass. The transition to the A_2 is clear or gradual. The A_2 subhorizon, 50–70 cm thick, consists mostly of a sandy clay, sometimes of clay or heavy clay. The colour hue is 10 YR or 7.5 YR, the value 5 or 6, the chroma 6 or 8. Brownish yellow (10 YR 6/8) is predominant. The structure is a moderate, fine subangular blocky and weak, very fine granular. Loose, hard plinthite concretions comprise 50–80% of the soil mass. The transition to the underlying horizon is gradual. The B_1 subhorizon, if present, is about 50 cm thick. Its texture is generally a clay or heavy clay. The main colour is predominantly reddish yellow (7.5 YR 6/8). Secondary colours, occurring as common, medium sized, distinct mottles, are red (*e.g.* 2.5 YR 5/6) and yellow (*e.g.* 10 YR 7/8). The structure is predominantly moderate, medium subangular to angular blocky. Faint clay skins are common, occurring especially at the surfaces of the concretions. Half loose, hard plinthite concretions comprise 25–50% of the soil mass. The transition to the B_2 is gradual. The B_2 subhorizon varies in thickness between 50 and 100 cm. The texture is a clay or heavy clay. The main colour is normally yellowish red (5 YR 5/8) or red (2.5 YR 5/8). Secondary colours, occurring as many, coarse, prominent mottles, are red (10 R 5/8), dusky red (7.5 R 3/4), yellow (10 YR 7/8) and white (N 8/2). The structure is a moderate, medium to fine subangular and angular blocky, the latter sometimes composing a weak, medium prismatic. Clay skins are usually few and faint. The transition to the B_3 is gradual. The B_3 subhorizon varies in thickness between 50 and 150 cm. The texture is mostly a clay, sometimes a sandy clay. The colours are generally identical to those in the B_2. The structure is usually a weak, medium subangular to angular blocky. Clay skins are normally absent. The transition to the C is gradual or diffuse. The C-horizon has mostly a sandy clay, sometimes a sandy clay loam texture. The predominant colour is dark red (*e.g.* 10 R 3/6). Secondary colours are often present, as mottles of variable quantity, size and contrast. The horizon is massive.

Profile 40. RED YELLOW PODZOLIC SOIL, intergrade to KAOLINITIC YELLOW LATOSOL, Concretionary phase (RP-KYL, CR); type of concretions: Mãe do Rio
Field description 238 (Sombroek, Sampaio)
Location: Along highway BR-14, km 43.8 S of São Miguel do Guamá.
Relief and drainage: Side of low hill in gentle undulating terrain. External drainage good; internal drainage slightly imperfect. Alt. 50 m.
Parent material: Fluviatile sediments of Late Miocene (?) age.
Vegetative cover: Primeval forest, of rather high timber volume (150–200 m^3/ha). Rather dense undergrowth, consisting partly of creepers and climbers, both predominantly thin.

O_1 *11–1 cm:* Undecomposed plant residues.

O_2 *1–0 cm:* Partly decomposed plant residues, with fungi and fine roots.

A_1 *0–10 cm:* Brown (10 YR 5/3) sandy clay loam. Weak, fine subangular blocky structure. Moist, very friable. Slightly sticky and slightly plastic when wet. Soft when dry. About 70% loose, hard plinthite concretions of various forms, sizes and grainage[1]. Many pores. Very many roots. Transition gradual.

A_2 *10–80 cm:* Strong brown (7.5 YR 5/8) clay. Moderate, fine subangular blocky and weak, very fine granular structure. Moist, friable. Plastic and sticky when wet. Soft when dry. About 75% loose hard plinthite concretions of various forms, sizes and grainages (in lower part predominantly fine blocky). The concretions are very mixed, without specific arrangement. Many pores. Many roots. Transition clear to gradual.

B_2 *80–160 cm:* Yellowish red (5 YR 5/8) clay, with many, coarse, prominent mottles of dusky red (7.5 R 3/2), red (10 R 5/8), yellow (10 YR 7/8) and white (5 YR 7/1). Mottling partly in well defined horizontal stripes, partly in poorly defined vertical pipes. Moderate, fine subangular and angular blocky structure. Tendency to prismatic. A few, faint clay skins. Moist, very firm. Sticky and plastic when wet. Hard when dry, locally, namely the dusky red, very hard. Compact. Much resistance to penetration with hammer. Very few pores. Few roots. Transition diffuse.
Within this plinthitic soil mass a few sharp boundered pockets occur (diam. 20 cm *ca.*) of yellowish red (5 YR 5/8) clay with a moderate, fine subangular blocky and weak, very fine granular structure. Moist, friable. Slightly hard when dry. Many pores. Many roots. Probably the result of local activity of termites in the plinthite.

B_3 *160–250 + cm:* Reddish yellow (5 YR 6/8) clay, with many, coarse, prominent mottles of dusky red (7.5 R 3/2), yellow (10 YR 7/8), white (5 YR 7/1) and red (10 R 5/8). Mottling poorly defined laminar. Massive to weak, medium to fine, subangular and angular blocky structure. Moist, very firm. Sticky and plastic when wet. Hard when dry. Compact. Moderate resistance to penetration with hammer. No pores. Very few roots.

For mineralogical analysis of the lower part of the C horizon of a similar profile: see sample 302-4 of the Tables 7 and 8, and Fig. 14a-e.

(V) RED YELLOW MEDITERRANEAN SOILS (RM)

General concept (reference be made to BARROS, DRUMOND, CAMARGO *et al.*, 1958; LEMOS, BENNEMA, SANTOS *et al.*, 1960): The Red Yellow Mediterranean soils are relatively shallow soils, well-drained and moderately weathered. The profile has an ABC or ABR sequence of horizons. These horizons are distinctly contrasting and the transition between them is clear. The A horizon is thin, consisting of an A_1, and occasionally also an A_3. The horizon is dark coloured and has often a granular structure. The B horizon is a textural-B (*cf.* II.2.1), with well developed angular blocky or prismatic structure. It is normally reddish coloured and clayey. Its base saturation is medium to high. The lower part of the B horizon and the C horizon contain still appreciable amounts of easily weatherable primary minerals. The silicate clay minerals of the soil are of the 2:1 lattice structure for a good part.

Few of such profiles were encountered in Amazonia. None contained all the above characteristics. The A horizon was often thick (more than 20 cm), consisting either of a thick A_1 only, or having a subhorizon with the appearance of an A_2, in which plinthitic gravel was a rather common feature. The texture of the B was more often loamy than

[1]) *Note page 146*
The following concretions are present:
Large (⩾20 cm diam.), irregularly shaped, massive blocks; dusky red (10 R 3/4); coarse grained: iron cemented quartz grains.
Medium sized (*ca.* 20 cm diam.), angular, massive blocks; dusky red (7.5 R 3/2), light red (10 R 6/8) and black (N 2/0); medium grained.
Medium sized (*ca.* 10 cm diam.), platy; alternately dark red (2.5 YR 3/6) very fine grained, and black (N 2/0) coarse grained.
Medium sized (*ca.* 20 cm diam.), vesicular; very dusky red (7.5 R 2/2) and red (10 R 4/8); predominantly fine grained.
Rather small (*ca.* 5 cm diam.), prismatic; dusky red (7.5 YR 3/3); predominantly fine grained.
Very small (0.5–1 cm diam.), subangular blocky; dark red; predominantly fine grained.

clayey, and the horizon sometimes showed considerable mottling. The amount of easily weatherable primary minerals seemed often rather small.

A portion of the profiles encountered are likely to be, in fact, intergrading to either Reddish Prairie soil or to Red Yellow Podzolic soil and Ground Water Laterite soil respectively.

Profile 41. RED YELLOW MEDITERRANEAN-LIKE soil (RM)
Field description 225 (Sombroek, Sampaio)
Location: Along highway BR-14, km 457.5 S of São Miguel do Guamá (km 9 N of Imperatriz).
Relief and drainage: Low hill top in irregular, undulating terrain. About 10 m above level of nearby rivulets. Alt. 120 m. External drainage good. Internal drainage slightly imperfect.
Parent material: Intimately interbedded shales and silt-stones, belonging to the Codó beds (Middle Cretaceous).
Vegetative cover: Original vegetation largely destroyed. At present low shrubs and a few scattered palms.

O_1–O_2 *5–0 cm:* Undecomposed and partly decomposed plant residues, and some loose fine sand.

A_1 *0–15 cm:* Dark brown (7.5 YR 3/2), in dry condition light reddish brown (5 YR 6/3), heavy very fine sandy loam. Weak to moderate, fine subangular blocky, to coarse granular structure. Moist, friable. Not sticky and not plastic when wet. Soft when dry. Many pores. Very many roots. Transition gradual.

$A_3(A_2)$ *15–50 cm:* Reddish brown (5 YR 5/3–4) heavy very fine sandy loam. Weak to moderate, medium to fine subangular blocky structure. Moist, friable. Not plastic and not sticky when wet. Slightly hard when dry. Many pores. Many roots. From 20 to 45 cm depth common (20%), very small (0.5 cm diam.), rather fine grained, red plinthite concretions. Transition clear.

B_2 *50–100 cm:* Red (2.5 YR 5/8) heavy very fine sandy clay loam. Structure moderate to strong, coarse angular and subangular blocky, composing weak, coarse prismatic. Common, faint clay skins. Moist, firm. Sticky and plastic when wet. Hard, to very hard when dry. Few pores. No roots. Transition gradual.

B_3 *100–160 cm:* Reddish yellow (7.5 YR 6/8) very fine sandy clay loam, with many, fine to medium sized (in lower part medium sized to coarse), distinct mottles of white (2.5 Y 8/2) and red (2.5 YR 5/8). Structure moderate to strong, coarse angular blocky, composing moderate, very coarse prismatic. A few, faint clay skins. Moist, firm. Slightly sticky and slightly plastic when wet. Hard, to very hard when dry. No pores. No roots. Transition clear to abrupt, wavy.

C_{1g} *160–230 cm:* Weathering shale: white (5 Y 8/1) heavy clay with many, coarse, prominent mottles, in horizontal stripes, of dark red (10 R 3/6) and yellow (10 YR 7/8). Moderate, medium sized to coarse, platy structure elements, falling apart into angular blocky. Moist, friable. Upper part rather hard when dry, lower part soft when dry. Transition abrupt.

IIC_{2g} *230–270 cm:* White (N 8/0) loam, with many, very coarse, prominent mottles, in vertical pipes, of red (2.5 YR 4/8) and yellow (10 YR 7/8). Massive. Soft when dry.

(VI) LITHOSOLS (L)

General concept: Lithosols are shallow, often stony soils without horizon development, over consolidated rock. Other characteristics and the properties vary considerably depending on the nature of the rock. They are therefore commonly subdivided into phases according to the geology of the substratum.

A *Sand-stone* substratum phase (L, SS), a *Cherty* substratum phase (L, CH), a *Quartzite* substratum phase (L, QU) and a *Kaolinite-stone* substratum phase (L, K or L) were encountered. Of the latter, one profile will be given, which is actually less shallow than normal.

Profile 42. KAOLINITIC LITHOSOL (L); or Lithosol, Kaolinite-stone substratum phase
Field description 241 (Sombroek)
Location: Along highway BR-14, km 66.0 S of São Miguel do Guamá.
Relief and drainage: Edge of terrace about 30 m above nearby rivulet. Surface drainage good, internal drainage slightly imperfect. Altitude 60 m.
Parent material: Consolidated kaolinitic sediments of Miocene age (?).
Vegetative cover: Recently cleared from primeval forest.

A_1 *0–15 cm:* Grey brown (2.5 Y 5/2) sandy clay loam. Weak, fine subangular blocky structure. Moist, very friable. Slightly sticky and slightly plastic when wet. Soft when dry. About 75% rather soft, somewhat rounded stones (diam. < 10 cm), white (10 YR 8/1), with very fine veins of yellow (10 YR 7/8). Many pores. Very many roots. Transition gradual.

A_3 *15–60 cm:* Pale olive (5 Y 6/3) sandy clay. Weak to moderate, fine subangular blocky and weak, very fine granular structure. Moist, friable. Slightly sticky and slightly plastic when wet. Slightly hard when dry. 5% stones similar to those in A_1, but not rounded, and somewhat larger (diam. 20 cm *ca.*). Many pores. Many roots. Transition gradual.

R_1–B_1 *60–110 cm:* Pale yellow (2.5 Y 7/4) clay, with common, fine, distinct mottles of reddish yellow (5 YR 6/8). Moderate, fine subangular blocky structure. Moist, friable. Sticky and plastic when wet. Slightly hard when dry. About 90% of the horizon consists of hard, sharp edged stones (diam. < 20 cm), white (5 YR 8/1) and with thin veins of pale red (10 R 6/4) in their centres, reddish yellow (5 YR 6/8) and yellow (10 YR 6/8) at the break-lines. In the earth some roots. Porous. Transition gradual.

R_2 *110–200 cm:* Horizontally layered, broken, hard stone, with colours identical to that of the stones of R_1–B_1. Some krotovinas of very pale brown (10 YR 7/4) earth, with structure and texture of the earth of R_1–B_1, and with much insect activity. Transition gradual.

R_3 *200–270+ cm:* White (5 YR 8/1) clay-stone, with many, medium sized, distinct mottles of pinkish white (7.5 YR 8/2), yellow (10 YR 8/8) and red (2.5 YR 5/8). Massive. Rather soft when dry. No pores. No roots.

(VII) GROUND WATER LATERITE SOILS (GL)

General concept (*cf.* also II.3.2.1). Ground Water Laterite soils are intermittently imperfectly drained, highly weathered soils. They have a light coloured and usually light textured A_2 subhorizon. The B horizon consists of largely soft plinthite; it is made up of dense, more or less clayey material, with prominent, coarse and abundant mottles of red, and often also some yellow, in a white or light grey matrix. The base saturation is low and the silicate clay minerals consist of kaolinite. The genesis and the variation in characteristics of the soils are discussed in detail in II.3.2.1, which section also includes many short profile descriptions. Only one full profile description follows.

Profile 43. GROUND WATER LATERITE SOIL (GL)
Field description 162/173 (Day, Sombroek)
Location: South-eastern part Marajó-island; About 25 km W of Soure (Lat. 0°.48′ S; Long 48°.40′ W).
Relief and drainage: Slightly dipped part of extensive, flat, low upland, about 2–3 m above high water level. Imperfectly drained: ground water level at 2,5 m depth during the dry season, at 1 m depth during the rainy season.
Parent material: Late Pleistocene, or Early Holocene, fluvio-marine (?) sediments.
Vegetative cover: Grasses; scattered low trees and shrubs. Vegetation is burned in most dry seasons. Formerly probably forest covered.
The profile is located near a patch with traces of former Indian occupation *(Terra Preta)*.

A_1 *0–30 cm:* Black (10 YR 2/1) sandy loam, with white points of bleached quartz grains. Single grains. Moist, loose. Not sticky and not plastic when wet. Soft when dry. Many pores. Many roots. Transition gradual.

A_2 *30–90 cm:* White (10 YR 8/2) light sandy clay loam. Very little coherent porous massive Moist, very friable. Not sticky and slightly plastic when wet. Slightly hard when dry. Many pores. Common roots. Transition gradual.

B_{1g} *90–120 cm:* Yellow (10 YR 6/8) light sandy clay loam, with many, medium sized to coarse, distinct to prominent mottles of red (2.5 YR 4/8) and white (10 YR 8/1). Within the red a few small plinthite concretions. Structure weak to moderate, medium sized prismatic, falling apart into weak, medium sized subangular to angular blocks. Common, faint clay skins.

B_{2g} *120–260 cm:* White (N 8/0) sandy clay loam, with many medium sized to coarse, prominent mottles of red (10 R 4/6) and some brownish yellow (10 YR 6/8), in a reticulate-prismatic pattern. Centres of the red half hardened. Structure moderate, medium sized angular blocky, composing weak, medium sized prismatic. Common, faint to distinct clay skins. Moist, friable. Slightly sticky and slightly plastic when wet. Hard when dry. Very few pores. No roots. Transition gradual.

With Dutch auger:

IIB_{3g} *260–300 cm:* White (N 8/0) light sandy loam, with many, coarse, prominent mottles of pale yellow (2.5 Y 8/4) and light red (2.5 YR 6/6). Scattered, large, loose plinthite concretions. (fossil), especially in the lower part.

(VII) Hydromorphic Grey Podzolic soils (HP)

General concept: This name, which is not encountered in the literature, is tentatively given to a locally frequently encountered group of imperfectly drained, moderately weathered soils with the following characteristics:

The A horizon is grey or grey brown and rather light textured. The B horizon is a textural-B (*cf.* II.2.1), with mottles of yellowish hue in a greyish matrix. This B horizon is dense, heavy textured, has a well developed prismatic to columnar structure, and prominent signs of clay illuviation (clay skins). The silicate clay minerals are non-kaolinitic for a good part. The base saturation is medium in the upper part of the profile, high to complete in the lower part. The pH of the lowest section of the profile (the C horizon) is often relatively high, namely 6–8. The surfaces of the structure elements in the B horizon are often comparatively dark coloured. Slickensides are distinct in the lower part of the B horizon. The soils differ from the Grey Hydromorphic soils in the high base saturation and the composition of the clay fraction. The soils have, in fact, several characteristics of Grumosols, of which they may constitute a kind of imperfectly drained phase. Morphometrically the soils are also similar to the Solodized Solonetz.

Because of the base saturation status, the soils are further classified as Hydromorphic Grey Podzolic soil, with *high base saturation* (HP_{hb}).

Three subtypes are distinguished, namely one that is (arbitrarily) called the *Ortho* (HP_{hb}, O), one called the *Shallow phase* (HP_{hb}, S), and one the *Dark phase* (HP_{hb}, D).

The *Ortho* sub-type has an A horizon of 40 to 80 cm thick, which consists of an A_1 and A_2, and sometimes an A_3. The B horizon is 80 to 150 cm thick and consists normally of a B_2 and a B_3. The C horizon is about 50 cm thick. The A_1 subhorizon, 10 to 30 cm thick, consists predominantly of light loam, or loam. Its colour value is 2 or 3, its chroma 6 or 7, its hue 10 YR; light brownish grey (10 YR 6/2) is most common. A few, fine, faint mottles, usually of yellowish brown (10 YR 5/8), are often present. The structure is weak, fine subangular blocky. The transition to the A_2 is gradual. The A_2 subhorizon, 20 to 40 cm thick, is predominantly a loam or heavy loam. The main colour is light grey or light brownish grey (10 YR 6/1 resp. 6/2), with few to common, fine, faint mottles of yellowish brown or brownish yellow (10 YR 5/8). The structure is massive or weak, fine to medium subangular blocky. The transition to the B_2 is clear or abrupt, and wavy. The B_2 subhorizon, 30 to 80 cm thick, has predominantly, clay loam textures. The main colour is light grey (10 YR 7/1, resp. 6/1). Mottles with value 5, 6 or 7, chroma 8 and hue 10 YR or 7.5 YR (predominantly reddish yellow: 7.5 YR 6/8) are common, medium sized and distinct. Also mottles of yellowish red (5 YR 5/8) or red (2.5 YR 5/8) are often present, but less conspicuous. The structure is usually moderate, medium prismatic, or columnar. Clay skins are common and distinct. The transition to the B_3 is gradual, wavy. The B_3 subhorizon, 40 to 80 cm thick, consists of clay loam or clay. The principal colour is light grey (10 YR 6/1, 10 YR 7/1, N 7/0), with many, medium, distinct to prominent mottles of yellowish hue, as in the B_2. Mottles of red (2.5 YR 4/8) are few and fine, if present. The structure is a weak to moderate prismatic. Clay skins are common, and distinct to faint. Slickensides are general on the subhorizontal surfaces. The C horizon consists mostly of silty clay loam. Its main colour is predominantly light olive grey (5 Y 6/2). Mottles, usually of brownish yellow (10 YR 6/8), are present in varying quantity, size and distinctness. Colourless crystals, of gypsum, are often found.

The *Dark phase* has an A horizon of only 20 to 40 cm. The B horizon is 30 to 80 cm thick and is relatively dark coloured. The C horizon is about 40 cm thick.

The A_1 subhorizon, about 10 cm thick, is loamy and grey or dark grey (10 YR 5/1, resp. 4/1). The structure is weak to moderate, fine subangular blocky. The transition to the A_2 is gradual and smooth. The A_2 subhorizon, 10–30 cm thick, consists of a loam or light clay loam. Its colour is normally grey (10 YR 5/1 or 6/1), often with some yellowish mottling. The structure is often weak, medium subangular blocky. The transition to the B is commonly gradual and irregular. The B_2 subhorizon, 30 to 40 cm thick, consists of a heavy clay. The main colour is dark grey (10 YR 4/1), with many, fine to medium, distinct mottles, usually of brownish yellow (10 YR 6/6). The structure is strong prismatic. Clay skins are common to continuous, and distinct. Slickensides are faint. The B_3 subhorizon, 10 to 40 cm thick if existent, is of clay or heavy clay texture. Its main colour is grey (10 YR 5/1), with mottles of yellowish hue. The structure is moderate prismatic. Clay skins are common and faint; slickensides distinct. The C horizon consists of a clay loam, with colours normally similar to those of the B_3. Colourless crystals, of gypsum, are general.

The *Shallow phase* has an A horizon of only 20 to 40 cm, a B horizon, being usually only a B_2, of 20 to 40 cm and a C horizon of 10 to 30 cm. Its total solum comprises 50 to 70 cm; below it, hard rock is found.

The A_1 subhorizon, 5 to 15 cm thick, is of sandy loam texture. Its colour is dark grey brown or very dark grey brown (10 YR 4/2 resp. 3/2), its structure weak to moderate, fine subangular blocky. The transition is gradual, smooth. The A_2 subhorizon, 20 to 30 cm thick, has the same texture as the A_1. Its main colour is predominantly light brownish grey (10 YR 5/2). Mottles of strong brown or reddish yellow (7.5 YR 56 resp. 6/8) are many, fine and faint. The structure is mostly weak, medium subangular blocky. The transition is clear to abrupt, irregular. The B_2 subhorizon is of clay texture. The colour of the matrix is grey (10 YR 5/1 or 6/1), with many, fine, distinct mottles of reddish yellow or yellowish red. The structure is strong, coarse prismatic, partly columnar. Clay skins are common and distinct. Slickensides are invariably present, and distinct. The C horizon is silty, with a variety of colours, in which olive grey predominates. Crystals of gypsum were not found.

Profile 44. HYDROMORPHIC GREY PODZOLIC soil, with high base saturation, Ortho (HP_{hb}, o)
Field description 288 (Sombroek, Sampaio)
Location: Araguaia Mahogany area, Bloco Piranha, southern half, transect 7, stake 38 (Lat. 6°01′ S; Long. 48°10′ W).
Relief and drainage: Flat terrain, less than 1 m above level of nearby, narrow, intermittent rivulets. Very distinct micro relief of *canaletes* (*kauwfoetoes*). Imperfectly drained: the *canaletes* are filled with non-stagnant rain water during rainy season. Profile studied in dry season, when ground water level was below 150 cm. Alt. 200 m *ca.*
Parent material: Gypsiferous and calcareous silty clay-stones of Motuca member of Pastos Bons beds (Jura-Triassic).
Vegetative cover: Primeval semi-deciduous forest. Nearly closed, rather high canopy, consisting predominantly of rather big mahogany trees; also some palms. Rather open undergrowth, with a few thin creepers and climbers. Open field layer of seedlings.

O_1 *2–0 cm:* Undecomposed plant residues.

O_2 *2–0 cm:* Partly decomposed plant residues, with fine roots. At the surface many outcasts of worms.

A_1 *0–10 cm:* Grey brown (10 YR 5/2) light loam. Weak to moderate, fine subangular blocky structure. Moist, very friable. Not sticky and not plastic when wet. Rather hard when dry. Many roots. Many, large pores. Transition gradual, and smooth.

A_2 *10–50 cm:* Dark grey brown (10 YR 4/2) light loam, with many, fine, faint mottles of yellowish red (5 YR 5/8). Porous massive to weak, medium to coarse, subangular to angular blocky structure. Moist, friable. Not sticky and not plastic when wet. Very hard when dry. Many roots. Common large and fine roots. Transition abrupt, wavy.

B_{2g} *50–80 cm:* Light grey (N 7/0) clay loam, with many, medium sized, distinct mottles of reddish yellow (7.5 YR 6/8) and some red (10 R 4/8). Structure weak, very fine prismatic, composing moderate, very coarse columnar. Common, distinct clay skins, somewhat darker coloured than rest of soil mass. Moist, very firm. Very sticky and very plastic when wet. Few roots. No pores. Transition gradual, wavy.

B_{3g} *80–120 cm:* Light grey (N 7/0) clay loam, with common to many, medium to coarse, distinct mottles of reddish yellow (7.5 YR 6/8). Weak to moderate, medium to fine prismatic structure. Common, distinct clay skins, somewhat darker coloured than rest of soil mass. Distinct slickensides on the (sub) horizontal surfaces. Moist, very firm. Very sticky and very plastic when wet. No roots. No pores. Transition clear, irregular.

C_g *120–150+ cm:* Olive grey (5 YR 5–6/2) silty clay loam, with many, medium to coarse, distinct mottles of brownish yellow (10 YR 6/0) and some red (2.5 YR 5/6). Massive. Moist, very firm. Slight sticky and slightly plastic when wet. Locally white (10 YR 8/1) spots, effervescing with HCl: carbonates. Many, mainly very small (1 mm), colourless crystals: gypsum.

Full mineralogical analysis was carried out on the A_2 horizon of a comparable profile (*cf.* sample 290-2 of the Tables 7 and 8, and the Figs. 14a-e). Its clay fraction contains 15% mica (illite), 25% 'intermediate', 30% kaolinite and 30% clay-sized quartz. In the fraction 2–16 micron, mica (illite) comprises 3% and chlorite 5%; the rest is quartz. The coarser fractions consist of quartz (95%) only, with some hematite.

Profile 45. Hydromorphic Grey Podzolic soil, with high base saturation, Dark phase (HP_{hb}, D)
Field description 291 (Sombroek, Sampaio)
Location: Araguaia Mahogany area, Bloco Piranha, southern part, transect 7, stake 25 (Lat. 6°01′ S; Long. 48°10′ W).
Relief and drainage: Flat terrain, less than 1 m above level of nearby, narrow, intermittent rivulets. Vague micro relief of *canaletes* (*kauwfoetoes*). Imperfectly drained: the *canaletes* are filled with non-stagnant rain water during rainy season. Profile studied in dry season, when ground water level was below 150 cm.
Parent material: Gypsiferous and calcareous clay-stones of Motuca member of Pastos Bons beds (Jura-Triassic).
Vegetative cover: Primeval deciduous forest. Open canopy, consisting mainly of low, thin, stunted mahogany trees, in a dense pattern. Rather open undergrowth, largely consisting of thin creepers and climbers. Rather open field layer, of some seedlings, clumps of *Cyperaceae*, and *Selaginellae*.

O_1 *3–1 cm:* Undecomposed plant residues.

O_2 *1–0 cm:* Partly decomposed plant residues, with fine roots. At the surface a few outcasts of worms.

A_1 *0–7 cm:* Grey (10 YR 5/1), light grey (10 YR 6/1) when dry, loam. Weak to moderate, medium to fine, subangular blocky structure. Dry, slightly hard. Not sticky and not plastic when wet. Friable when moist. Many roots. Many large, and few fine pores. Transition gradual and smooth.

A_2 *7–30 cm:* Light brownish grey (10 YR 6/2), light grey (10 YR 7/1) when dry, loam, with many, fine, faint mottles of yellowish brown (10 YR 5/6). Weak to moderate, medium to coarse, subangular to angular blocky structure. Dry, hard. Slightly sticky and slightly plastic when wet. Friable to firm when moist. Common roots. Few large, and common fine pores. Transition gradual, irregular.

B_{2g} *30–75 cm:* Dark grey (10 YR 4–5/1) heavy clay, with common, medium sized, distinct mottles of reddish brown (2.5 YR 4–5/4). Structure moderate to strong, medium to coarse prismatic, with tendency to columnar. Many, distinct clay skins. Faint slickenslides on the (sub) horizontal surfaces. Moist, firm to very firm. Plastic and very sticky when wet. Very hard when dry. Few roots. A few, large pores. Transition gradual, wavy.

B_{3g} *75–120 cm:* Grey (10 YR 5/0) clay, with common, medium sized, distinct mottles of yellowish brown (10 YR 5/6) and red (2.5 YR 6/6). Moderate, coarse prismatic structure. Common, faint clay skins. Distinct slickensides on the (sub)horizontal surfaces. Moist, firm, to very firm. Very sticky and very plastic when wet.

C_g *120–140+ cm:* Light grey (N 6/0) clay loam, with many, coarse faint mottles of brownish yellow (10 YR 6/6). Massive, Moist, firm. Very sticky and very plastic when wet. Scattered, fine, white (N 8/0) points. Very many colourless crystals (gypsum).

Profile 46. HYDROMORPHIC GREY PODZOLIC soil, with high base saturation, Shallow phase (HP_{hb}, s).
Field description 294 (Sombroek, Sampaio)
Location: Araguaia Mahogany area, Rio Antonino, transect 1a, stake 190 (Lat. 6°09′S; Long. 48°14′ W).
Relief and drainage: Flat terrain, about 1 m above level of nearby, narrow, intermittent rivulet. Conspicuous micro relief of *canaletes* (*kauwfoetoes*). Imperfectly drained: the *canaletes* are filled with non-stagnant rain water during the rainy season. Profile studied in dry season, when ground water level was below 100 cm.
Parent material: Calcareous cherty silt-stones of Pedra de Fogo beds (Permean).
Vegetative cover: Deciduous hydromorphic shrub. A very few, thin, stunted, low trees emerge above a dense layer of shrubs and thin creepers and climbers. Rather dense field layer (*Gramineae, Cyperaceae, Selaginellae, Araceae*).

O_1 *5–0 cm:* Undecomposed plant residues.

O_2 Absent. Surface very irregular, due to abundance of outcasts of worms.

A_1 *0–8 cm:* Dark grey brown (10 YR 4/2) sandy loam, with few, fine, faint mottles of yellowish brown (10 YR 5/4). Moderate, fine subangular blocky structure. Dry, hard, slightly crusted. Slightly sticky and slightly plastic when wet. Friable when moist. Many roots. Common large and fine pores. Transition gradual, smooth.

A_{21} *8–25 cm:* Grey brown (10 YR 5/2) sandy loam, with many, fine, faint mottles of strong brown (7.5 YR 5/6). Weak to moderate, medium to fine, subangular blocky structure. Dry, slightly hard. Not plastic and slightly sticky when wet. Friable when moist. Common roots. Many large and fine pores. Transition gradual, wavy.

A_{22} *25–37 cm:* Grey (10 YR 6/1) light loam, with many, fine, faint to distinct mottles of grey brown (7.5 YR 4/4). Weak, coarse, subangular to angular blocky structure. Dry, hard. Not plastic and slightly sticky when wet. Friable when moist. Few roots. Few large, and common fine pores. About 25% very small (diam. < 5 mm), fine grained plinthite concretions. Transition clear, irregular.

B_{21g} *37–57 cm:* Light grey (10 YR 6/1) clay, with many, fine, distinct mottles of reddish brown (5 YR 4/4). Structure strong, very coarse prismatic, with tendency to columnar. Common to general, distinct clay skins. Distinct slickensides on the (sub)horizontal surfaces. Dry, hard. Very sticky and very plastic when wet. Very firm when moist. Very few roots. No pores. Transition gradual, wavy.

B_{22g} *57–77 cm:* Grey (5 Y 5/1) clay, with many, fine, faint mottles of yellowish brown (10 YR 5/6). Strong, coarse prismatic structure. Common, faint clay skins. Strong slickensides on all (sub)horizontal surfaces. Dry, hard. Very sticky and very plastic when wet. Very firm when moist. Very few roots. No pores. Transition abrupt, irregular.

C_{1g} *77–87 cm:* Brownish yellow (10 YR 6/8) silt loam, with many, distinct horizontal stripes of white (10 YR 8/1) and grey (10 YR 5/1). Moderate, medium platy structure. Moist, friable to firm. Sticky, very plastic when wet. A few, fine roots. No pores. Transition abrupt, irregular.

C_{2g} *87–102 cm:* Bluish olive grey and purplish olive silty clay. Moderate, medium platy structure. Moist, very firm. Very sticky and very plastic when wet. With white spots, which give effervescence with HCl.

R *102+ cm:* Pale yellow calcareous silt-stone.

(IX) Ground Water Podzols and White Sand Regosols (GP and WSR)

General concept: Ground Water Podzols are imperfectly drained, highly weathered soils. They are characterised by a light to very light texture throughout the profile, a bleached A_2 horizon of varying thickness, and a dark coloured B horizon with a concentration of humic material. This B horizon is usually, for a part, cemented by sesquioxides, thus forming a hardpan (Ortstein).

The thickness of the A_2 horizon in the Amazon Ground Water Podzols varies from 20 cm to 200 cm and more. The thickness and hardness of the Ortstein also vary considerably. There are indications that the cementing sesquioxides are aluminum oxides, not iron oxides. This further classifies the soil as *Ground Water Humus Podzol.*

Under *White Sand Regosol* are classified those soils that consist of bleached sand to a great depth. The soil occurs commonly in a well-drained position.

Profile 47. Ground Water Humus Podzol (GP)
Field description 234 (Sombroek, Sampaio)
Location: Along highway BR-14, km 38.8 S of São Miguel do Guamá.
Relief and drainage: Approximately flat, narrow terrace, 3–4 m above level of nearby rivulet. Alt. 25 m *ca.* Imperfectly drained.
Parent material: Pleistocene fluviatile sediments.
Vegetative cover: Secondary shrub.

A_1 *0–10 cm:* Dark brown (7.5 YR 3/2) sand, spotty by presence of very many white sand grains. Single grains. Moist, loose. Not sticky and not plastic when wet. Soft when dry. Many roots. Many pores. Transition clear and spotty.

A_2 *10–45 cm:* Light grey (10 YR 6/1) sand. Single grains. Moist, loose. Not sticky and not plastic when wet. Soft when dry. Many pores. Many roots. Transition gradual and smooth.

B_{1h} *45–60 cm:* Dark grey (10 YR 4/1) sand. Weak, medium to fine subangular blocky structure. Moist, friable. Not sticky and not plastic when wet. Slightly hard when dry. Many pores. Many roots. Transition abrupt and irregular. Krotovinas of B_{1h} penetrating into underlying horizon.

B_{21hm} *60–80 cm:* Ortstein: Brown to dark brown (7.5 YR 4/2) loamy sand. Massive, indurated. Moist, extremely firm. Extremely hard when dry. Not sticky and not plastic when wet. No pores. No roots. Transition abrupt and broken.

B_{22hm} *80–110 cm:* Ortstein: Brown to dark brown (7.5 YR 4/4) loamy sand. Massive, strongly cemented. Moist, very firm. Very hard when dry. Not sticky and not plastic when wet. No pores. No roots. Transition gradual and irregular.

B_3 *110–150 cm:* Light olive brown (2.5 Y 5/4) sand. Single grains to weak, medium to fine subangular blocky structure. Moist, very friable. Soft when dry. Not sticky and not plastic when wet. No pores. No roots.

Profile 48. White Sand Regosol (WSR)
Field description 131 (Day, Sombroek)
Location: Lower Amazon region, about 10 km N of Oroximiná (Lat. 1°42′ S; Long. 55°49′ W)
Relief and drainage: Extensively flat, to gently undulating terrain. Atl. 50 m *ca.* Excessively drained.
Parent material: Pleistocene fluviatile (?) sediments.
Vegetative cover: Dense and low forest; burned in preceding dry season.

O_2 *3–0 cm:* Reddish brown, partially decomposed organic material, with very many fine roots

A_1 *0–20 cm:* Grey (N 6/0) sand. Single grains. Many roots. Transition gradual.

A_2? *20–480+ cm:* White (N 8/0) sand. Single grains. In upper part a few roots, in lower part none. Sand grains are angular to subangular. Little variation in grain size distribution with depth.

(X) Low Humic Gley and Humic Gley soils (LHG and HG)

General concept: These are poorly drained soils from recent non-marine sediments, with little profile development. They have an A_1 horizon of varying thickness and prominence, overlying a mineral, gleyed sub-surface and subsoil. The A_1 horizon of the Low Humic Gley soils is thin and/or little humic. The A_1 horizon of the Humic Gley soils is prominent and dark, without being, however, an organic horizon proper. A prominent A_1 in this respect is arbitrarily defined as being 20 or more cm thick and having a percentage of Carbon which surpasses $1.5 + 0.015 \times \%$ clay.

The gleyed sub-surface and subsoil horizons of the profiles of both Low Humic Gley and Humic Gley soils encountered in Amazonia have a main colour of grey or light grey. Mottling is usually common, fine to medium sized and distinct, and its colours are predominantly yellowish brown or strong brown (10 YR 5/6–5/8 and 7.5 YR 5/6–5/8 respectively). Hues redder than 5 YR are rare. The soils are usually heavy textured and often contain considerable percentages of silt. The structural development of the subsoil is mostly weak. Signs of clay illuviation (clay skins) are often little conspicuous, if present at all. Because of stratification of the original sediments, sudden changes in texture within a profile may occur. The presence of one or more humic or peaty layers in the subsoil is not uncommon. The soils vary considerably in consistence and degree of subsoil compactness. The mineralogical composition of the soils varies from site to site, and there are also considerable differences in the base saturation percentages. Amongst the Low Humic Gley soils, a *Carbonate subsoil phase* (LHG, c) is separated. This phase is characterised by being strongly alkaline in the subsoil, which also contains carbonate concretions. A very compact and usually dark coloured horizon (*laklaag*, 'lacquer') is invariably found just above this alkaline subsoil.

Amongst the Humic Gley soils, an *Upland phase* (HG, u) is distinguished. It is characterised by being extremely acid, having low amounts of silt, and silicate clay minerals of 1:1 lattice structure (kaolinite) only.

Profiles, intergrading to Ground Water Laterite soil, are not uncommon, concerning both the Low Humic Gley and the Humic Gley soils (*cf.* Profile 18).

A few profile descriptions are given. More details about the soils, many profile descriptions, and analytical data are reported by Sombroek (1962b).

Profile 49. Low Humic Gley soil (LHG)

Field description 265 (Sombroek, Sampaio)

Location: Lower Tocantins floodplain, about 20 km WNW of Igarapé-mirim (Lat. 1°.58′ S; Long. 49°.09′ W).

Relief and drainage: Flat lowland; floodplain of fresh water tidal creeks. Poorly drained: daily flooded by water with a considerable load of sediments. The difference between high tide and low tide level of nearby creek is about 3 m.

Parent material: Recent, fresh water deltaic sediments on older deposits.

Vegetative cover: Swamp forest with many palms.

A_1 *0–7 cm:* Very dark grey (10 YR 3/1) heavy clay loam. Moderate, medium to fine subangular blocky, to crumbly structure. Moist, very friable. Plastic and very sticky when wet, hard when dry. Very many roots. Transition clear.

With Dutch auger:

C_{1g} *7–18 cm:* Light grey (10 YR 6/1–7/1) silty clay loam, with a few, fine, distinct mottless of strong brown (7.5 YR 5/8). Wet, very sticky and very plastic. Common roots. Transition gradual.

C_{2g} *18–50 cm:* Light grey to grey (N 6/0) heavy clay, with many, fine to medium sized, distinct mottles of strong brown (7.5 YR 5/8). Wet, very sticky and very plastic. Common roots. Transition clear.

C_{3g} *50–110 cm:* Dark reddish brown (5 YR 2/2) peaty sandy clay loam. Transition clear.

C_{4g} *110–130 cm:* Grey (N 5/0) silt loam. Wet, very sticky and very plastic. No roots. Transition gradual.

C_{5g} *130–240 cm:* Light grey (N 7/0) silty clay, with few, coarse, distinct mottles of light olive brown (2.5 Y 5/6). Wet, very sticky and very plastic. No roots. Transition gradual.

IIC_{6g} *240–380 cm:* Light grey (N 7/0) clay, with many, medium to coarse, prominent mottles of dusky red (10 R 3/4). Mottles slightly hardened in their centres. Wet, very sticky and very plastic. Compact. No roots.

Profile 50. HUMIC GLEY soil (HG)

Field description 188 (Sombroek)

Location: Lower Amazon floodplain, about 20 km S of Prainha (Lat. 1°59′ S; Long. 53°30′ W).

Relief and drainage: Flat lowland; backswamp of floodplain of river Amazon and rivulet Purus. Poorly drained: during high water season flooded with about 1.5 m water which has a load of sediments.

Parent material: Recent fluviatile sediments.

Vegetative cover: Grasses, and other herbaceous plants.

A_1 *0–25 cm:* Grey (10 YR 5/1) silty clay loam, with some strong brown (7.5 YR 5/8) along the grass roots. Structure medium sized subangular blocky, of moderate strength. Surface hard when dry, slightly cracked. Moist, friable. Sticky and plastic when wet. Transition clear.

With Dutch auger:

C_{1g} *25–70 cm:* Light grey (N 6/0) silty clay loam, with many, medium sized, distinct mottles of reddish yellow (7.5 R 6/8). Moist, friable to firm. Sticky and plastic when wet. Transition abrupt.

$C_{2g\text{-}b}$ *70–120 cm:* Very dark grey (10 YR 3/1) clay, with common, fine, faint mottles of dark yellowish brown (10 YR 4/4). Moist, firm. Sticky and very plastic when wet. Compact. Transition gradual.

C_{3g} *120–170 cm:* Grey (N 4/0–5/0) clay with many, medium sized, distinct mottles of reddish yellow (7.5 YR 6/6). Moist, firm. Sticky and very plastic when wet. Transition abrupt.

C_{4b} *170–190 cm:* Very dark grey (10 YR 3/1) clay. Moist, firm. Sticky and very plastic when wet. Transition gradual.

C_{5g} *190–210 cm:* Grey (N 5/1) clay with common, fine, distinct mottles of yellowish red (5 YR 5/8). Moist, firm. Sticky and very plastic when wet. Transition clear.

C_{6b} *210–220+ cm:* Black (10 YR 2/1) clay, with organic relics. Moist, firm. Sticky and very plastic when wet.

A full mineralogical analysis was carried out on a sample of the second horizon. The data concerning sample 188-2 of Tables 7 and 8 and Figs. 14a-e show that indeed the mineralogical composition is favourable, for which the Ki and Kr data give already an indication. In the clay fraction, only 22% kaolinite is present, while mica (illite) occupies 30%, 'intermediate' 10%, swelling illite 8%, and chlorite 7%. A considerable amount of felspar (15%) occurs in the 2–16 micron and 16–80 micron fractions. Photo 11 illustrates the composition of the clay fraction.

Sample 190-2 has approximately the same mineralogical composition; it is of a Low Humic Gley soil, Carbonate subsoil phase, of the same physiographic unit (the horizon sampled occurs above the lacquer and the alkaline horizons of the profile).

Profile 51. Humic Gley soil, Upland phase (HG, u)
Field description 119 (Day, Sombroek)
Location: Amapá Territory, catchment area of Igarapé do Lago (Lat. 0°27′ N; Long. 51°38′ W).
Relief and drainage: Bottom land in undulating upland with savannah cover. Poorly drained. Alt. below 50 m.
Parent material: Colluvial deposits from heavy textured sediments of surrounding upland.
Vegetative cover: Tall grasses.

A_{11} *0–40 cm:* Black (5 YR 2/1) clay. Strong, very fine subangular blocky structure. Moist, friable. Plastic and slightly sticky when wet. Apparently high in organic matter. Many roots.
With Dutch auger:
A_{12g} *40–60 cm:* Olive brown (2.5 Y 4/2) clay, with common, medium sized, distinct mottles of dark grey (N 4/0) and dark brown (7.5 YR 4/4). Wet, sticky and plastic.
C_{1g} *60–100 cm:* Yellowish brown (10 YR 5/4) clay, with many, medium sized, distinct to prominent mottles of yellowish red (5 YR 4/6) and black (N 3/0). Wet, sticky and plastic, to very plastic.
C_{2g} *100–120+ cm:* Pale brown (10 YR 6/3) clay, with common, medium sized, faint to distinct mottles of yellowish red (5 YR 6/6).

(XI) Saline and Alkali soils

General concept: The Saline and Alkali soils are characterised by either excessive concentrations of exchangeable Na^+ and Mg^{++}, or soluble salts, or both.

They are termed *saline*, if the conductivity of the saturation extract exceeds 4 mmhos/cm at 25 °C, corresponding to about 0.15% salts in the dry soil (Soil Survey Manual, 1931, page 360). Assuming the soluble salts to be predominantly NaCl, this value corresponds to about 2.5 m.e. /100 g 'soluble salts', as this datum is provided by IQA.

The *Solonetz* is a soil with a cloddy B horizon and a prominent prismatic or columnar structure. The exchangeable cations of this horizon are Na^+ and/or Mg^{++} for a good part ($Mg^{++} + Na^+ > Ca^{++} + H^+$; *cf.* Soil Survey Staff, 1960, p. 45). It has recently been suggested that Mg^{++} may have a similar detrimental effect on the structure as Na^+ and this has been confirmed by laboratory trials, for instance those of Schuylenborgh and Veenenbos (1951). Solonetzes are usually found in dry climates. They also exist, however, along ocean coasts, independent of climatic conditions, where they have developed on sediments with high percentages of Mg^{++} and Na^+, due to deposition in marine-deltaic conditions. They are known as 'coastal Solonetzes' and are described for instance by Edelman (1950) for Holland, where they have the local names *pik* or *knip* clays.

The Amazon soils denoted as *Solonetz, Coastal phase* (Sol, c) have usually only a moderate prismatic structure. A number of them have a thick humic top with a crumbly structure and slickensides in the subsoil horizons. These soils are, in fact, *intergrades to Grumosols.* Others, with only a thin humic top and moderate to weak prismatic structure, are *intergrades to Low Humic Gley soils.* The soils may have a saline subsoil.

In coastal Amazonia also there are saline soils that have no structure, or a weak, fine, granular one. The water movement through the profile is rapid, contrary to the situation with the Solonetz, Coastal phase. These soils are classified as *Saline soils.* More data about the Saline and Alkali soils of Amazonia are reported by Sombroek (1962b).

Profile 52. SOLONETZ, COASTAL PHASE (Sol, c)
Field description 175 (Day, Sombroek)
Location: Eastern part of Marajó island, about 40 km NW of Soure (Lat. 0°32′ S; Long. 48°47′ W).
Relief and drainage: Flat lowland. Poorly drained: during the rainy season submerged under about 1 m rain water.
Parent material: Subrecent marine-deltaic sediments.
Vegetative cover: Grasses, and other herbaceous plants.

A_1 *0–20 cm:* Dark grey (10 YR 4/1) with many, fine, distinct mottles of strong brown (7.5 YR 5/8), mainly along the grass roots. Trampled by cattle. Structure very coarse prismatic, of moderate strength; breaking into coarse angular blocks, generally of weak, but in lower part, locally, of moderate strength. Dry, very hard; strongly cracked. Very sticky and very plastic when wet. The upper 10 cm has many insect channels; the lower part is massive within the structure elements. Transition clear and irregular.

B_{21g} *20–40 cm:* Very dark grey brown (10 YR 3/2) clay, with common, very fine, faint mottles of strong brown (7.5 YR 5/8). Structure moderate, coarse prismatic, locally columnar. Faint, locally distinct, clay skins on all vertical ped faces. Distinct slickensides on the sub-horizontal surfaces. Dry, very hard. Very sticky and very plastic when wet. Scattered, small (2–5 cm diam), round, half-hard, black concretions, effervescing with H_2O_2: concretions of manganese. Transition clear and wavy.

B_{22g} *40–140 cm:* Dark grey (5 Y 4/1) clay, with many, fine, faint mottles of light yellowish brown (2.5 Y 6/4). In the upper part the structure is medium prismatic, of weak to moderate strength. Common, faint clay skins on vertical ped faces. Distinct slickensides on the sub-horizontal surfaces. Moist; lower part wet. Very sticky and very plastic. Concretions of manganese as above. No effervescence with HCl. Transition gradual.

With Dutch auger:

B_{3g} *140–210 cm:* Light grey (5 YR 6/1) clay, with many, coarse, prominent mottles of yellowish red (5 YR 5/8). In the yellowish red, half-hard plinthitic tubes. Wet, very sticky and very plastic. No effervescence with HCl. Transition clear.

C_g *210–225+ cm:* Grey (N 4/0) clay. Wet, very sticky and very plastic. No effervescence with HCl.

Note: Sampling of the A_1 at the beginning of the dry season, of the B_{21g}, the B_{22g} and B_{3g} at the end of the dry season.

Full mineralogical analysis was carried out on a sample of the B_{22g} horizon. The data of sample 175-3 of Table 7 and 8 show that in the clay fraction kaolinite comprises only 25%, while 2:1 lattice silicate clay minerals comprise together about 50%. Of these, 'swelling illite' is particularly important (24%). Felspar is present in considerable amounts (17 and 10% respectively) in the 2-16 and 16–80 micron fractions.

To some extent sample 154-2 has the same mineralogical composition (*cf.* the Tables 7 and 8 and the Figs. 14a-e), which is of the B_{2g} horizon of another Solonetz, Coastal phase profile (intergrade to Low Humic Gley soil). Photo 12 illustrates the composition of the clay fraction of the latter sample.

(XII) TERRA PRETA SOIL (TP)

General concept: Terra Preta soil is a well-drained soil characterized by the presence of a thick black, or dark grey, topsoil which contains pieces of artefacts.

As discussed in III.3.4, the Terra Preta soil is a kind of kitchen-midden, developed at the dwelling sites of Pre-Columbian Indians. A general discussion of its qualities is given in V.3.1.2. Here, only one full profile description is given.

Profile 53. TERRA PRETA, light textured (TP_l)
Field description 39 (Day)
Location: Santarém, at Silviculture plots of Sawmill training centre.
Relief and drainage: Gentle undulating terrain (slope 1–3 %). Well-drained. Alt. less than 50 m.
Parent material: Pleistocene sediments.
Vegetative cover: Low secondary forest.

A_p	*0–35 cm:* Black (N 2/0) loamy sand. Moderate, medium crumb structure. Moist, friable. Many roots. Scattered pieces of old ceramics. Transition gradual, smooth.
A_3	*35–70 cm:* Very dark greyish brown (10 YR 3/1) loamy sand. Moderate to weak, medium crumb structure. Moist, friable. Many roots. Transition diffuse, smooth.
B_{21}	*70–100 cm:* Dark brown (10 YR 3/3) heavy loamy sand. Weak, coarse subangular blocky structure. Moist, friable. Slightly more compact than B_{22}. Transition diffuse, smooth.
B_{22}	*100–160+ cm:* Dark brown, to brown (10 YR 4/3) light sandy loam. Weak, coarse subangular blocky structure. Moist, friable.

(XIII) OTHER SOILS

A number of other soils were encountered in Amazonia. Since they have not been properly studied and/or are of limited occurrence, they will be described only in short.

One such a soil is a fertile, red, clayey soil, locally known as *Terra Roxa.* Whether it is predominantly a *Terra Roxa Legítima* (a Latosol, *cf.* group *IIa* of Table 6), or a *Terra Roxa Estruturada* (a soil with a textural-B), is not established.

One profile studied[1] (Alenquer) proved to be more like the latter than like the former: The A horizon of this profile is of clay loam texture and the B horizon of light clay texture, giving a textural ratio B/A of 1.43. The structure of the B horizon is moderate to weak, very fine to medium subangular, with common and weak clay skins. Analysis revealed that the silt fraction (2–50 micron) is relatively high (20–25 %, while 45 % clay is present). Ki data decrease from 2.0 in the topsoil to 1.5 in the central part of the B horizon. The Al_2O_3:Fe_2O_3 ratio increases in the same stretch from 1.6 to 1.9. The T-value decreases from 18 m.e./100 g in the topsoil to about 3 m.e. in the subsoil. The pH-H_2O is between 6.0 and 6.5 throughout the profile down to 200 cm depth, and the base saturation is between 70 and 90 %.

Another fertile soil encountered is a black, very sticky and very plastic clayey soil, denoted *Grumosol.*

One profile studied[1] (Monte Alegre) consists to 40 cm depth (A horizon) of black clay loam, of weak or moderate, medium to coarse, mainly subangular blocky structure. Below this, olive grey clay or heavy clay is encountered, with white specks of carbonates and presence of slickensides. Analysis of this profile gave Ki data of 4.5 to 5.0, high amounts of natural clay, high T-value (40 m.e./100 g and more) and high to complete base saturation, with Ca^{++} as strongly predominant cation.

A well-drained, moderately weathered soil with the following characteristics has been tentatively classified as a *Non Calcic Brown-like soil, Gravelly phase* (NB, G): Reddish brown colour throughout the profile; presence of much gravel and stones of laterized chert; loam to clay loam texture, without much textural difference between the A and the B horizons. The structure in both horizons is moderate, medium to fine subangular blocky.

An analysed example of such profiles (Araguaia Mahogany area) shows a low base saturation in both the A and the B horizons, together 50 cm thick, but high base saturation in the C horizon (50 cm thick) in which the Ca^{++}ion is very predominant. In all three horizons the Ki value is about 2.9 and the percentage Carbon 1–2 %.

[1]) Excursion Eighth Brazilian Congress of Soil Science, 1961.

A well-drained, moderately weathered, shallow soil with the following characteristics has been tentatively classified as an *Acid Brown Forest-like soil, Gravelly phase* (AF, G): Presence of many fine gravelly plinthite concretions (of laterized silt-stone) in the lower part of the profile; yellowish brown to light yellowish brown colour below the surface layer; silty clay loam texture. The A horizon does not seem to be much lighter textured than the B horizon, and the structure is moderate subangular blocky and weak subangular blocky respectively.

One analyzed profile (Araguaia Mahogany area) shows about 35 % clay in the A horizon (40 cm thick), 45 % clay in the B horizon (40 cm thick), high percentages of silt (40-50 %), and much natural clay in the B horizon. Ki and Kr data of the solum decrease with depth from 2.4 to 2.2 and from 1.7 to 1.5 respectively. The cation exchange capacity (T-value) of the solum decreases with depth from 12 m.e./100 g to 8 m.e., and the base saturation from 40 to 20 %, at pH-H_2O values of 5.5–5.0.

Under *Alluvial soil* are classified well or moderately well-drained soils on recent sediments, with little profile development.

The profiles of this soil encountered (Araguaia Mahogany area) are generally light or medium textured, usually with colours of yellowish hue, and with flakes of mica in the sand fraction. In one analysed profile, the distinguishable soil layers up to 350 cm depth, vary in their clay content between 10 and 20 % and in their silt content between 20 and 30 %. Natural clay comprises about half of the total clay. The structure is weak subangular blocky in the upper part, massive in the lower part of the profile. Ki data vary between 3.5 and 2.7 and Kr data between 2.8 and 2.1. The T-value varies between 3.7 and 5.0 m.e./100 g, and the base saturation decreases with depth from 60 to 20 %.

The name *Pará Podzol* has been given to a highly weathered, well-drained, very light textured soil, with a thin bleached A_2 horizon and humus accumulation, without cementation, in the B horizon. A profile description is given by DAY (1961). No analytical data are available about this soil.

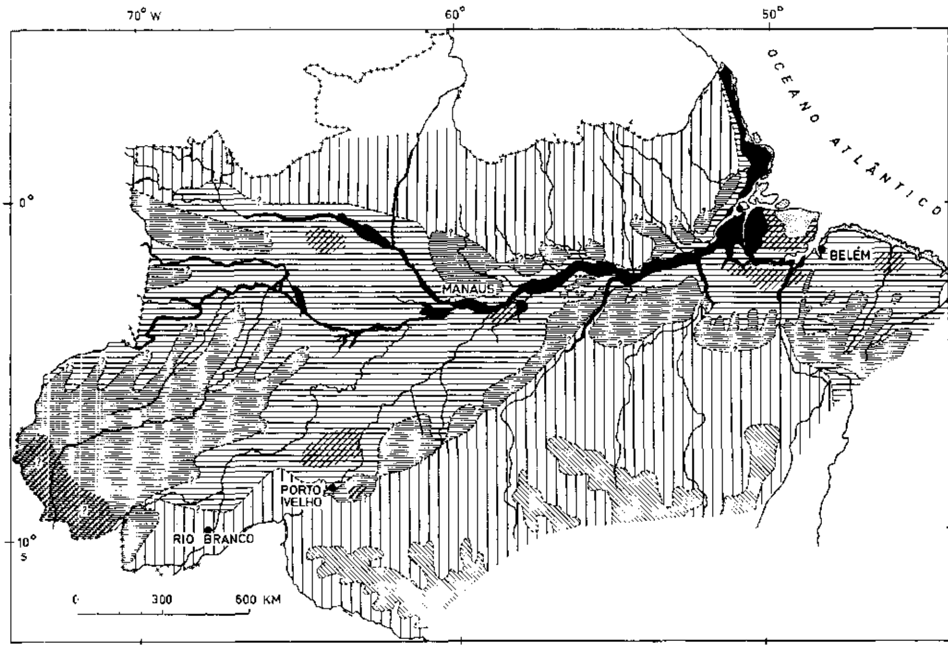
Under *Grey Hydromorphic soil* is classified a strongly weathered, imperfectly to poorly drained soil, which has a light textured, bleached A_2 horizon, that grades sharply into a relatively heavy textured, mottled, dense B horizon, which is not plinthitic. The main colour of this horizon is grey or light grey, and mottles of reddish yellow or strong brown are present in varying abundance and size. The silicate clay minerals are supposedly of 1:1 lattice structure (kaolinite), and the base saturation is thought to be low, to very low.

Organic soils have also been encountered in Amazonia. They are waterlogged and very acid. A peaty horizon of varying thickness overlies mineral soil material that is commonly very light textured, and bleached. For these soils, the names *Half Bog soil* or *Bog soil* are applied, if the organic layer is between 30 and 60 cm thick, and more than 60 cm thick respectively.

III.3 The Occurrence of the Soils in Relation to the Various Geomorphologic Units

In this subchapter, a picture is given of the distribution of the soils as described and classified in the preceding pages. The geomorphologic units described in I.4 are taken as the basis. The situation is illustrated, very diagrammatically, in Fig. 17. For the soils

Fig. 17 Mapa esboçado dos solos amazônicos principais na sua relação com as unidades geomorfológicas



Holocene terrains – Saline and Alkali soils
Terrenos Holocenos – Solos Salinos e Alcalinos

Holocene terrains – Low Humic Gley and Humic Gley soils
Terrenos Holocenos – Solos Glei Húmico e Glei Pouco Húmico

Ground Water Laterite soils
Solos Laterita Hidromórfica

Pleistocene terraces – Kaolinitic Yellow Latosols (of varying texture) and Kaolinitic Latosolic Sands
Terraços do Pleistoceno – Latosolos Amarelos Caoliníticos (de textura variada) e Areias Latosólicas Caoliníticas

Amazon planalto – Kaolinitic Yellow Latosols of very heavy texture (4 + 5: Planície)
Planalto amazônico – Latosolos Amarelos Caoliníticos de textura muito pesada (4 + 5: Planície)

Outcropping crystalline basement and outcropping Paleozoic, Mesozoic and Early Tertiary deposits, as well as Early Tertiary(?) peneplanation surface – Red Yellow Latosols, Dark Red Latosols, Red Yellow Podzolic soils, Lithosols, Ground Water Laterite soils
Embasamento cristalino aflorante e depósitos aflorantes do Paleozóico, Mesozóico ou do Terciário Inferior, bem como superfície de peneplanação do Terciário Inferior(?) – Latosolos Vermelho-Amarelo, Latosolos Vermelho Escuro, solos Podzólicos Vermelho-Amarelo, Litosolos, solos Laterita Hidromórfica

Cretaceous(?) peneplanation surface – Areno-Latosols
Superfície de peneplanação Cretácea(?) – Areno-Latosolos

Fig. 17 Sketch map of the main Amazon soils in their relation to the geomorphologic units of the Planície, which have been comparatively thoroughly studied, the influence of several soil forming factors is discussed in some detail. These factors are *Time* (degree of profile development, depending upon terrace level), *Man* (Terra Preta), and *Ground Water* (Ground Water Laterite soil *versus* Ground Water Podzol).

III.3.1 The Soils of the Undulating Terrains with Outcropping Crystalline Basement

Only a few data are available as to the soils in the regions where the Pre-Cambrian crystalline basement, of the Guiana and the Central Brazilian shields, outcrops. In the Araguia Mahogany area (*cf.* Appendices 2 and 6), on the outskirts of Amazonia, the crystalline, western section consists of mica schists and quartzites. The mica schists, which occupy undulating to hilly terrain, have resulted in the formation of shallow reddish soils which have been classified as *Red Yellow Podzolic soil, with rather high base saturation* (RP_{rhb}; Profile 37). The quartzites are present in mountainous terrain (Dome formations), and have resulted in *Lithosol, Quartzite substratum phase* (L, Q). On the crystalline rocks elsewhere in Amazonia (granites, gneisses, syenites, mica schists), the deep, friable, reddish or yellowish *Red Yellow Latosols* (RL) are probably the most frequent. An example of such a soil is the profile from Serra de Navio in Amapá Territory, which has probably developed on amphibole and mica schists (Profile 34). Examples of profiles on granites, gneisses and syenites are not available. The comparatively small areas with basic effusions (gabbro, diabase, dolerite) have probably *Terra Roxa (Legítima* or *Estruturada)* soils for the most part.

III.3.2 The Soils of the Undulating Terrains with Outcropping Paleozoic, Mesozoic or Early Tertiary Deposits

The soils on these terrains, where consolidated and slightly metamorphosed sediments of a whole series of geological periods are found within short distances (*cf.* Appendix 8 and the Figs. 5 and 6), are naturally very diverse. It has to be borne in mind that a large portion of the areas indicated on the geological maps as having these deposits, have in fact a thin cover of Late Tertiary or Quaternary sediments. Areas with soils derived from Paleozoic, Mesozoic or Early Tertiary deposits are therefore comparatively small. Lithosols, of hematized sand-stones and shales, are apparently rather common among them.

No data are available on the soils of the Silurian and Pre-Silurian deposits of the Amazon basin.

A little is known about the soils derived from the Devonian deposits of both the Amazon and the Maranhão basins. In the Araguaia Mahogany area (Appendices 2 and 6), the principal soil on the Pimenteiras beds is a *Dark Red Latosol, Shallow phase* (DL, s; Profile 35). SAKAMOTO (1960) mentions a soil on the Miacurú of beds the Amazon basin, in the area of the lower Trombetas and the Erepecurú rivers. He describes it as 'loose sands with a limited amount of clay, light orange and brilliant reddish orange coloured over more than 1 m'. It is possibly a Red Yellow Latosol. In describing a red shale, occurring at the lower Jari river and supposedly of Devonian age, the same author states that it weathers into yellow kaolinitic clay.

The Carboniferous deposits of the Amazon basin are very interesting economically because of the presence of lime-stones, evaporites and diabase (the latter are Jurassic in part). In the Monte Alegre-Alenquer area, a few studies of the soils derived from these deposits have been made. The lime-stones have given a *Grumosol*, while a *Terra Roxa Estruturada* has developed on the diabase (Excursion Eight of the National Brazilian Soil Congress, 1961; *cf.* notes under **(XIII)** of III.2). The evaporites are likely to have resulted in the formation of soils similar to those present upon the Pastos Bons-Motuca beds of the Maranhão basin (*cf.* below). No consistent data are available on the soils on the less rich deposits within the Carboniferous strata of the Amazon basin (*cf.*, however, Profile 17 of II.3).

The Carboniferous strata in the Maranhão basin are also very diversified. In the Araguaia Mahogany area (Appendices 2 and 6), *Acid Brown Forest-like soil, Gravelly phase* (AF, G) has been found to be the common soil on reddish brown silt-stones, which are probably of the lower section of the Piauí beds. The presence of *Lithosol, Sand-stone substratum phase* (L, SS) has been established on coarse grained sand-stones which probably belong to the Potí beds. In the same area, Carboniferous lime-stones occur, associated with very resistant chert (chalcedony) in the superficial layers (Piauí beds, *c.q.* Pedra de Fogo beds and upper section of Piauí beds). The soil is therefore only a *Lithosol, Cherty substratum phase* (L, CH), or a very gravelly *Non Calcic Brown-like soil* (NB, G). On flat land surfaces, with the same substratum, *Hydromorphic Grey Podzolic soil, with high base saturation, Shallow phase* (HP_{hb}, S; Profile 46) has developed.

Also a few data are available on the soils derived from the Lower Mesozoic deposits of the Maranhão basin. As to the Jurassic-Triassic deposits, it can be said that on approximately flat terrains in the Araguaia Mahogany area, with a substratum of silt-stones and clay-stones that are, in part, calcareous and gypsiferous (Pastos Bons-Motuca beds; Piauí beds of other geological mapping), various hydromorphic soils have developed (mapping unit H of Appendices 2 and 6; *cf.* also Fig. 23). Among them are *Hydromorphic Grey Podzolic soil, with high base saturation, Ortho* and *Dark phase* (HP_{hb}, O and HP_{hb}, D; Profiles 44 and 45 respectively) and *Ground Water Laterite soil, intergrade to Hydromorphic Grey Podzolic soil (Deep phase* and *Clay-stone substratum phase,* GL-HP, D and GL-HP, C; *cf.* Profiles 14 and 15 respectively of II.3). Undulating ground composed of coarse grained sand-stones (Pastos Bons-Sambaiba beds) was found to have *Kaolinitic Latosolic Sand* profiles, *Transition phase* and *Savannah phase* (KLS, T and KLS, S; *cf.* Profile 33 for the latter).

The survey of the Guamá-Imperatriz area (Appendices 1 and 5) provides for some clues as to the soils derived from the Cretaceous deposits of the Maranhão basin. Red Yellow Mediterranean-like soil (RM; Profile 41) is the common soil of the undulating country, at the southern end of the area, which is composed of the relatively rich Codó beds. In the same stretch, patches of *Ground Water Podzol* (GP) have been found. This soil is likely to have developed on the sandy Corda beds which occur immediately below the Codó beds.

SAKAMOTO (1960) states that the sediments of the Itapecurú or Serra Negra beds (Late Cretaceous, or Tertiary) contain a small percentage of volcanic elements, contrary to the sediments of the Late Tertiary Barreiras beds. He thinks it likely that the soils derived from the former sediments have a higher content of bases. In the meagre amount of geological literature relevant to this area, it is assumed that the Itapecurú or Serra Negra beds occurs in a stretch of the Guamá-Imperatriz area north of the zone of outcropping of the Codó beds. In studying Appendices 4 and 5 it is, however, evident that the land surface in this stretch was modelled during the Plio-Pleistocene epoch (planalto with Belterra clay) and the Pleistocene epoch (terraces at lower level). The characteristically rather high base saturation of the Kaolinitic Red Latosol occurring on the terraces in the stretch (*cf.* III.3.4), may however be an indication that the modelling was done exclusively with the above-mentioned, volcanic elements containing Early Tertiary sediments.

The Cretaceous and Early Tertiary sediments of the Amazon basin are apparently nearly everywhere covered with a thin layer of Late Tertiary and/or Pleistocene materials (*cf.* III.3.4). In contrast, the Cretaceous and Tertiary deposits of the Acre basin outcrop, according to indications, in the eastern part of Acre State over considerable stretches. In this area, the presence of *Red Yellow Podzolic soil, with low base saturation* (RP $_{lb}$; Profile 36) has been established. Also a dark red, friable, clayey soil, provisionally classified as *Dark Red Latosol* (DL) occurs. It was not possible to make a definite correlation of these soils with known geological strata (*cf.* Appendix 8).

III.3.3 The Soils of the Cretaceous and/or Early Tertiary Peneplanation Surfaces

No field data exist on the soils of the presumably Cretaceous plateaux in the transition zone between Amazonia and Central Brazil. On the FAO Soil Map of South America, second draft, they are indicated to have *Areno-Latosols* or *Rego-Latosols*. The supposedly Early Tertiary peneplanation surface, occurring about halfway between these plateaux and the Amazon river, are likely to have a predominance of *Hydromorphic soils* and *Lithosols*. It is believed that the same soils predominate in the savannah covered areas of the boundary region of Pará State and the Guianas (Cretaceous and/or Early Tertiary). According to indications, the terrains concerned are extensively flat, with a number of crystalline ridges (*cf.* discussions in IV.1.2).

III.3.4 The Soils of the Planície

As discussed in I.4, the uplands in the broad axial part of Amazonia consist of unconsolidated kaolinitic sediments largely of the vaguely dated Alter do Chão or Barreiras beds. They are shaped into a heavy clay covered Plio-Pleistocene plateau (the Amazon planalto with Belterra clay), and more or less sandy Pleistocene terraces at a lower level. These uplands are collectively called Planície. The soil data on this Planície are relatively numerous. A general discussion of the soil qualities in relation to the agricultural capabilities is given in Chapter V.

III.3.4.1 *The Soils of the Amazon Planalto*

The soils of the Belterra clay covered Amazon planalto have an uniform profile development over large areas. In the eastern part of the region, east of Manaus, the soils are very predominantly *Kaolinitic Yellow Latosol (,Ortho), very heavy textured* (KYL_{vh}; Profile 24). Its presence has been established in a considerable part of the Guamá-Imperatriz area (*cf.* Appendix 1), near Tucuruí on the Tocantins river, along Curuá-una river (*cf.* Fig. 11), at Belterra Estate along the lower Tapajós river (*cf.* Fig. 20) and in the central section of the Manaus-Itacoatiara area. There is a gradation in the compactness of the subsoil, which has apparently an influence upon the quality of the forest cover (*cf.* IV.1.1.2). The thickness of the A_1 subhorizon also varies considerably. *Terra Preta* soil (TP_{vh}) only occurs very locally on the planalto (*cf.* Fig. 20).

As discussed in I.4.2, the Belterra clay covered plateau is relatively low-lying in western Amazonia (west of Manaus), and the clay itself probably slightly less heavy. The plateau has been studied near Porto Velho, along a 100 km stretch of the Acre – Brasília highway (BR-29). The soils in this stretch are, for a part, *Kaolinitic Yellow Latosol (,Ortho), heavy textured* (KYL_h) *and Kaolinitic Yellow Latosol, intergrade to Dark Horizon Latosol, heavy textured* ($KYL\text{-}DHL_h$). The central sections of planalto have, however, heavy textured *Kaolinitic Yellow Latosol, intergrade to Ground Water Laterite soil* ($KYL\text{-}GL_h$; Profile 12). It is likely that about the same soil situation exists for plateau land in western Acre State. On the low plateau land between the lower Purús and the Catuá rivers, (very) heavy textured Kaolinitic Yellow Latosol, intergrade to Ground Water Laterite soil (*c.q. Planosolic Latosol; cf.* III.2) is probably predominant. The notes of Marbut and Manifold (1925, 1926) concerning the dissected plateau land in all the region west of the Catuá river, point to good drainage. They suggest their soil group 3: 'clay loams and clays with red or reddish friable clay subsoils', to be the most common on these plateau parts (*cf.* Fig. 18). Since this group comprises the soil on the planalto south of Santarém, it may be assumed that the *Kaolinitic Yellow Latosol (,Ortho), (very) heavy textured* (KYL_{vh} or KYL_h) is also predominant on the planalto areas in this part of Amazonia. The only available soil data as to the planalto stretches in the Peruvian-Columbian part of Amazonia are also those of Marbut and Manifold. They indicate a similarity to the adjoining Brazilian parts. In Bolivia, however, much of the plateau land is imperfectly drained (Madre de Dios area; *cf.* Arens, 1963).

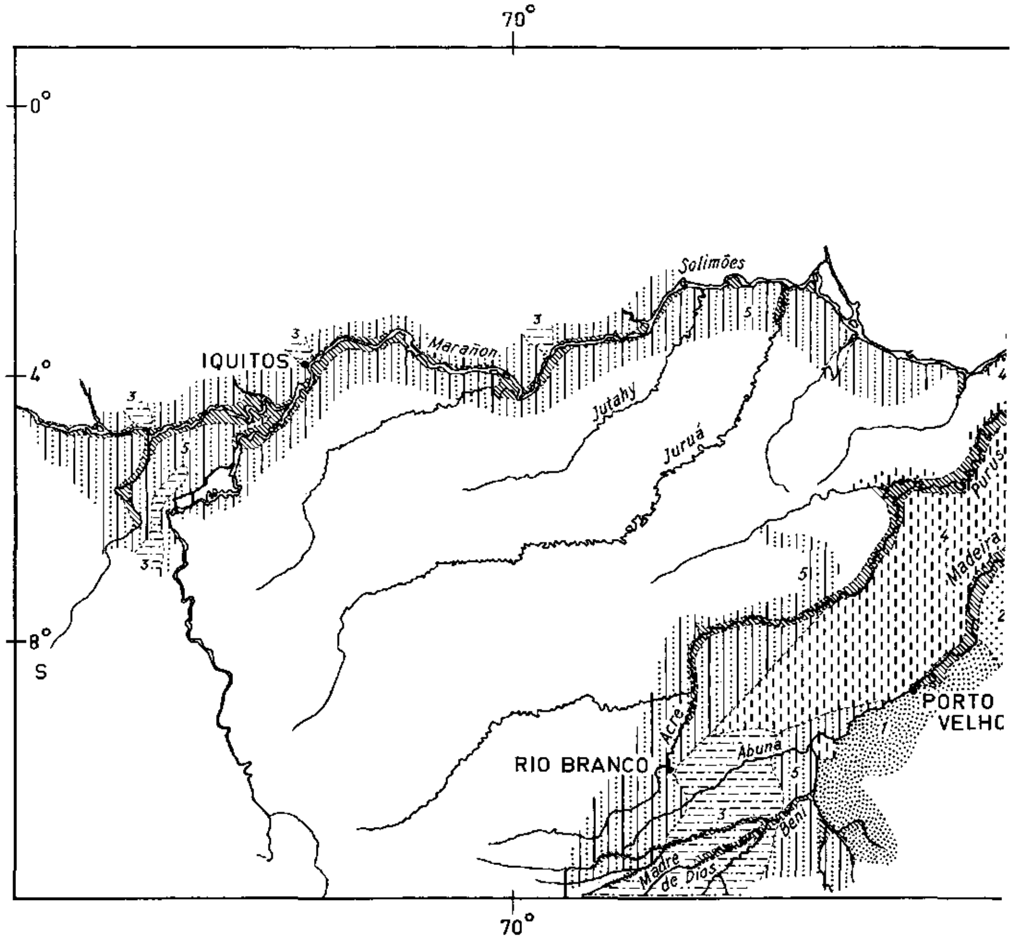


Fig. 18 Mapa de Marbut and Manifold *(1926) dos grupos de solos da Bacia Amazônica Interior*

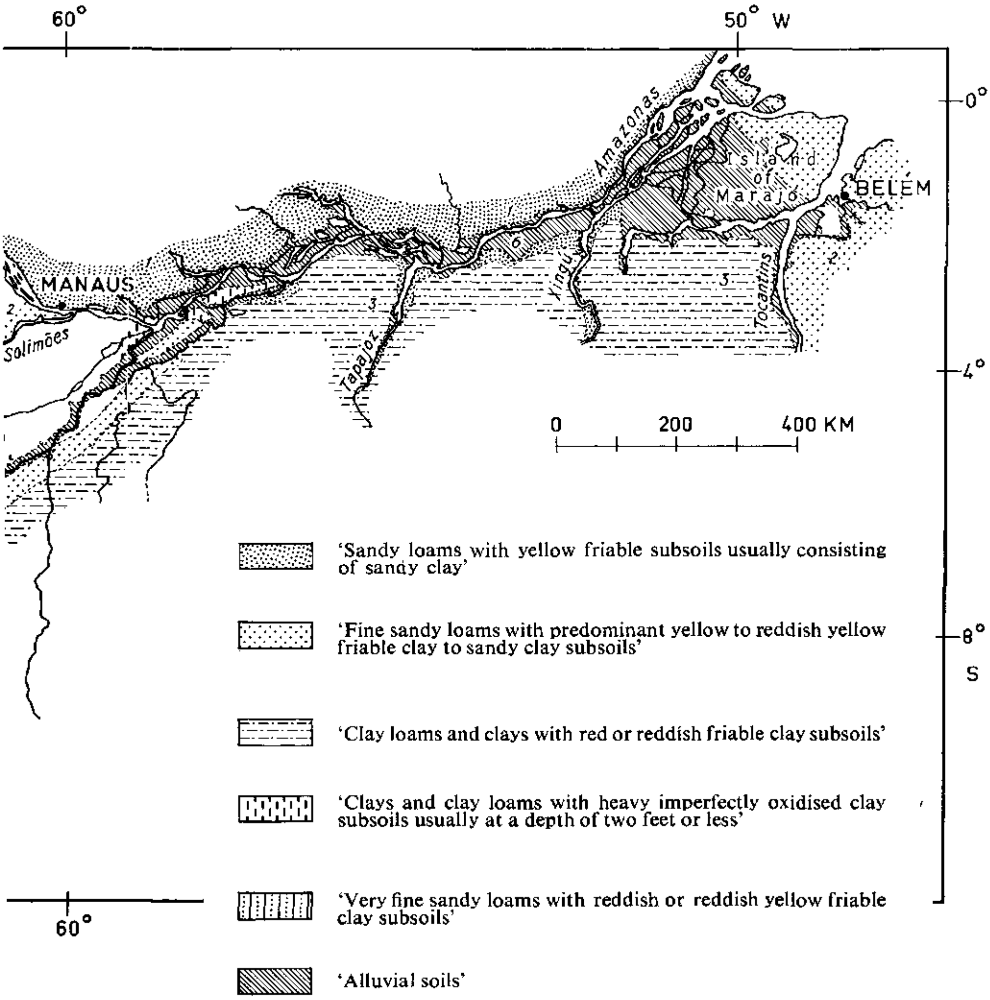
Fig. 18 The soil groups of the Inner Amazon Basin according to Marbut and Manifold*'s map (1926)*

III.3.4.2 *The Soils of the Pleistocene Terraces*

Both the uplands with sediments of undisputedly Pleistocene age (*cf.* I.3) and those with supposedly Late Tertiary sediments that were however re-modelled into terraces during the Pleistocene (*cf.* I.4.3), have soils that are comparatively well known because of their easy access.

Main soils

In the eastern part of Amazonia, all the area east of Manaus, the principal soils on all Pleistocene terraces are yellowish and deeply friable, and of varying texture. They are classified as *Kaolinitic Yellow Latosol (,Ortho), medium, rather heavy or heavy textured* (*e.g.* Profile 25: KYL_m). They have been mapped for large stretches of the Guamá-Im-

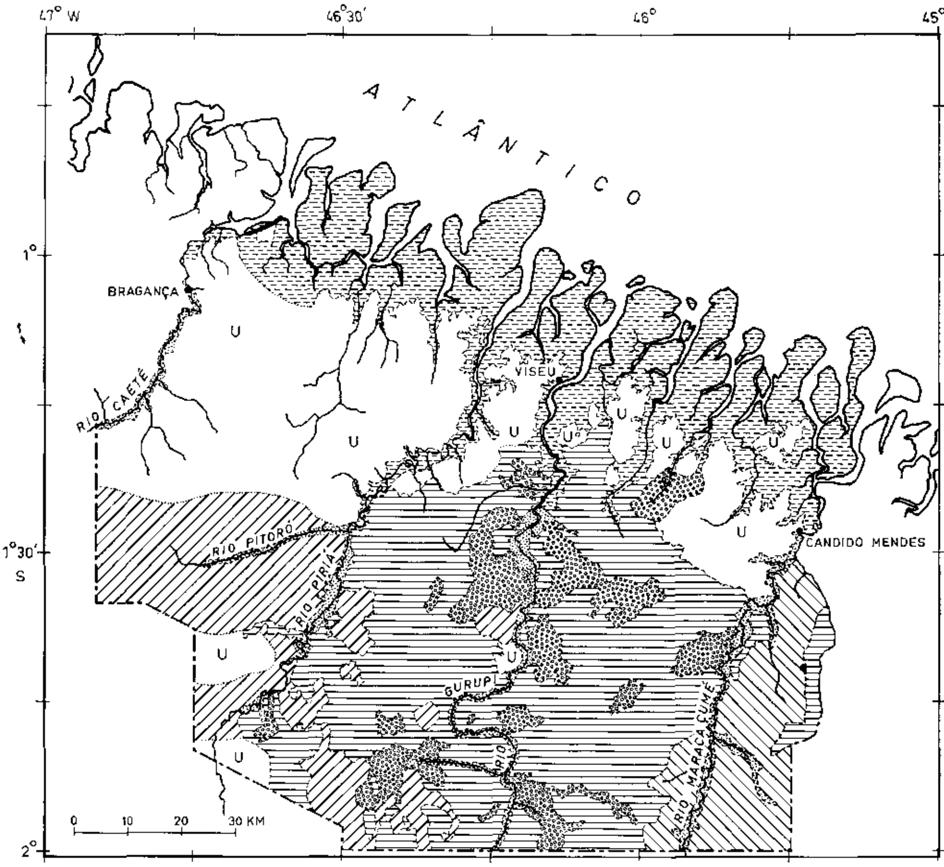


peratriz area (Appendix 1). In the Caeté-Maracassumé area (*cf.* Fig. 19) and the Bragantina area they are the predominant soils (mapped as 'Yellow Latosol' by Day (1959) and Filho *et al.* (1963) respectively; medium textures predominate). The light textured relatives to these soils, classified as *Kaolinitic Latosolic Sand* (KLS), are normally present near the rivers and are of frequent occurrence in the Lower Amazon region. The uplands with Kaolinitic Yellow Latosols or Kaolinitic Latosolic Sand are largely under forest. A number of the savannah terrains, however, also have these soils (*cf.* IV.1.2.1). In that instance, 'Savannah phase' is applied.

PROFILE DEVELOPMENT IN DEPENDENCE OF TEXTURE AND TERRACE LEVEL

Many profiles of both the Kaolinitic Yellow Latosols and the Kaolinitic Latosolic

Fig. 19 O levantamento expedito da área Caeté-Maracassumé por DAY *(1959)*



Association Maracassumé ('Yellow Latosol' + 'Ground Water Laterite' predominantly)
Associação de Maracassumé (predominantemente 'Latosolo Amarelo' + 'Laterita Hidromórfica')

Association Gurupí ('Ground Water Laterite, low phase' predominantly)
Associação de Gurupí (predominantemente 'Laterita Hidromórtica, fase Baixa')

Association Pitoró ('Ground Water Laterite' + 'podzolised Ground Water Laterite' + 'Yellow Latosol' predominantly)
Associação de Pitoró (predominantemente 'Laterita Hidromórfica' + 'Laterita Hidromórfica podzolizada' + 'Latosolo Amarelo')

'Low Humic Gley soil'
'Solo Glei Pouco Húmico'

'Saline soils'
'Solos Salinos'

'Ground Water Laterite, low phase'
'Laterita Hidromórfica, fase baixa'

U 'Agricultural soils, undifferentiated'
'Solos agrícolas, não diferenciados'

Fig. 19 The reconnaissance soil survey of the Caeté-Maracassumé area by DAY *(1959)*

Sands have been studied. There is a general and clear tendency for the profiles of heavier texture to have shallower B_2 horizons, a smaller textural ratio B/A, thinner A_1 subhorizons, and thinner superficial films of loose bleached sand ('micro podzol'). It is inferred that there are also slight differences in the morphometry and in the physical and chemical properties of the profiles, which are related with the terrace level on which the profiles occur. Since higher terraces are of greater age, this may enable an evaluation to be made of the influence of the soil forming factor *Time* on these profiles This is especially possible, because other soil forming factors – Parent Material, Topography, Vegetation and Soil Fauna, Ground Water, and Climate – are fairly equal throughout the Planície of eastern Amazonia. The profiles on higher level, *i.e.* older, terraces show the following trends:

The superficial film of bleached loose sand is slightly thicker; the A_1 subhorizon is slightly thicker; the depth of the horizon of maximum clay accumulation and minimum silt content, *i.e.* the B_2 subhorizon, is larger; the difference in texture between the A and the B horizons, as expressed in the textural ratio B/A, is slightly larger; the silt/clay ratio is slightly smaller; the activity of the clay-sized particles is slightly smaller; the C/N value of the organic matter is somewhat larger. The P-fixation and the percentage of exchangeable $(Al)^+$ may depend also on the terrace level.

These trends are separate from the above-mentioned much larger differences in morphometry which are a consequence of a difference in the over-all texture of each individual profile. For studying of the time factor therefore, profiles of similar general texture should be compared. A quantitative evaluation is not possible because not enough precise data are available on profiles with comparable texture from completely flat and non-eroded parts of the terraces at different levels. Moreover, the differences due to the time factor are so small that they cannot be measured with accuracy with the method of horizon sampling used and the present day level of refinement of laboratory analysis. Minute differences in parent material, in the forest cover, the soil fauna or in the climate may also obscure one or more trends. The mentioned aspects of profile 'ageing' are therefore only exemplified by two profiles of Kaolinitic Yellow Latosol (,Ortho), medium textured (KYL_m). They occur both on flat and non-eroded sections of terraces in the northern part of the Guamá-Imperatriz area, and are both under primeval forest cover (Table 10, the numbers 233 and 231).

The data of three profiles of Kaolinitic Latosolic Sand (KLS) are also given, although the terrace levels of these latter profiles are not well established. Parent material and climate of Profile 296 are moreover probably slightly different from those of the numbers 45 and 169.

That under long existing and man-induced savannah growth (*cf.* IV.1.2.1), the trends are stronger, becomes apparent from the data on number 337. The much clearer influence of the over-all texture on the variations in morphometry can be judged from the data of two profiles of Kaolinitic Yellow Latosol (,Ortho), very heavy textured (KYL_{vh}) of the non-eroded planalto, also under primeval forest cover.

Table 10 Variations in a number of data on soil profiles from terraces at different levels, showing the influence of Time

No. field descr. *decsr. de campo*	Classification *classificação* (*cf.* Table 9) (*cf. Tabela 9*)	Location *localização*	Vegetative cover *cobertura vegetal*	Terrace level *nivel de terraço* (m)	Age *idade*
42/112	KYL_{vh}	Curuá-una, km 6.5	primeval forest *floresta primitiva*	180	Calabrian *Calabriano*
210	KYL_{vh}	BR-14, km 247.0	primeval forest *floresta primitiva*	200	Calabrian *Calabriano*
233	KYL_{m}	BR-14, km 12.7	primeval forest *floresta primitiva*	65	Milazzian *Milaziano*
231	KYL_{m}	BR-14, km 58.0	primeval forest *floresta primitiva*	3–4	Epi-Monastirian *Epi-monastiriano*
337	KYL_{h}	Amapá-Fazendinha, km 8	anthropogenic savannah *savana antropogênica*	3–4	Epi-Monastirian *Epi-monastiriano*
45	KLS	Curuá-una, km 5 *ca.*	primeval forest *floresta primitiva*	100 *ca.*	Sicilian? *Siciliano*?
169	KLS	Curuá-una, km 2.5 *ca.*	primeval forest *floresta primitiva*	60 *ca.*	Milazzian? *Milaziano*?
296	KLS	Araguaia, Rio Corda	primeval forest *floresta primitiva*	10 *ca.*	Late Monastirian *Monastiriano superior*

Constitution of B_2 horizon / *constituição do horizonte* B_2

No. field descr. *descr. de campo*	SiO_2: Al_2O_3 Ki	SiO_2: (Al_2O_3 + Fe_2O_3) Kr	Clay *argila* (< 2μ) (%) c.	Carb. (%) C	Cation exch. cap. *capacid. de troca* (NH_4OAc-pH = 7) (m. e./100 g) T	Base saturation *saturação de bases* (%) V	Moist. equiv. *equiv. de umidade* (g/100 g) M.E.
42/112	1.90	1.71	88.0	0.83	4.81	10.8	35.8
210	1.77	1.48	88.5	0.69	4.56	14.0	34.0
233	1.85	1.63	20.4	0.16	1.69	23.0	9.8
231	1.82	1.63	23.9	0.22	2.14	18.7	13.2
337	1.83	1.63	53.8	0.30	2.07	17.9	25
45	1.60	1.23	10.0	0.22	1.06	37.7	4.7
169	1.50	1.24	14.9	0.08	–	–	6.7
296	1.77	1.53	10.9	0.09	1.61	25.5	6.0

[1]) Silt-Int. fraction estimated, by graphical interpolation on summation curve, with known silt-U.S. / *Fração silte-Int. estimada, por interpolação gráfica em curva cumulativa, com silte-U.S. conhecido.*

[2]) Depth of central part of B_2 / *Profundidade da parte central do* B_2

[3]) $\frac{\%\ 20\text{–}2\ \mu}{\%\ < 2\ \mu} \times 100$

[4]) a Estimated, by graphical comparison of horizons of the individual profile that have approximately identical percentage of Carbon / *Estimado, por comparação gráfica de horizontes do perfil individual que apresentam percentagem de Carbono aproximadamente idêntica*

ıbela 10 Variações em dados de perfis de terraços de diferentes níveis, mostrando a influência do fator Tempo

Thick-ness *espes-sura* A_1 (cm)	Bleached sand cover *cobertura de areia alvejada* (cm)	Depth *profun-didade* B_2[2] (cm)	Textural ratio *relacão textural* *B/A*	Int. silt / clay *silte Int. / argila*[3]	C/N of / *do* A_1	B_2	P-fix in B_2 *fix. de P no B_2* (P-total / P-Bray)	$(Al)^+$ in B_2 (% of T) *$(Al)^+$ no B_2*	Classif. (*cf.* Table 9) *(cf. Tabela 9)*
30	0	65	1.12	4.9	13.7	13.8	–	–	KYL_{vh}
2	0	40	1.12	5.4	10.9	8.6	150	23	KYL_{vh}
20	2.0	230	1.82	3.4	14.7	7.7	225	39	KYL_m
20	0.5	100	1.15	16.7	9.7	7.3	75	25	KYL_m
15	–	$\geqslant$ 90	1.60	7.4[1]	15.4	15.0	130	16	KYL_h
35	?	$\geqslant$120	1.85	2.0	17.2	22.0	–	–	KLS
20	?	350	2.07	2.7	14.6	8.0	–	-	KLS
10	0.5	255	1.31	34.9[1]	9.7	4.5	66	20	KLS

Moisture equiv. of pure clay in B_2 *equivalente de umidade da argila pura do B_2* (m.e./100 g)		Cation exchange cap. of clay in B_2 *capacidade total de troca da argila do B_2*			Spec. surf. of clay[5] in B_2 *superf. espec. da argila*[5] *do B_2* (m^2/100 g)	Classif. (*cf.* Table 9) *(cf. Tabela 9)*
		NH₄OAc-pH = 7 pure clay / *argila pura* (m.e./100 g)		NaO Ac – pH = 8.2 clay / *argila*[5] (m.e./100 g)		
a[4]	b[4]	c[4]	d[4]			
39	46.7	0.5	1.8	4.8	54	KYL_{vh}
43	41.0	1.3	2.1	4.8	81	KYL_{vh}
45	43.8	1.5	5.2	6.5	73	KYL_m
57	49.6	3.7	5.4	–	–	KYL_m
46	43.6	2.7	1.7	–	–	KYL_h
33	43.3	2.9	2.0	–	–	KLS
35	43.9	8.6	–	–	–	KLS
77	53.7	12.2	11.6	–	–	KLS

b Calculated, using the factor 1.7 for the activity of the organic matter *(cf.* V.3.1.1) / *Calculado, usando o fator 1.7 para a atividade da matéria orgânica (cf. V.3.1.1)*
c Estimated, by graphical comparison of horizons of the individual profile that have approximately identical percentage of clay / *Estimado, por comparação gráfica de horizontes do perfil individual que apresentam percentagem de argila aproximadamente idêntica*
d Calculated, using the factor 3.9 for the activity of the organic matter *(cf.* V.3.1.1) / *Calculado, usando o fator 3.9 para a atividade da matéria orgânica (cf. V.3.1.1)*
Organic matter not destroyed / *Matéria orgânica não destruida*

OTHER WELL-DRAINED SOILS

Reworked Belterra clay is present on parts of the higher Pleistocene terraces (*cf.* I.4.2). The main soil developed on this clay is more compact, and at the same time paler than the soil developed on Belterra clay on the planalto proper. It is classified as *Kaolinitic Yellow Latosol, Compact phase, very heavy textured* (KYL, C_{vh}; Profile 26). The presence of this soil has been established for a part of the Guamá-Imperatriz area, where peculiar hummocks, called *jabotis*, are an associated terrain feature (*cf.* Appendix 1, km 130–km 190; Appendix 3 and Photo 20). In the headwater region of Igarapé do Lago in Amapá Territory, the soil is found also, largely under savannah cover. Also near both Manaus and Itacoatiara, where the reworked Belterra clay seems to have a slight admixture with coarser sediments, the soil has a compact appearance.

Also relatively compact and pale profiles may be found which possess lighter textures. They seem to be restricted to the older Pleistocene terraces, for instance the one of about 60 m^+ (Milazzian). An example is the *Kaolinitic Yellow Latosol, Compact phase, rather heavy textured* (KYL, C_{rh}; Profile 27) of the terrains east of the stretch km 50–km 90 of the Guamá-Imperatriz area.

In the southern stretch of the Guamá-Imperatriz area, which has a pronounced dry season although it has a forest cover, a soil much comparable to the Kaolinitic Yellow Latosol (,Ortho), medium textured has been found. It is, however, of redder hue and has a higher base saturation. This soil is classified as *Kaolinitic Red Latosol, medium textured* (KRL_m; Profile 31).

Well-drained soils were also found to occur which have a reddish subsoil (B horizon) below a yellowish topsoil (A horizon). When these subsoils are friable, then such profiles are classified as *Kaolinitic Yellow Latosol, intergrade to Red Yellow Podzolic soil.* This a common soil in the stretch km 90–km 140 of the Guamá-Imperatriz area (Appendix 1 and 3), where the subsoil is largely rather heavy textured (KYL-RP_{rh}; Profile 29). In part, these reddish subsoils are firm, and then also the textural ratio B/A is rather large. Such profiles, which are classified as *Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol,* were frequently found to occur in the central part of the Guamá-Imperatriz area. The texture of the subsoil varies there from rather heavy to very heavy (RP-KYL_{rh} and RP-KYL_{vh}; Profiles 39 and 38 respectively). Similar soils have been described for the Caeté-Maracassumé area, more especially the south-western part of the area of the 'Association Pitoró'. At that time, the name 'Red Yellow Podzolic' was applied (DAY, 1959; *cf.* Fig. 19).

Many parts of the Planície in eastern Amazonia have fossil plinthite near the surface. The well or moderately well drained soils which have a considerable quantity of such fossil plinthite in the solum, are discussed extensively in II.3.2.2. They are classified either as *Kaolinitic Yellow Latosol, Concretionary phase* (KYL, CR; Profile 22, 28), or as *Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol, Concretionary phase* (RP-KYL, CR; Profiles 19, 21, and 20, 40). The former soil is found in sizeable expanse east of Belém (*Latosol Concrecionário* of FILHO *et al.*, 1963). The latter soil occurs frequently in the northern part of Guamá-Imperatriz area.

Imperfectly or excessively drained soils

Imperfectly drained soils with plinthite-in-formation within the solum, *i.e. Ground Water Laterite soils* (GL), occur in a number of areas of eastern Amazonia. In watershed parts of extensive flat terrains, where savannah or savannah-forest forms the vegetative cover, the profiles are often outstandingly hydromorphic, constituting the so-called Ground Water Laterite soil, Low phase. Many descriptions of the occurrence of these hydromorphic soils are given in IV.1.2. Discussions on the variability in the profile characteristics, depending on the character of the fluctuation of the ground water level, the texture of the parent material, and the degree of pre-weathering of the parent material, are given in II.3.2.1. The Profiles 2, 4, 5, 7/43, 8, 9, and 10 are of Ground Water Laterite soils on Pleistocene terrains in eastern Amazonia.

Imperfectly to poorly drained soils with a bleached surface horizon and an Ortstein, *i.e.* Ground Water Podzols, have also been encountered, commonly in strip-like patches. The few analytical data suggest that *Ground Water Humus Podzols* (GP; Profile 47) are involved. It can be inferred from the detailed descriptions in IV.1.2, that these soils often bear savannah or savannah-forest of a kind.

It may be mentioned that Ground Water Laterite soils and Ground Water Podzols have a different position. The former predominate, as extensive units, on watershed areas with flat relief, and the latter on narrow strips of low upland along the rivers and on former river beds, when these terrains are sandy. This implies that on imperfectly drained sites where lateral ground water movement does not take place, Ground Water Laterite soils develop, while on imperfectly drained sites where the ground water can move laterally, Ground Water Podzols develop. It may be concluded that on imperfectly drained watershed terrains there is merely a concentration, partly by downward movement (bleached top of GL, Low phase), of sesquioxides into mottles in the zone of fluctuating phreatic level. On imperfectly drained sandy terrains along rivers, on the other hand, only the Al component of downward moving sesquioxides concentrates, together with humus, into a homogeneous layer, while the Fe component is carried away to the river (the latter conclusion may be drawn only when all Ground Water Podzol profiles prove to have indeed only aluminum concentrated in their Ortsteins).

An excessively drained soil which consists, to a great depth, of bleached sand and is classified as *White Sand Regosol* (WSR; Profile 48), seems to have a restricted, patch-like occurrence, commonly on relatively high terraces with sandy parent material. This soil usually supports savannah-forest (*cf.* IV.1.2), but it may be found under high forest.

Shallow Podzols on sandy terrains in good drainage position were found to occur also, but very locally: *Pará Podzol* of Day (1961). This Pará Podzol occurs in close association with, and often in a position between the Kaolinitic Latosolic Sand and the White Sand Regosol. The soil is therefore probably an intermediate stage in a weathering process that may transform Kaolinitic Latosolic Sand into White Sand Regosol (*cf.* Day, 1961).

Because of the excessive thickness of the bleached sand layer of the White Sand

Foto 17 Algumas das cerâmicas das tribos índias pré-colombianas que com freqüência se acham nos solos de Terra Preta. Vêem-se um sapo, a trompa de uma anta, as cabeças de três pássaros e de um macaco e uma estatueta de fertilidade

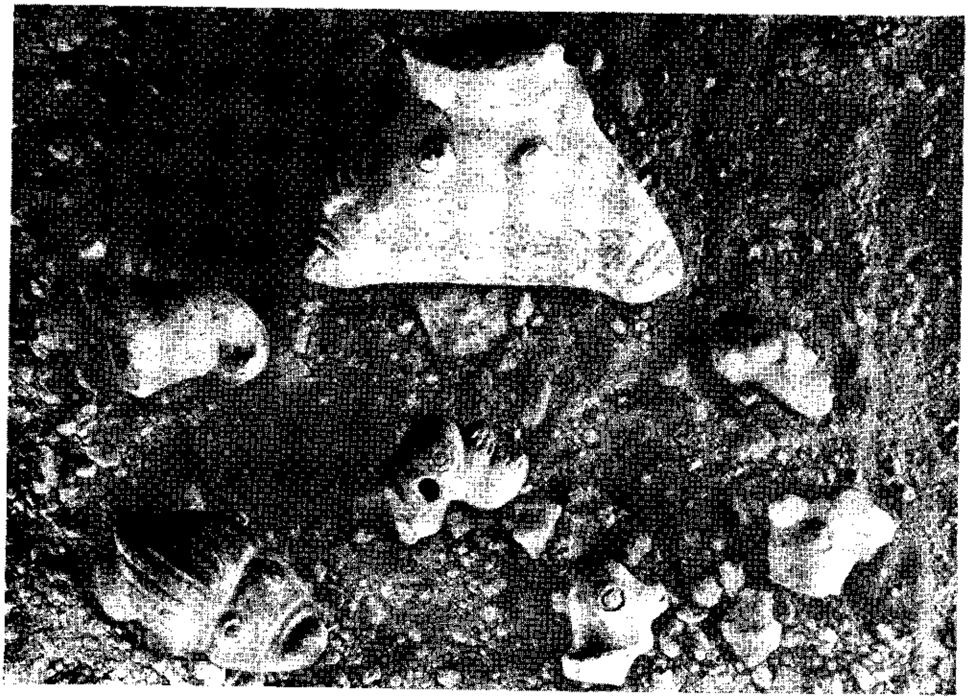


Photo 17 Some of the ceramics of Pre-Columbian Indian tribes that are commonly found in the Terra Preta soil. There can be seen a toad, the trunk of a tapir, the heads of three birds, a monkey and a fertility symbol

Regosol, it can normally not be established whether or not a humus accumulation occurs below the layer. The above mentioned physiographic position of the soil, however, implies that the White Sand Regosol is likely to be actually very deeply and strongly wheatered *in situ*. Instead of Regosol, a very deep Podzol or Ground Water Podzol would be concerned. Even in the case that a layer of bleached sand was deposited as such, alluvially or colluvially, one may assume that the layer will have increased in thickness because of podzolisation, which seems to be the only possible soil forming process on such a site. In any case, therefore, a name as 'Giant Podzol' may be more appropriate for the soil than White Sand Regosol.

Terra preta soil

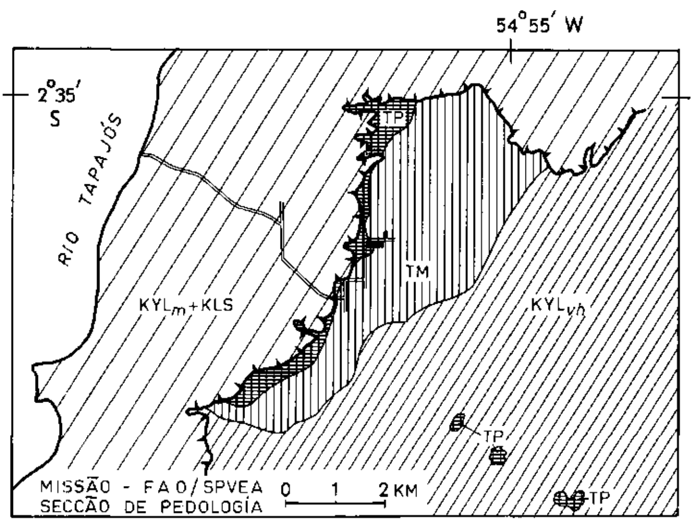
Throughout the Planície in eastern Amazonia there can be found patches of so-called *Terra Preta* or *Terra preta do índio* (TP; Profile 53). This is an upland soil with a thick, black or dark grey top, contains pieces of artefacts, and is famed locally for its fertility. Gourou (1949) mentions a number of places where the soil occurs.

The patches are invariably small, often not exceeding 1000 m². They are usually located at sites where the upland is near the navigable waterways. They are especially frequent at outer bends of the rivers, where no floodplains occurs between the water and the upland, and where the waterway can be scanned freely. Many of the TP patches occur at, or near, present-day villages or towns. Their location implies that the soi predominates on the Pleistocene terraces, not on the planalto. It is only where the latter closely approaches the main rivers, being banded by only narrow strips of lower terraces, that patches of TP may be found on its edges. The latter is the case in the Santarém-Belterra area, where the planalto edges provide for an excellent view over the area of the confluence of the rivers Tapajós and Amazonas. The patches of TP on Belterra Estate have been mapped (*cf.* Fig. 20)[1]. On eastern Marajó island the TP soil is found, likewise as small patches, on the ridgy elevations *(tesos)* within general lowland and on the highest parts of continuous low upland.

Apparently, all TP profiles contain, in their dark toplayer and/or just below this, pieces of artefacts, in varying frequency. They can be identified with ceramics of pre-Columbian Indian tribes (*cf.* HILBERT, 1955). The fantasy employed in producing these ceramics is illustrated in Photo 17.

It can be taken for certain that the patches were occupied by the former Indian population of Amazonia. Those small groups of wild Indians still in existence today, have been driven far away from the means of communication and the population centres.

Fig. 20 Mapa de solos do Estabelecimento de Belterra no baixo rio Tapajós (executado por JOSÉ BENITO SAMPAIO, *1962)*



KLS = Kaolinitic Latosolic Sand/*Areia Latosólica Caolinítica*

KYL_m = Kaolinitic Yellow Latosol, medium textured/*Latosolo Amarelo Caolinítico, de textura média*

KYL_{vh} = Kaolinitic Yellow Latosol, very heavy textured/*Latosolo Amarelo Caolinítico, de textura muito pesada*

TP = Terra Preta

TM = Terra Mulatta

Fig. 20 Soil map of Belterra Estate on the lower Tapajós river (executed by J. B. SAMPAIO, *1962)*

[1]) The mapping unit Terra Mulatta (TM), which is characterised by a slightly less dark topsoil than the TP (Terra Preta) and the absence of artefacts, occurs in a broad band around several of the TP patches. It seems likely that this soil has obtained its specific properties from long-lasting cultivation. The gardens around the former Indian villages were probably situated here. No analytical data are however available concerning these TM soils, which have not been observed outside the Santarém – Belterra planalto.

At the time of the first European penetration, however, the then populous Indian tribes used to dwell in well developed communities on dry terrains along the water ways, which were the best sites for fishing, hunting and warfare strategy (*cf.* MILLER, 1954)[1].

There have been many discussions on the subject of the origin of the TP fertility (*cf.* GOUROU, 1949). The following two hypotheses predominate:

1. The Indians chose these settlements because of higher natural fertility of the soil.
2. The present day fertility is solely due to prolonged Indian occupation. Previously, the soils were no better than the surrounding ones.

Only the second hypothesis can be the right one, for the following reasons:

a. The texture of the TP profiles is varying, but always comparable to that of immediately surrounding soils (usually more or less sandy; sometimes concretionary, or very clayey as on Belterra Estate).

b. The composition of the clay fraction of the TP profiles is identical to that of the surrounding soils. It consists very predominantly of kaolinite (Ki values between 1.7–2.0; Kr values above 1.5).[2]

c. The deeper subsoil (C horizon) and the substratum of the TP profiles are the same as those of the surrounding soils.

Apparently, the TP soil is a kind of 'kitchen-midden', which has acquired its specific fertility, notably much Calcium and Phosphorus, from dung, household garbage, and the refuse (bones) of hunting and fishing. For detailed discussion of the TP fertility please refer V.3.1.2.

THE PLEISTOCENE TERRACES OF WESTERN AMAZONIA

Only a limited number of actual data is available on the soils of the terrains with Pleistocene influence in the western part of Amazonia, the area west of Manaus. Indications are that the principial soils are similar to those of eastern Amazonia. However, the textures seem to be, on the whole, heavier and the sand fraction finer, at least in the area between the rivers Solimões and Madeira (*cf.* the textural data of MARBUT and MANIFOLD, 1926, and Fig. 18 for the area concerned). Only in the area along the Rio Negro the textures are believed to be relatively light.

Kaolinitic Yellow Latosol (,Ortho), rather heavy or heavy textured (KYL_{rh}, KYL_h) probably predominate. Rather heavy or heavy textured *Kaolinitic Yellow Latosol, intergrade to Red Yellow Podzolic soil* (KYL-RP) and *Kaolinitic Yellow Latosol, intergrade to Ground Water Laterite soil* (KYL-GL, or *Planosolic Latosol; cf.* III.2) – seem

[1]) For southern Brasil such patches are not known. This may be because of nomadic living conditions of the former tribes in that region. The Amazon tribes, in contrast, are supposed to have been of a more sedentary predisposition or to have returned repeatedly to old dwelling sites.

[2]) Other Ki and Kr data are to be expected for patches of TP in the non-Planície part of Amazonia.

Foto 18 O terraço superior da unidade de terra Candirú. A superfície de 'plinthite' fóssil é parcialmente enterrada sob uma camada de argila de Belterra remodelada, de uma espessura de 1 a 2 metros. É notável o arranjo vertical dos elementos concrecionários (tipo Ipixuna) na parte superior da camada de 'plinthite' fóssil, à altura do martelo. Também é caraterístico o fim abrupto da camada de argila de Belterra. Á direita extrema vê-se a escarpa do terraço (BR-14, km 140 m. ou m.)

Photo 18 The upper terrace of the land-unit Candirú. The surface of fossil plinthite is for a part buried under a one to two metres thick layer of reworked Belterra clay. Noteworthy is the vertical arrangement of the concretionary elements (Ipixuna type) in the uppermost part of the fossil plinthite layer, which is at the height of the hammer. Also characteristic is the sudden end of the layer of Belterra clay. The scarp of the terrace can be seen at the far right (BR-14, km 140 ca.)

to be also rather frequent, the latter for instance at Tefé. It is supposed that soil group 5 of MARBUT and MANIFOLD (1926) which consists of 'very fine sandy loams with reddish or reddish yellow friable clay subsoils' (*cf.* Fig. 18), largely applies to the three mentioned soils. Also well developed *Ground Water Laterite soil* (GL) is apparently rather frequent, especially between the rivers Madeira and Purús. It is, for instance, the main soil of the extensive savannahs of Humaitá – Lábrea, as described by BRAUN and RAMOS (1959). There can be little doubt that soil group 4 of MARBUT and MANIFOLD, which consists of 'clays and clay loams with heavy, imperfectly oxidised clay soils usually at a depth of two feet or less' refers largely to Ground Water Laterite soils.

Ground Water (Humus) Podzol (GP) is also present. It is, for instance, the soil of the caatinga amazônica of the upper Rio Negro (VIEIRA and FILHO 1961; *cf.* IV.1.2.2).

Concretionary soils seem to have a restricted occurrence, in contrast to the situation in eastern Amazonia (*cf.* MARBUT and MANIFOLD, 1926; p. 434).

III.3.5 The Soils of the Holocene terrains

As to the soils of the Holocene terrains in eastern Amazonia, many data are assembled in the study of SUTMÖLLER *et al.* (1964), and in the related report of SOMBROEK (1962b). Summarising the following can be said:

On the várzeas, intermittendly poorly drained and non-peaty soils, classified as *Low Humic Gley soil* (LHG; Profile 49) or *Humic Gley soil* (HG; Profile 50) predominate. Also *Ground Water Laterite-like soil* is found. Well or moderately well-drained soil from recent alluvium, *Alluvial soil*, seems to be restricted to small areas far upstream of the main rivers (*cf.* a portion of mapping unit F of Appendix 2).

The soils of the igapós are permanently poorly drained, often peaty and normally very acid. They are *Bog soil*, *Half Bog soil* and *Humic Gley soil, intergrade to Ground Water Podzol* (*cf.* SOMBROEK, 1962a).

The bottom lands within grass-covered upland, which physiographically are related to the igapós, were found to have *Humic Gley soil, Upland phase* (HG, U; Profile 51). A sizeable area with this soil has been mapped near Bragança, as 'Glei Húmico', by FILHO *et al.* (1963).

Along the Ocean coast and in eastern Marajó island the lowland soils are characterised by salinity and/or a predominance of Na^{+} or Mg^{++} at the adsorption complex. They are grouped together as *Saline and Alkali soils* (for instance Solonetz, Coastal phase (Sol, C; Profile 52).

The massapé terrains have well developed *Ground Water Laterite soil* (GL; Profile 3). Also other Early Holocene terrains have such soil. In part, they intergrade to Low Humic Gley or Humic Gley soil (*cf.* Profiles 11 and 13).

III.4 Soil Associations and Land-Units

The above described soils may occupy stretches large enough to be mapped on the scale of a reconnaissance soil survey. Usually however, they occur together with other soils, with or without a specific pattern: soil associations and undifferentiated soil units. The *soil association* is a group of defined and named taxonomic soil units, regularly geographically associated in a defined proportional pattern. If the taxonomic units do not occur in a regular geographic association, or if they are not defined, the mappable group is an *undifferentiated soil unit* (SOIL SURVEY MANUAL, 1951).

A soil association or an undifferentiated unit may occur on one and the same topographic unit, for instance a terrace. An example is the association of Kaolinitic Yellow Latosol (,Ortho), heavy textured (KYL_h), Kaolinitic Yellow Latosol, intergrade to Dark Horizon Latosol, heavy textured ($KYL\text{-}DHL_h$) and Kaolinitic Yellow Latosol, intergrade to Ground Water Laterite soil, heavy textured ($KYL\text{-}GL_h$) which occurs on the planalto east of Porto Velho.

An example of an undifferentiated unit on one terrace is the occurrence of Kaolinitic Yellow Latosol (,Ortho), medium textured (KYL_m), Kaolinitic Yellow Latosol, Com-

Foto 19 A base do terraço superior da unidade de terra Candirú. Os sedimentos caoliníticos não consolidados que ocorrem por baixo da camada de 'plinthite' fóssil, podem mostrar pinturas peculiares em cortes de estrada fundos. Isto é devido aos diferentes coloridos das camadas sedimentárias, provàvelmente devidas á água freática que passa, rica em óxidos de ferro. Estas partes vermelhas não endurecem em poucos anos (BR-14, km 135 m. ou m., ladeira do jacaré)

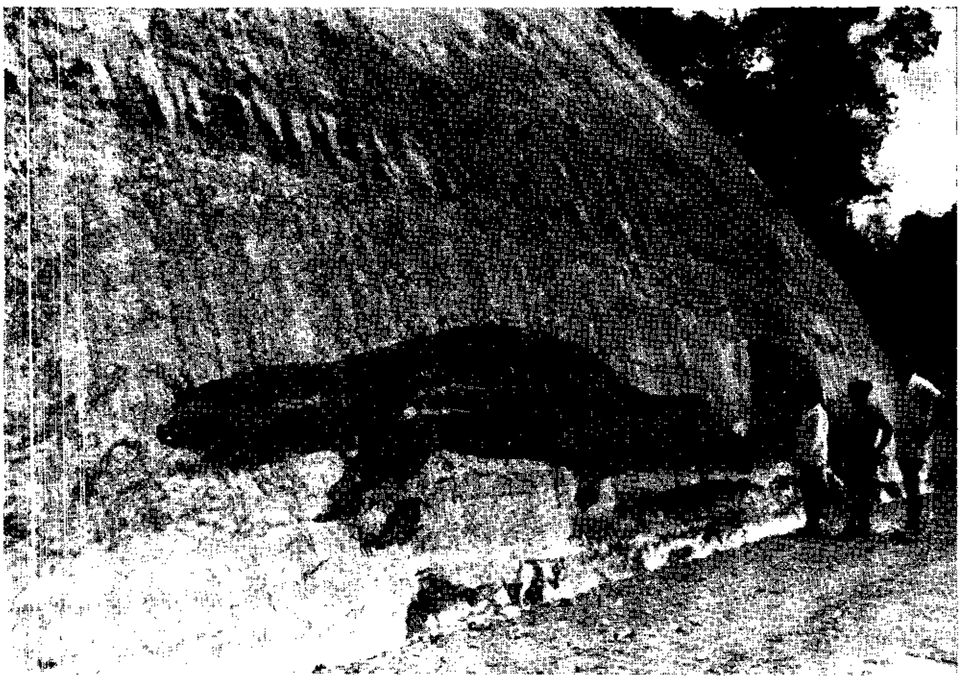


Photo 19 The base of the upper terrace of the land-unit Candirú. The unconsolidated kaolinitic sediments that occur below the cap of fossil plinthite may show peculiar pictures on deep road embankments. This is due to different colour staining of the sedimentary layers, presumably by passing ground water rich in iron oxides. These deep reddish layers do not indurate within a few years (BR-14, km 135 ca.,crocodile hill)

pact phase, rather heavy textured (KYL, c_{rh}), Ground Water Laterite soil (GL), and Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol, Concretionary phase (RP-KYL, CR) in the area east of the stretch km 60–km 90 of the Guamá-Imperatriz area (*cf.* Appendix 1).

Usually however, an association or undifferentiated unit covers several topographical units which occur in a specific pattern and have each their specific soil, or group of soils. The parent materials of each of these topographic units are usually different. On the Planície part of Amazonia little more than differences in texture are involved, but even in that case the associations of soils on a range of relief cannot be called a 'catena' in its strict sence. It would be allowed only when adopting the East-African concept of the latter ('second-class catena' of MILNE; *cf.* SOIL SURVEY MANUAL, 1951, p. 160).

During the combined forest inventory soil survey of the Guamá-Imperatriz area, it was thought desirable to introduce the '*land-unit*'. This is defined as a tract of country

Foto 20 'Jabotís'. Êstes montículos são caraterísticos para muitos terrenos cobertos de argila de Belterra na área Guamá-Imperatriz. Os montículos são provàvelmente os restos de enormes termiteiros, construidos durante alguma época do Pleistoceno. Morfomètricalmente o perfil dos montículos não difere notàvelmente do das partes planas dos terrenos (BR-14, km 372 m. ou m.)

Photo 20 Jabotís. These hummocks are a characteristic feature of many of the terrains with Belterra clay cover in the Guamá-Imperatriz area. The hummocks are presumably the relics of huge termite mounds, constructed during a time of the Pleistocene. Morphometrically, the soil profile of the hummocks is not noticeably different from that of the flat parts of the terrains (BR-14, km 372 ca.)

within which the geologic, topographic and hydrographic elements, the climate, the pattern of vegetation, and the pattern of soils are approximately uniform. The description of such land-units can give, comprehensively, many data about an area hitherto completely unknown. An insight into a surveyed area, for the purpose of planning of forest management or agricultural settling, is likely to be obtained more readily from comprehensive descriptions of land-units than from the very technical data about soils and soil associations. This is particularly likely since, at the commonly applied level of classification, the Planície soils themselves are similar in many aspects. The differences in topographical characteristics, and others, are then very important. Future detailed soil surveys can also be facilitated by taking the characteristics of the land-unit under consideration into account.

A land-unit may comprise only one soil. An example of this is the Kaolinitic Yellow Latosol (,Ortho), very heavy textured (KYL_{vh}), on non-attacked planalto terrain in the region south-east of Santarém. Usually however, a land-unit coincides with the area, or part of the area, of an association of soils. In that case the land-unit is not

Fig. 21 Esbôço da composição da unidade de terra Candirú (para a legenda, veja o Apéndice 4 e Tabela 9 da página 126)

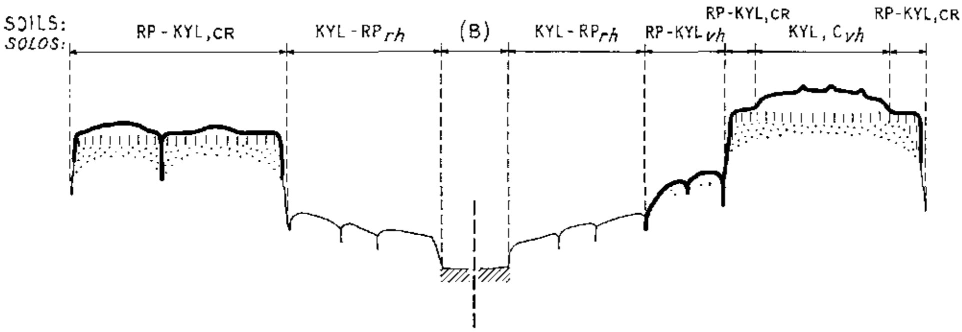


Fig. 21 Sketch of the constitution of the land-unit Candirú (see for legend Appendix 4 and Table 9 of page 126)

identical with the association, but comprises many more characteristics of the area concerned.

The three observed 'Associations' of the Caeté-Marassumé area (*cf.* Fig. 19 and DAY, 1959) are, in fact, also land-units[1], as are the mapping units of the Araguaia Mahogany area (*cf.* Appendices 2 and 6, and the detailed descriptions in SOMBROEK and SAMPAIO, 1962).

In the Guamá-Imperatriz area, eight land-units have been discerned: *Santana, Médio Guamá, Candirú, Alto Guamá, Cunhanta, Gurupí-mirim, Planalto, Itinga* and *Imperatriz* (*cf.* Appendix 4, and SOMBROEK, 1962a).

As to land-unit *Candirú*, see Fig. 21 and the Photos 18, 19 and 20. A small portion of the area of this land-unit is given in Appendix 3.

[1]) As real associations the Pitoró and Maracassumé ones are, as DAY himself states, practically identical. Their separation largely took place because of the difference in the composition of the vegetative cover.

IV The Soils and the Vegetative Cover

Introduction

An important part of the Amazon soil studies by FAO technicans concerned the relationships between the soils and the natural vegetative cover. In fact, the author's specific duty was to cooperate closely with the FAO/SPVEA Forest Inventory team. His task was to establish to what degree differences in vegetative cover, as encountered during the forest inventories, can be ascribed to differences in edaphic conditions. Such a study necessarily implies the recognition and evaluation of the influence of the non-edaphic factors climate and man.

The data collected on edaphic and non-edaphic factors and those on vegetative cover are incomplete and only cover a small percentage of the enormous area that constitutes Amazonia. The data on the vegetative cover are also of limited value for the purpose of the study of plant-soil relationships, since it was not possible to apply methods of ecological research proper.

For a thorough study, a clear picture of the position of the various components (tree species, palms, climbers and creepers, epiphytes, shrubs) in the total structure of the tropical forest is a prerequisite. The relative competition strength of these components directly determines the timber volume. Tree species themselves vary much in their reaction to conditions of micro climate, whether it be radiation, light, heat or humidity. Some species need full sunlight, or associated conditions, during their entire life, some only when they are young. Others do not need full sunlight, or cannot even stand it, during a part or the whole of their life. Commonly, two main groups of species are discerned: 'light-demanding' or 'intolerant' trees (upper-storey trees), and 'shade-bearing' or 'tolerant' trees (under-storey trees). The average life cycle of species varies considerably. There are several natural causes of decay and death: old age, smothering, direct or indirect windfall, sunburn, attack by (micro) flora or fauna. On the other hand, a number of species require a special soil micro flora *(Mycorrhizae)* for their development. The geographical distribution of a species depends not only on climate, man and soil conditions, but also on the length of time elapsed since it first appeared somewhere in the hileia, and the rate of distribution. The latter is directly related to the mobility of the seeds. Possibly connected with this is the tendency of some species to grow in patches or colonies, of varying size.

Although Heinsdijk (1957, 1960) and Pitt (1961) give many notes on the position of tree species in the total structure of the Amazon forest units, systematic research in this respect is still lacking.

The forest inventories were meant only to obtain, in a short time, general data on the economic value of the primeval forest cover over large areas (*cf.* HEINSDIJK and MIRANDA BASTOS, 1963). Its sampling units therefore comprise only about 0.03% of the forest covered land surface under consideration. Within a sample unit, only trees were considered, and only those with a DBH (diameter at breast height) larger than 0.25 m. Only the merchantable bole, *i.e.* the part of the stem below the first major branching, was considered in assessing the gross timber volume. Tree species with characteristic thin stems therefore, and those with characteristic low branching, figure with relatively low timber volume in the inventory tables. Stretches with swamp forest or secondary forest were not sampled. Areas with savannah were avoided. Likewise patches of savannah-forest and shrub-forest were not sampled, as it was assumed that such patches would not contain trees with DBH larger than 0.25 m.

In view of the near absence of published data on plant-soil relationships in Amazonia, and the winding up of the FAO/SPVEA forest inventory – soil survey programme, the conclusions of this programme are discussed in the present chapter, though in many cases one would have preferred to await more definite and adequate data.

IV.1 The Uplands with Forest Cover

IV.1.1 Evaluation of Non-Edaphic Factors

IV.1.1.1 *The Influence of the Climate*

It is likely that the difference in climate between the northwestern part of Amazonia and the central and eastern parts (*cf.* Fig. 2) is responsible for some of the differences between the general vegetative covers of the uplands in those parts. This is suggested by the phytogeographic data of DUCKE and BLACK (1954) as related in I.5. These differences apply not only to the timber volume and the occurrence of tree species, but also to the composition of the undergrowth. For instance, it was observed that within the 'pocket' area with *Af* climate around Belém (*cf.* Fig. 2), epiphytes are rather frequent on the tree stems in the upland forests. In regions outside this pocket, with *Am* climate, epiphytes are found in considerable quantities in the patches of forest on the permanently waterlogged igapó parts, but are practically absent in the forests of the uplands. It is supposed that the absence of epiphytes in the latter is due to a drop in the relative humidity in the tree layer during the dry season. The plants can only flourish in the igapó parts, where the waterlogging of the soil prevents such a drop. The absence or presence of epiphytes in upland forests may give an indication of the local climate in areas where weather recording stations are absent.

TIMBER VOLUME

Higher annual amounts of rain and a more regular distribution of the rainfall over the year (Figs. 3 and 4) apparently does *not* imply a higher mean gross timber volume, edaphic conditions being constant. The FAO/SPVEA forest inventories apply to the Planície for a large part, and the freely draining soils of this section of Amazonia are similar to a large degree (*cf.* III.3.4). As Fig. 22 shows, the highest timber volumes (inventory units Planalto I, Planalto II, Planalto II Baixo, Portel, and especially Caxiuana) are found in a stretch with about 2000 mm rainfall and a fairly well defined dry season. In a westerly direction the mean gross timber volume decreases, although the rainfall is higher and also more regularly distributed over the year. In the area where the Amazon enters Brazil, the timber volume on the uplands is still lower (100 m^3/ha *ca.*; unpublished data of FAO/SPVEA Mission about the Benjamin Constant area), although total rainfall is nearly 3000 mm and a dry season is absent. The description by DUCKE and BLACK (1954) of their 'Norte' region (*cf.* Fig. 13), much of which is located in a section of the Planície with *Af* climate, also points to a relatively low timber volume (for instance: 'less high trees than elsewhere in the hileia').

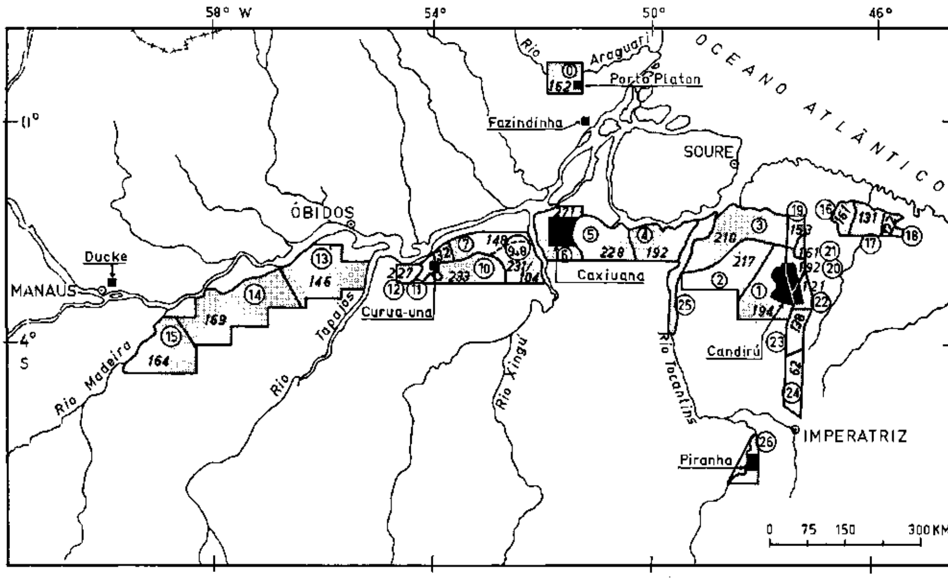
Going from the mentioned stretch with maximal mean gross timber volume in easterly and south-easterly directions, the timber wealth begins to decrease substantially only in the transition zone towards the savannahs of North-Eastern Brazil. In this zone the dry season becomes fairly pronounced (4 months with less than 50 mm rainfall each, although total annual rainfall is still, probably, about 2000 mm). This decrease in timber wealth was studied in the Guamá-Imperatriz area. The fact that the timber volume in the southern part of this area (inventory unit Açailândia) is very low in comparison with that of areas north and northwest, must be largely due to a different distribution of the rainfall over the year. This is, because the soils are similar or identical, and planalto parts with Kaolinitic Yellow Latosol, very heavy textured (KYL_{vh}) in the area of the inventory unit Açailândia have a distinctly lower timber volume than planalto parts with the same soil in the area of the inventory unit Ligação. That the timber volume in this region decreases with increasing seasonal drought is also illustrated by the fact that in the southern half of the Guamá-Imperatriz area steep slopes facing the east, *viz.* the direction of the rains, generally have a better forest cover than those facing the west. The latter often bear a low vegetation largely consisting of shrubs. This phenomenon has not been observed in the areas of the inventory units nearer to the Amazon.

Also the timber volume situation in the inventory units Piriá, Gurupi, and Maracassumé reflects the influence of an increasingly pronounced dry season. Although the areas of the units Piriá and Maracassumé have the same main well drained soil, namely the Kaolinitic Yellow Latosol, medium textured (KYL_m) of the Associations Pitoró and Maracassumé respectively (*cf.* Fig. 19), there is a substantial difference in timber volume between both units.[1]

As will be discussed below (IV.1.2), many differences in timber volume between the

[1]) DAY (1959) suggests that a larger extraction of timber throughout the years in the Maracassumé unit may account for the difference. GLERUM (1960) however states that this extraction concerns only the *Cedro (Cedrela odorata)* and the *Andiroba (Carapá guianensis)*. The first species contributes generally, and also in the Piriá unit, hardly anything to the gross timber volume of the Amazon forests. The occurrence of the second species is only slightly higher in the Piriá unit than in the Maracassumé unit (6.6 m^3/ha and 4.3 m^3/ha respectively).

Fig. 22 Inventários Florestais e Reservas Florestais. Extrato de MIRANDA BASTOS *(1958)*, HEINSDIJK *(1957, 1958a, 1958b, 1958c)*, GLERUM *(1960, 1962)*, GLERUM and SMIT *(1962a, 1962b) e* HEINSDIJK and MIRANDA BASTOS *(1963)*



Forest inventory units, with mean gross timber volume in m³/ha
Unidades de inventário florestal, com volume médio de madeira bruta em m³/ha

Established or proposed forest (production) reserves, and silviculture centres
Reservas florestais (de renda), e centros de silvicultura

FOREST INVENTORY UNITS/*Unidades de Inventário Florestal*
0. Amaparí-Matapí-Cupixí; 1. Capím; 2. Acará; 3. Belém-Sul; 4. Cametá-oueste; 5. Portel; 6 Caxiuana; 7. Flanco II; 8. Planalto II baixo cipoal; 9. Planalto II baixo; 10. Planalto II; 11. Flanco I; 12. Planalto I; 13. Arapiuns; 14. Maués; 15. Canhumá; 16. Piriá; 17. Gurupí; 18. Maracassumé; 19. Santana; 20. Candirú; 21. Médio Guamá; 22. Alto Guamá; 23. Ligação; 24. Açailândia; 25. Tocantins (Ucuuba); 26. Araguaia (Mogno)

Fig. 22 Forest Inventories and Forest Reserves. Extracted from MIRANDA BASTOS *(1958)*, HEINSDIJK *(1957, 1958a, 1958b, 1958c)*, GLERUM *(1960, 1962)*, GLERUM and SMIT *(1962a, 1962b) and* HEINSDIJK and MIRANDA BASTOS *(1963)*

various inventory units may be ascribed to differences in soil qualities. Nevertheless, the above comparison with climatical conditions gives a tentative conclusion that highest timber volumes of the Planície may be found in those areas where the total annual rainfall is not excessively high and a short relatively dry season exists. Only when this dry season becomes pronounced (four or more months with less than 50 mm rainfall each) it may have a negative effect on the growth of the forest.

OCCURRENCE OF INDIVIDUAL TREE SPECIES

A number of the differences established in occurrence of tree species are also likely to be due to differences in climate, in particular as regards the amount and distribution of rainfall. Comparison of the species composition of the unit Açailândia, which has a fairly pronounced dry season, with those of inventory units located north and northwest of it confirms this impression (*cf.* GLERUM and SMIT, 1962a). Many species found in one or more of the latter units are absent, or sparsely present, in the Açailândia unit, although the soils are comparable, and in parts even identical. This applies, for instance, to the *Angelim pedra (Hymenolobium excelsum)* and the *Pau amarelo (Euxylophora paraensis)*. A few species, such as the *Jutaí-açú (Hymenaea courbaril)*, have a higher timber volume per ha in the Açailândia unit than in the units with a less pronounced dry season.

A further example is found in the Araguaia Mahogany area, which has a relatively low total annual rainfall (about 1700 mm) and a pronounced dry season. In some parts of this area, the soil is fully comparable to those of the Planície part of Amazonia. This applies to the Kaolinitic Latosolic Sand, Forest phase (KLS, F; *cf.* Appendix 2), which occurs also in the region directly south and southeast of Santarém, in the centre of the valley. The composition of the forest cover in the two localities is nevertheless very different. The type 1 'high forest, closed canopy, no mahogany' and type 2 'high forest, closed canopy, dominant tree species: *Umirí (Humiria floribunda)*, no mahogany' of GLERUM and SMIT (1962b) may be compared with the unit Flanco I of HEINSDIJK (1957). Many species of the Flanco I unit are not found in the forests on the same soil in the Araguaia Mahogany area, while a few found in the former unit occur more frequently in the latter. Absent, or nearly absent, in the Araguaia Mahogany area are species such as the *Abiuranas (Pouteria spp.)*, the *Maçaranduba (Manilkera huberi)* and *Maparajuba (Manilkera paraensis)* and the *Freijós (Cordia spp.)*; these are species which form the bulk of the canopy in the Planície forests. At least a number of these differences must be due to the difference in climate.

The fact that some species are more frequent in regions with a lower annual rainfall and/or more pronounced dry season does not necessarily imply that they actually grow better under these conditions. It may be that they only endure a restricted moisture supply better than other species, with the result that they are better able to withstand competition for a place in the forest.

IV.1.1.2 *The Influence of Man*

Although Amazonia as a whole is very sparsely populated, it is possible to discern several traces of anthroprogenic influence on the characteristics of its forests.

SECONDARY FORESTS

The influence of man is of course very clearly visible in the areas with secondary forests (for their location *cf.* Fig. 12). Young secondary forest (*capoeira*) can be recognized easily on aerial photographs, as well as in the field. The first is often difficult with very old secondary forest *(capoeirão)*, but for the trained eye the differences from primeval forest are clearly visible in the field. DUCKE and BLACK (1954) give data on the differences in composition of the secondary forests, whether regenerating after felling only, or after felling and burning.

Selective cutting

Also seemingly primeval forest may have undergone anthropogenic influence, for instance by selective cutting of certain very valuable tree species. This applies to the *Maçaranduba (Manilkera huberi)*, a tree often present in large quantities, which is cut for its latex (Heinsdijk, 1958a). Forests are often penetrated very deeply for cutting the rare *Pau rosa (Aniba roseodora)*, which renders oil used in the perfume industry (Heinsdijk, 1958c). The same applies to the rare *Cedro (Cedrela odorata)*, which has very valuable timber (Heinsdijk, 1957; Glerum, 1960).

Heinsdijk (1960) notes, in agreement with observations elsewhere (Surinam), that forests in regions which have long been under man's influence (occasional cutting of trees, large areas of secondary forest nearby) often have more trees of certain species than forests not influenced by man, but with otherwise similar growing conditions. This applies to the species *Cupiuba (Goupia glabra)* and the *Quarubas (Vochysiaceae)*, and is the case with the inventory units Belém-sul and Cametá-ouest, both 'anthropogene facies' of the Pouteria association (*cf.* I.5.1.2).

Indians

The original inhabitants of Amazonia, the Amer-Indians, are likely to have exerted a considerable influence upon the Amazonian forests. These people were, apparently, far from insignificant in number in pre-Columbian times. They used to dwell, in sizeable communities, along very many of the navigable rivers and rivulets (*cf.* discussions on 'Terra Preta' in III.3.4). Indications of their influence are present for instance in the area south of Santarém, where many Indian settlements are known to have existed (*cf.* Fig. 20). All the forest in this area was mapped, after aerial photograph analysis, as 'cipoalic forest east of Belterra' thus distinguishing it from the real (?) primeval forest east of the area (Heinsdijk, 1957). The visual impression of the forest parts on the Belterra estate itself is distinctly different from that of the forest at Curuá-una centre, although both are growing on identical soil namely Kaolinitic Yellow Latosol, very heavy textured (KYL_{vh}).

Pieces of charcoal in the soil might also indicate former Indian influence. In this connection it should be mentioned that in all of three profile pits dug under Planalto II forest at the Curuá-una centre (*cf.* the numbers 112, 303 and 304 of Fig. 11) there were found pieces of charcoal. These pieces mostly occurred at a depth of about 150 cm, and were surrounded by baked clay. One may deduce that extensive burning of the forest took place in former days. It is unlikely that lightning is the cause of this. It is true that burning of tap roots after a tree is struck by lightning sometimes occurs, but such fire seats would not spread over an extensive area (in contrast to the conditions on the lower, sandy terrains, with Flanco I forest, intentionally started fires of artificial clearings on this planalto stretch do not penetrate into adjacent forest parts). Human interference is therefore likely. This must have taken place long ago, because the present day planalto forest has one of the highest mean gross timber volumes known for Amazonia and has hitherto been considered as real primeval. Large-scale burning by a former Indian population is therefore likely to have occurred on the planalto of

Curuá-una centre. It may be noted that a small patch of Terra Preta, which is certain indicator of former Indian settling, is found at the riverside (point A of the cross section in Fig. 11).

TABOCAL

A peculiar example of human influence on the forest cover became apparent during the survey of the Guamá-Imperatriz area. As reported in I.5.1.2, a special forest type, called *tabocal*, is found in the headwater region of the Gurupí, where it occupies broad bands along the river and its tributaries (*cf.* Fig. 23). The composition and the gross timber volume of the forests north, west and south of the tabocal-covered area, as well as of the patches of forest within this tabocal, are approximately uniform. South of the Serra de Gurupí more palms are found than in the other parts with forest, but all of

Fig. 23 Vegetação nas cabeceiras do rio Gurupi. De GLERUM and SMIT *(1962a)*

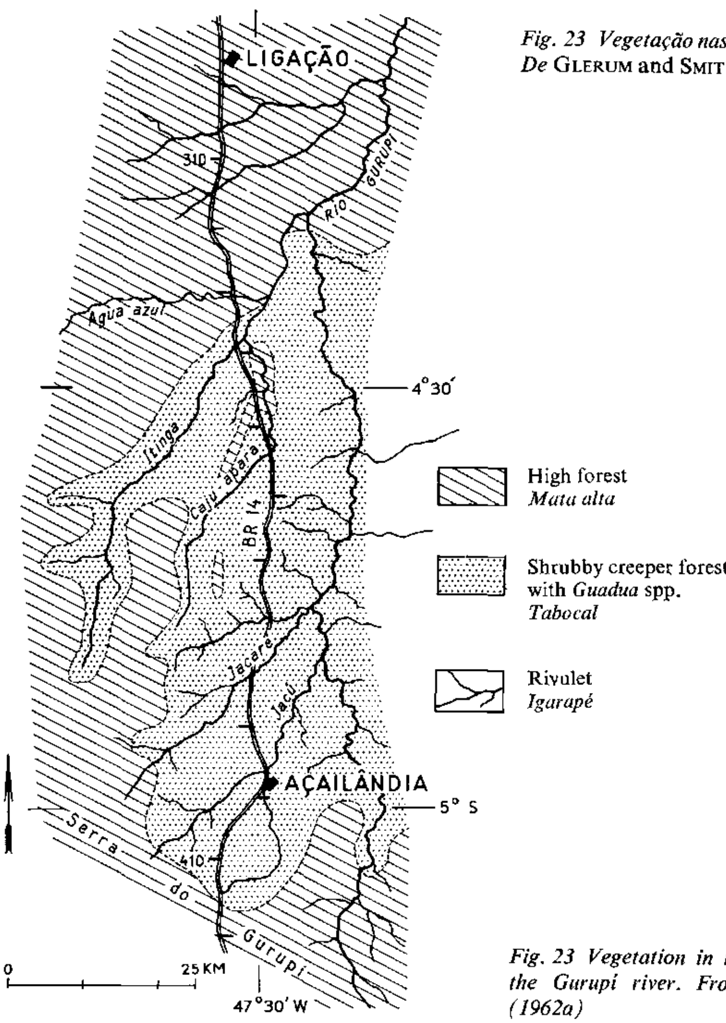


Fig. 23 Vegetation in the headwater region of the Gurupí river. From GLERUM and SMIT *(1962a)*

it belongs to the inventory unit Acailândia. The soils of the tabocal-covered parts are neither physically nor chemically different from those under forest cover (*cf.* data of SOMBROEK, 1963a). Apparently, the *Guadua* species of the tabocal die after two or three years. During the pronounced dry season the dead stakes are very susceptable to burning. It was observed that, during that season if burning is initiated at one spot, the fire sweeps very rapidly over enormous areas of tabocal, also consuming considerable parts of adjoining, relatively poor and dry, forest. The *Guadua* species have an extensive, fire resistent root stock, and the tabocal vegetation therefore can re-establish itself fully after burning. The burned forest parts, however, do not regenerate as readily under the existing climatic conditions. The result is a gradual enlargement of the area covered with tabocal.

It is supposed that anthropogenic factors have stimulated, if not caused, the occurrence of tabocal vegetation in the region. The facts that have lead to this supposition are: the geographic distribution of tabocal; the uniformity of the adjoining forested parts; the equality of the soils both under tabocal and under forest; the behaviour of the vegetation under influence of burning, and the reported existence of considerable former, and locally present-day, settling of Indians along the headwaters of the Gurupí.

Indians have always used bamboo stakes, for arrows and other purposes. Probably the *Guadua* species were already a constituent of the primeval vegetation, but their present occurrence as the dominant species over a large area is believed to be due to the burning practices of Indians. The tabocal therefore is a 'fire-subclimax'.

IV.1.2 Soils and Forest Characteristics

Nearly all forest inventory areas are located in the Planície. It has already been shown in II.2.2 and III.3.4 that the freely draining soils of the Planície are similar to a large degree, at the applied level of classification. Any differences in forest characteristics within an area of uniform climatic conditions and non-existent or uniform anthropogene influences, are therefore apt to show a correlation with lower category soil differences. Among these are the moisture holding capacity, the total available amounts of the various plant nutrients, and the penetration possibilities for roots. These qualities depend on such factors as the soil texture, the compactness of the subsoil, and the presence of plinthitic materials. The coinciding of differences in forest characteristics with differences in these latter factors are discussed below. The exact causal factors of each of the established coincidences remains often uncertain.

Among the differentiating forest characteristics, the gross timber volume and the occurrence of individual tree species are considered in particular.

IV.1.2.1 *Land-Units and Forest Inventory Units*

As related in I.5.1.2, the geographical boundaries of FAO/SPVEA forest inventory units were not solely established on the differentiating characteristics of the forests itself, but to a degree also on the topography and the soils. On the other hand, the geo-

Table 11 Forest inventory units and land-units in the Guamá-Imperatriz area

Forest inventory unit *unidade de inventário florestal*	Number of trees per ha *número de árvores por ha*	Mean gross timber volume per ha *volume médio de madeira bruta por ha*	Salient tree species *espécies de árvores salientes*	Peculiarities *peculiaridades*	Land-unit *unidade de terra*	Main soils (*cf.* Table 9) *solos principais (cf. Tabela 9)*
Santana	106	152.5	Acapú (*Vouacapoua americana*)	Locally anthropogenic influences *influências antropogênicas em alguns locais*	Santana	KYL_m RP-KYL, CR (Mãe do Rio)
Médio Guamá	108	161.2			Médio Guamá	KYL_m KYL, C_{rh} RP-KYL, CR (Ipixuna)
Candirú	124	191.6	Pau amarelo (*Euxylophora paraensis*) Pau roxo (*Peltogyne lecointei*) Quaruba (*Vochysia maxima*)		Candirú	$KYL\text{-}RP_{rh}$ RP-KYL, CR (Ipixuna)

graphical boundaries of land-units were established, in part, on the local pattern of vegetation (*cf.* definition of land-unit in III.4). Therefore, a comparison between inventory unit and land-unit always gives a correspondence. For the Guamá-Imperatriz area, the geographical boundaries of the inventory units coincide completely with those of the land-units. A comparison between the forest data and the soil data of this area is given, summarised, in Table 11.

The land-units under consideration are, for the most part, concerned with associations of two or three main soils. It can therefore be said that a degree of relationship between the forest growth and the soils has been established for the Guamá-Imperatriz area. This is true, even though the over-all differences going from North to South may be ascribed largely to a difference in climate, as previously discussed. That for this area no relationship whatsoever has been established between a certain identified soil and one or more characteristics of the forest growing on it, is without doubt due to the system of forest inventory. If the total structure of the vegetative cover had been studied

Table 11 continued/Tabela 11 continuada

Forest inventory unit *unidade de inventário florestal*	Number of trees per ha *número de árvores por ha*	Mean gross timber volume per ha *volume médio de madeira bruta per ha*	Salient tree species *espécies de árvores salientes*	Peculiarities *peculiaridades*	Land-unit *unidade de terra*	Main soils (*cf.* Table 9) *solos principais (cf. Tabela 9)*
Alto Guamá	94	121.1	Cedro *(Cedrela odorata)* Breu preto *(Protium opacum)*	Many 'cipoalic' parts *muitas partes cipoálicas*	Alto Guamá	KYL, C$_{vh}$ RP-KYL$_{vh}$ RP-KYL, CR (Paragominas)
Ligação	101	138.0	Angelim Pedra *(Hymenolobium excelsum)*	Locally 'cipoalic' parts *partes cipoálicas em alguns locais*	Cunhanta Planalto Gurupí-mirim	KYL$_{m}$ RP-KYL$_{rh}$ RP-KYL, CR (Campinho) KYL$_{vh}$ RP-KYL$_{rh}$
Açailândia	51	61.6	Cedro *(Cedrela odorata)* Jutaí-açú *(Hymenaea courbaril)* Itauba *(Mezilaurus itauba)*	Locally 'cipoalic' parts *partes cipoálicas em alguns locais* 'Tabocal' parts frequently *tabocais frequentes*	Itinga Imperatriz	KYL$_{h}$ KYL$_{vh}$ KRL$_{m}$ KRL$_{m}$ RM

Tabela 11 Unidades de inventário florestal e unidades de terra na área Guamá-Imperatriz

(a practical impossibility), and the data from individual, or parts of individual, inventory sampling units had been compared with the soil *in loco*, then certainly several relationships could have been shown.

IV.1.2.2 *Soils and Timber Volume*

The gross timber volume of a forest will become of special interest once it is economically possible for the pulp and paper industry to utilise all or a great number of the tree species from the highly mixed tropical forest. When forested areas are being considered for agricultural settlement, the standing total timber is also of importance; it normally determines a good deal of the amount of organic matter that becomes incorporated into the soil at the time of clearing. The timber volume may also be handled as a guide for the productivity of a soil. For these reasons it is not only of purely scientific, but also of practical value, to consider the relationship between soil and gross timber volume, if any.

SOIL TEXTURE

Within the northern part of the Guamá-Imperatriz area, the soil with the highest mean gross timber volume is the deeply friable, porous and well-rooted, rather heavy textured soil which is classified as Kaolinitic Yellow Latosol, intergrade to Red Yellow Podzolic soil (KYL-RP_{rh}). This is a main soil of the land-unit Candirú, which coincides with the forest inventory unit Candirú. The gross timber volume of the forest on this soil is estimated to be 200 to 250 m^3/ha, against 100 to 200 m^3/ha for the other main soil occurring in the area of the land unit: RP-KYL, CR (Ipixuna).

The variation of timber volume with the texture of soils otherwise approximately similar was studied fairly closely by HEINSDIJK (1957) in the western half of the Tapajós-Xingú inventory area. The conditions of climate and anthropogenic influence are approximately uniform in this area. The differences in soil texture are very outstanding and consistent. The soils are namely either Kaolinitic Yellow Latosol, very heavy textured (KYL_{vh}), or Kaolinitic Latosolic Sand (KLS). The former is the soil of the planalto parts and the latter the soil of practically all the terrain below this level (flanco parts). The boundaries of the forest inventory units in the area coincide with the boundaries of the two mentioned soil units. On the planalto of this area, the occurrence of cipoal (a distorting factor in the comparison, see below) is limited. HEINSDIJK (1957) established that the inventory units on the very heavy textured soil have a distinctly higher mean gross timber volume than the unit on the light textured soil (Planalto I unit with 227 m^3/ha. and Planalto II unit with 233 m^3/ha against the Flanco I unit with 132 m^3/ha).

The very timber-rich Caxiuana unit (271 m^3/ha) occurs, according to HEINSDIJK (1958a), on a 'transition from a planalto to a plain', the highest parts of which are about 20 m above local river level. There are some parts with savannah or savannah-forest coverage in the watershed region; these are most probably sandy (*cf.* IV.2.2). The other parts, however, especially those at the eastern side, according to indications, are all similar and rather heavy to heavy textured. Actual soil data have been gathered from the northeastern part, where the terrains are practically flat and 5 to 10 m above local river level. The soil in question is a heavy textured Kaolinitic Yellow Latosol (KYL_h).

In discussing all forest inventory units 1 to 15 together, HEINSDIJK (1960) mentions as a general tendency, that heavier textured soils have a higher gross timber volume. The basis for this conclusion are his own field observations concerning soil textures (the units 1, 4, 7, 11 and 13 of Fig. 22 are believed to be located on 'sandy to pure sand soils', and the units 6, 8, 9, 10 and 12 on 'definitely heavy soils').

The above data enable us to draw the tentative conclusion that for the Planície a relation exists between soil texture and gross timber volume. The rather heavy and

Foto 21 O aspeto da floresta alta nos solos da Planície, de fácil penetração das raizes e relativamente bôa armazenagem de umidade. Para o dossel sobem os troncos lisos de todas as espessuras e faltam quase por completo os cipós (BR-14, km 130 m. ou m.)

Photo 21 The aspect of the high forest on the Planície soils which have easy penetrability for roots and comparatively good moisture storage. Slender boles of all sizes tower towards the canopy, and creepers and climbers are practically absent (BR-14, km 130 ca.)

heavy textured soils (35–70% < 2 micron in the B horizon) in particular, lend themselves to support forest with a high gross timber volume. A comparatively high moisture holding capacity of these soils is probably a major reason (*cf.* V.3.1.1).

SUBSOIL COMPACTNESS AND CIPOAL

That the areas with *very* heavy textured freely draining soils tend to have a less high timber volume than areas with similar soils but of slightly less heavy texture, is related to an often higher compactness of the subsoil of the Belterra clay soils and the occurrence of cipoal and 'cipoalic forest' (*cf.* the descriptions in I.5.1.2). Because of the regularity in occurrence and the often large expanse of the vegetative types concerned, the possibility that a normal regeneration phase of the adjoining high forest is involved, can be discarded. HEINSDIJK (1957) supposes the cipoal to be a 'para-climax' vegetation.

The occurrence of these vegetation types was studied in some detail in the Guamá-Imperatriz area. The completely flat central sections of planalto parts in the stretch km 190–km 315 (unit Ligação; *cf.* Photo 22) are covered with cipoal or 'cipoalic forest'. The very gently sloping edges, above the escarpment proper, bear however a heavy forest cover. This consists of big trees and an open undergrowth which is nearly devoid of creepers and climbers. A similar difference in vegetative covers of the edges and the central sections occurs on the southernmost planalto parts (stretch km 315–km 420, forest inventory unit Açailândia) although the timber volume as a whole is much lower there. The soil of both the edges and the central sections is the same, namely Kaolinitic Yellow Latosol, very heavy textured (KYL_{vh}). Many planalto stretches were studied, and analytical data of several profiles compared. Phycical and chemical qualities of the profiles are about identical for both sites. One detectable difference is however that the central sections may have a conspicuously dark (dark grey to black), crusted, often irregular and clodded, aquaphobe surface, with an intense activity of termites. The pH-H_2O of this surface (field testing) is invariably slightly higher (about 6.0 instead of 4.0–5.0) than that of a non-crusted surface layer, as is common on the planalto edges. Laboratory analysis of a few dark surface clods revealed a stronger predominance of Ca^{++} in the adsorption complex than is common for the Planície soils. Another small difference between the profiles on the edges and those on the central sections of the planalto is that, on the former, the A_1 subhorizon is often not quite as thin (3–5 cm against 2 cm). The central sections have also a slightly more compact subsoil (B horizon), which manifests itself in a friable to firm consistence in contrast with the friable to very friable consistence of the subsoil at the edges, and a larger resistance to penetration with a soil hammer.

'Cipoalic forest' is of general occurrence on the terrains with reworked Belterra clay in the stretch km 150–km 195 of the Guamá-Imperatriz area. The soil of these terrains is classified as Kaolinitic Yellow Latosol, Compact phase, very heavy textured (KYL, c_{vh}). It has characteristically a very thin A_1 subhorizon (0.5–3 cm), and is compact and rather firm, particularly in the B horizon. The frequency of fallen trees on the terrains seems to be larger than elsewhere.

Foto 22 Floresta cipoálica numa parte central inteiramente plana de um trecho de planalto. A ambos os lados desta estrada de floresta recentemente aberta, vê-se claramente a freqüência de cipós que trepam às copas das árvores (BR-14, km 295 m. ou m.)

Photo 22 'Cipoalic forest' on a completely flat central section of a stretch of planalto. On both sides of this recently opened forest road, the frequency of climbers up to the tree crowns is clearly visible (BR-14, km 295 ca.)

The cipoal on the planalto and on the terrains with re-worked Belterra clay in the region between the rivers Xingú and Tapajós (*cf.* Fig. 24) have been studied by HEINSDIJK (1957). He observed that under the cipoal the soil surface is much darker than under the high forest. The local farmers consider the cipoal parts preferable for shifting cultivation. The author was unable to visit these areas with cipoal proper, but did study the local changes in vegetative cover and soil qualities on the planalto at Curuá-una centre (*cf.* Fig. 11). One examined soil profile is located on the edge of planalto (No. 112), where very timber-rich forest is found, with an open undergrowth. At 8km distance from this edge, another profile (No. 303) was examined. The forest there is slightly different in composition from that of the edge (*cf.* GLERUM and SMIT, 1960) and the timber volume is probably slightly lower. A third examined profile is located at 10 km from the mentioned edge (No. 304). This is an area where the timber volume is distinctly lower and the composition of the forest quite different from that at the other sites. Creepers and climbers are rather frequent. Many trees with stilt-roots occur, for instance the *Andiroba (Carapa guianensis)* which is often considered to be an igapó tree. Also, several tall herbs commonly found in igapó parts are present, for instance *Guarumá (Ischinosiphon aruma)*. The frequency of fallen trees is remarkable.

The soil profile at the edge has a very loose appearance in its subsoil (B horizon). The second profile is already somewhat dense, and the most interior one is considerably compact and resistant to penetration with a soil hammer. While the colour of the A_1 subhorizons is the same (brown to dark brown) in all tree profiles, its thickness decreases from 30 cm to 20 cm and to 10 cm respectively.

From the above described comparative observations it is tentatively concluded that cipoal and 'cipoalic forest' grow on those very heavy textured soils that have a compact subsoil, and a thin A_1 subhorizon, in comparison to soils of the immediately surroundings. Owing to the compactness, the maximum depth of rooting is smaller. The soil is therefore, as regards the requirements of the forest vegetation, a shallow one, on which high trees cannot compete with the apparently vigorously growing creepers and climbers. Probably both a lack of ground support for the trees (fallen trees, stilt-roots) and a limited moisture supply during the dry season (*cf.* V.3.1.1) are the causes of the small competition force of the trees. The locally found intense termite activity, crustiness, higher pH and dark colour of the superficial layer is believed to be a consequence rather than a cause of the cipoal growth.

There are a few facts that support the above tentative conclusion as to the cause of the cipoal and the 'cipoalic forest' on the Belterra clay terrains. In the Guamá-Imperatriz area, other types of creeper forest (in general much less vigorous than the Belterra clay cipoal) and dense shrub vegetation are often associated with Ground Water Laterite soil (GL) and Kaolinitic Yellow Latosol, Compact phase, rather heavy textured (KYL, c_{rh}). Both soils have shallow root penetration, because they have either an intermittently shallow ground water level or a compact subsoil. For the Araguaia Mahogany area, which is outside the Planície, it has been established that the soils with cipoal and 'cipoalic forest' are of varying natural fertility, but all of them are shallow: shallowness of the bedrock or of the ground water level. The soils in this area which have a coverage of closed-canopy-forest are also of varying fertility (it is, in fact, usually low), but are deep (*cf.* Appendix 6). Apparently, the occurrence of cipoal or 'cipoalic forest' as opposed to closed-canopy-forest in this area is less determined by the chemical than by the physical qualities of the soils. Considering the whole of Amazonia, it may be a general rule that creeper forests prevail on soils with shallow rooting, whether having low or high natural fertility.

It is evident that it is of much practical importance to study further the factors that determine the occurrence of forest types with very low timber volume such as the cipoal. A prerequisite for further study is a sound plant-ecological classification of the various types of cipoal and 'cipoalic forest'. Of special interest is the checking of the tentative conclusion as to the cause of the Belterra clay cipoal, since silvicultural methods are being tried out predominantly on planalto terrains (FAO/SPVEA silviculture programme at Curuá-una centre).

The foregoing discussions have concerned the timber volume on the Planície soils that are freely draining. Generally speaking, the timber volume of the forests on the

Fig. 24 Cipoal na região ao Leste do baixo rio Xingú. De HEINSDIJK *(1957)*

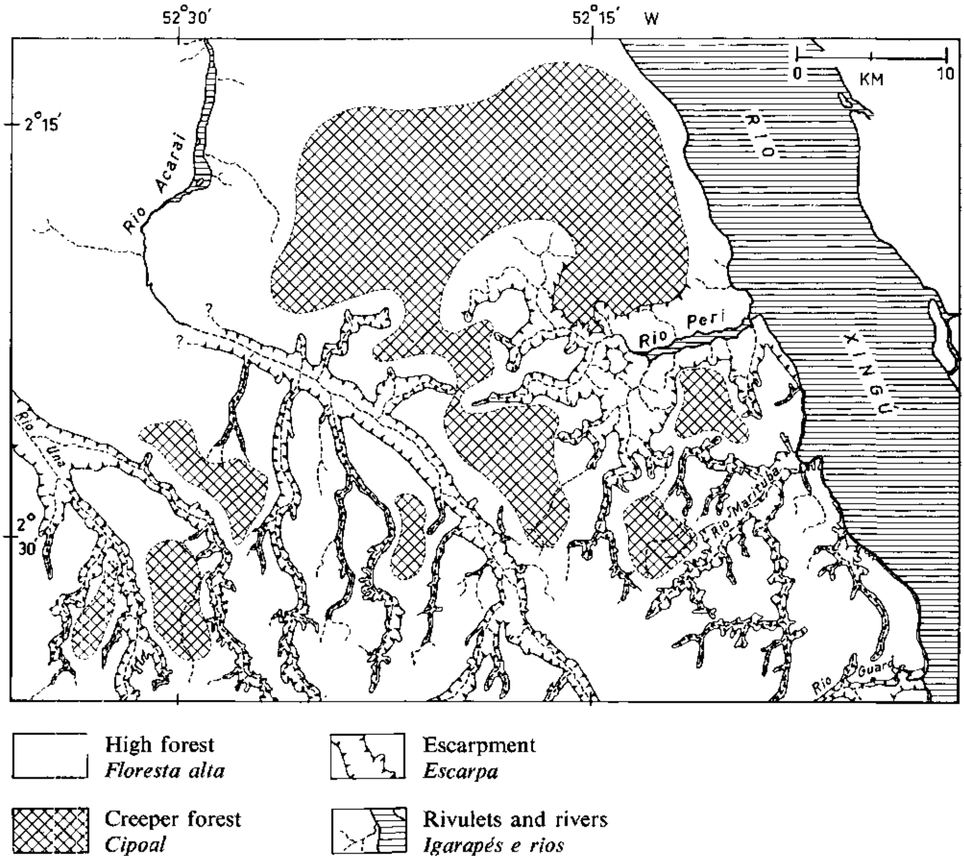


Fig. 24 Creeper vegetation in the region east of the lower Xingú river. From HEINSDIJK (1957)

imperfectly drained Planície soils (Ground Water Laterite soil, Ground Water Podzol) is considerably lower. Large stretches with these soils even have a coverage of savannah-forest (with DBH of the trees supposedly all smaller than 0.25 m) or of savannah. It is stipulated that the situation is different for the freely draining soils with fossil plinthite, though they are genetically related to the Ground Water Laterite soils. The soils in question, classified as Kaolinitic Yellow Latosol, Concretionary phase (KYL, CR) or Red Yellow Podzolic soil, intergrading to Kaolinitic Yellow Latosol, Concretionary phase (RP-KYL, CR), have on the average a *not* lower timber volume than adjoining non-plinthitic freely draining soils, except in the rare cases when practically no earth is present between the concretions.

Considerable differences in gross timber volume may occur on the various soils outside the Planície part of Amazonia. This is already evident from qualitative observations in the Araguaia Mahogany area (*cf.* GLERUM and SMIT (1962b) and Appendix 6).

Measurements of mean gross timber volume were however not executed for those areas.

IV.1.2.3 *Soils and Occurrence of Individual Tree Species*

Several tree species are found only in a part of the hileia-covered area. In the introduction to the present chapter it was stated that the study of the causes of established differences in the occurrence of a certain tree species is a complex one. Some of the differences are believed to be related to the non-edaphic factors climate and man (*cf.* IV.1.1). To say that the others are related with soil differences is however an oversimplification. A typical controversial species is the *Acapú (Vouacapoua americana)*. This tree, rendering much-used timber, is a conspicuous under-storey tree. It occurs usually in colonies, of varying size. Averaged over larger areas the species can occupy as much as 10% of the total number of trees (*cf.* HEINSDIJK, 1957, 1960). On the south side of the Amazon river the tree is found only east of the tributary Curuá-una; it forms there one of the distinguishing features between the Planalto I and Planalto II inventory units. Its eastern boundary of occurrence is formed by the middle reaches of the rivers Capím and Guamá, where the species forms one of the distinguishing features between the inventory units Capím and Acará, and Candirú and Santana respectively. At the North side of the Amazon river the tree is found, according to DUCKE and BLACK (1954), only east of the large tributary Trombetas. The species is also found in Surinam and there known as *Bruinhart*. SCHULZ (1960) studied some soils in the Mapane region of this country, where the tree is found in some sharply delimited stands and then occupies 1/6–1/3 of the total canopy. Several analytical data of three profiles taken in such stands were, when averaged, slightly different from those of profiles in adjacent non-*Bruinhart* containing forest (the soil on both sites is red coloured, kaolinitic, and predominantly medium textured). SCHULZ deduced from these soil data that the uneven occurrence of the species in the Mapane region is determined by soil factors.

For the Curuá-una – Xingú region of Amazonia, HEINSDIJK (1957) noted that the species is present in large numbers on the planalto, on the clayish parts of the slopes of the planalto, and on clayey terrains near the rivers. Kaolinitic Yellow Latosol, heavy or very heavy textured (KYL_h, KYL_{vh}) are involved, which soils are also found west of the Curuá-una, on identical topographical units. HEINSDIJK states also that 'the colonies of Acapú never appear on sandy soils'.

The author studied the growing site of the species in the area of the Santana unit of the Guamá-Imperatriz area. Colonies of the tree were found to occur here, equally frequently, on all the soils of the area, for instance on the very common Kaolinitic Yellow Latosol, medium textured (KYL_m), the few patches of Kaolinitic Latosolic Sand (KLS), the scattered Red Yellow Podzolic soil, intergrading to Kaolinitic Yellow Latosol, Concretionary phase (RP-KYL, CR) whether with the common Mãe do Rio type of plinthite concretions or with the less frequent Ipixuna type.

The Amazon data therefore do not suggest a consistent coincidence with a certain soil. There are no indications that the climatic conditions of the Planalto I area are different from those on the Planalto II area. The same is most probably true of the areas of the inventory units in the region of the eastern limit of occurrence of the species. One likely explanation for the absence of *Acapú* west of the Curuá-una and east and south of the middle reaches of the Guamá and the Capím is that the species still has a limited historical dispersion (SCHULZ states that *Bruinhart* grows very slowly and that its heavy seeds need to be pressed into the ground to germinate). Some support for this supposition is given by the fact that in the southern part of the area of the Santana inventory unit, which is a boundary area for the species, the colonies of *Acapú* are infrequent, small, and consisting of small trees.

SOIL TEXTURE

Since soil textural differences are rather easily noticed by non-pedologists, the forest inventorists paid attention to a possible coincidence of soil texture differences and differences in occurrence of tree species. As to the Planície (inventory units 1–15, *cf.* Fig. 22), HEINSDIJK (1957, 1960) reports that tree species found more abundantly on light textured soils are *Axuá (Sacoglottis guianensis)*, *Angelim rajado (Pithecolobium racemosum)*, *Faveira bolacha (Vatairea cythrocarpa)*, *Jutaí-mirim (Hymenaea parvifolia)*, *Itauba (Mezilaurus itauba)* and *Macucú (Licania macrophylla)*. Species found regularly on heavy textured soils, and not or only in very small numbers on sandy soils are *Ingá (Inga alba)*, *Tauarí (Curatari spp.)*, *Castanheira (Bertholletia excelsa)* and *Ucuuba (Virola cuspidata, Virola cebifera)*.

It was not possible to check in the field if this is indeed a general rule, which also applies to the Guamá-Imperatriz area. A comparison in the office of inventory data and soil data of this area did not give any clear indications.

One of the species that is easily noticed in the field by non-botanists, is the *Angelim pedra (Hymenolobium excelsum)*. This is a conspicuous upper-storey tree, normally occupying less than 0.5 %, averaged over larger areas, of the total number of trees. In the Guamá-Imperatriz area its occurrence is restricted to the area of inventory unit Ligação. It was found that the tree is concentrated on the Kaolinitic Yellow Latosol, very heavy textured (KYL_{vh}) of the very gently sloping edges of planalto. Elsewhere the tree occurs practically only, and less frequently, on very heavy textured soils at a lower level than the planalto. These are Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol, very heavy textured ($RP\text{-}KYL_{vh}$), and, locally, Kaolinitic Yellow Latosol, very heavy textured (KYL_{vh}). The species is not found on the flat centres of planalto (also with KYL_{vh}), nor on terrains with reworked Belterra clay north of km 195, which have Kaolinitic Yellow Latosol, Compact phase, very heavy textured ($KYL,\ c_{vh}$). These are sites of cipoal or 'cipoalic forest' as already described.

The apparent concentration of the species on very heavy textured soils in those parts where the forest is not 'cipoalic', nor where climatic conditions are adverse (the latter in the area of inventory unit Açailândia), is more or less in agreement with observations in the Tocantins-Xingú region. HEINSDIJK (1957) states that '*Angelim pedra* is... found in patches on the planalto (not on planalto de Santarém) in the highest parts of the forest. Found occasionally on the higher parts of the slopes, prefers clayey soil'.

It should be borne in mind that an established predominance of a certain species on sandy soil as against on clayey soil, does not necessarily mean that the species finds better absolute growing conditions on the former. It may well be that the species is less frequently found on clayey soil only because it falls short in competition force with other species there. HEINSDIJK (1960) even states 'all observations confirmed the fact that a tree species growing on sandy soil was, on an average, always smaller and gave a much poorer impression than the same species growing on heavier soils'.

PLINTHITE CONCRETIONS

That the occurrence of a tree species may coincide with the presence of fossil hard plinthite concretions of a certain type, became apparent during the combined forest inventory – soil survey of the Guamá-Imperatriz area. The valuable timber rendering *Pau amarelo (Euxylophora paraensis)*, which species only occurs in the Atlantic sector of the hileia, above Maranhão (DUCKE and BLACK, 1954), seems to have its maximum frequence in the middle reaches of the river Capím. It is a low branching tree and occupies maximally 1 %, averaged over larger areas, of the total number of trees in the forest. Within the Guamá-Imperatriz area, the species was not measured in the areas of the Santana, Médio Guamá and Açailândia inventory units. The species occurs relatively frequently in the Candirú unit (4.0 m^3/ha timber volume), and sparsely in the Alto Guamá unit (0.6 m^3/ha). During the field work in the area of the Candirú unit, it was observed that the tree is concentrated in the uppermost reaches of the rivulets. In view of this, one small part was studied in detail. It is located within the area of the Candirú unit, but near the boundary with the Alto Guamá unit, namely at km 130. A semi-detailed soil survey was executed, while the forest inventorists made a 10% survey of the *Pau amarelo*. The results are shown on Appendix 3 (only those *Pau amarelo* trees were enumerated that are within 10 m distance of all latitudinal traverses and the outer and innermost longitudinal traverses of each block, and within 5 m distance of the other longitudinal traverses). From this map it is apparent that the species is concentrated on the slopes and the approximately flat edges of the upper terrace, where plinthite concretions are frequent. The soil on these sites is classified as Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol, Concretionary phase (RP-KYL, CR). The concretions are all of the Ipixuna type (*cf.* I.4.5). A few trees are found on Red Yellow Podzolic Soil, intergrade to Kaolinitic Yellow Latosol, very heavy textured ($RP\text{-}KYL_{vh}$), which occurs locally alongside the concretionary parts. *Pau amarelo* is absent, or practically absent, on the Kaolinitic Yellow Latosol, Compact phase, very heavy textured (KYL, C_{vh}) that has developed on the reworked Belterra clay of the central parts of the upper terrace, as well as on the Kaolinitic Yellow Latosol, intergrade to Red Yellow Podzolic soil, rather heavy textured ($KYL\text{-}RP_{rh}$) of the second terrace (with the highest gross timber volume!), and on the soils of the lowland stretches.

The coincidence is only true of one type of concretions. In the area of the Santana inventory unit, many parts have RP-KYL, CR soil, but usually with concretions of the

Mãe do Rio type. Here no *Pau amarelo* trees were enumerated by the forest inventorists. In fact, some *Pau amarelo* do occur in the southern part of this area, as well as in a few parts of the area of the Médio Guamá unit, but the trees fell outside the inventory sampling units. It was observed that in these places they are growing invariably on RP-KYL, CR soil with Ipixuna type concretions, not on RP-KYL, CR with Mãe do Rio type concretions. A few trees were found on RP-KYL$_{vh}$ soil.

Also the few *Pau amarelo* trees in the area of the Alto Guamá inventory unit were found to occur either on soils with Ipixuna type concretions, which in this area are only very locally present at the surface, or on RP-KYL$_{vh}$. The situation is somewhat different further southward in the Guamá-Imperatriz area, in the area of the Ligação inventory unit. There the tree is found too, down to km 315, but in relatively small numbers. South of km 260 the Ipixuna type concretions give way to the Ligação type concretions, which have the same relative position and age as the Ipixuna ones (*cf.* I.4.5). The species occurs on the soils with either of these types. In the northernmost part of the area with this unit, namely at km 195, another small tract was studied in semi-detail. The terrain is this tract consists essentially of 1) an upper terrace (planalto), which can be divided into totally flat central sections, and very gently sloping edges, and 2) very sloping terrain, below the level of the planalto, usually with plinthite concretions, of the Ipixuna type. The *Pau amarelo* of the surveyed block is found concentrated on the strongly sloping terrain, as well as on the gently sloping edges of planalto. The flat central sections of planalto have a 'cipoalic forest' (see before), without the species. The soil of the strongly sloping terrains is classified as Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol, Concretionary phase (RP-KYL, CR-Ipixuna). That of the edges of planalto is classified as Kaolinitic Yellow Latosol, very heavy textured (KYL$_{vh}$), which is also the soil of the central sections. Ipixuna type concretions are not found at the surface of the planalto edges, yet *Pau amarelo* is present. Also elsewhere in the area of the Ligação unit, the species is not restricted to the places with Ipixuna type *c.q.* Ligação type concretions. The tree also occurs on the very gently sloping concretionless terrains with KYL$_{vh}$ or RP-KYL$_{vh}$ profile, even where these terrains are at a considerably lower level than the planalto.

It may be noted that Ligação type concretions and gently cloping terrains with KYL$_{vh}$ occur also in the area of inventory unit Açailândia, which lacks *Pau amarelo*. In this stretch however, the climate is believed to be too dry for this and several other species (*cf.* IV.1.1).

Combining these observations, it can be said that in the Guamá-Imperatriz area *Pau amarelo* occurs predominantly on soil with Ipixuna type *c.q.* Ligação type concretions (RP-KYL, CR-Ipixuna; RP-KYL, CR-Ligação) and, to a lesser extent, on very heavy textured soil (KYL$_{vh}$ and RP-KYL$_{vh}$) where this occurs on gently sloping terrain, *i.e.* when the forest is not 'cipoalic'. The optimal growing conditions for the species are apparently found on the concretionary soils classified as RP-KYL, CR-Ipixuna (respectively Ligação), but the species can spread to the mentioned very heavy textured soils. The latter are located always near the concretionary soils.

Table 12 Comparison of chemical data of soils with and without Pau amarelo (Euxylophora paraensis)

No. field descr. / *descr. de campo*	Classification (*cf.* Table 9) / *classificação (cf. Tabela 9)*	Location / *locação* BR-14	Clay / *argila* (%)		Cation exch. capac. / *capacidade de troca* (m.e./100 g) T		pH–H_2O		Exchangeable metallic cations / *bases trocáveis* (m.e./100 g) Ca^{++}		Mg^{++}	
			a	b	a	b	a	b	a	b	a	b
SOILS WITH PAU AMARELO/*solos com Pau amarelo*												
202	RP-KYL, CR (Ipixuna)	km 109.6	54.3	59.9	13.07	2.91	4.5	5.2	0.66	0.18*	2.11	0.18*
216	KYL*vh*	km 291.3	69.8	90.8	13.20	3.88	5.0	5.2	3.08	0.33*	2.28	0.33*
236	RP-KYL*rh*	km 232.0	63.0	83.5	11.26	3.31	4.2	4.5	0.41	0.24*	0.72	0.24*
204	RP-KYL*vh*	km 172.0	26.7	55.9	10.83	3.28	4.0	4.8	1.08	0.35*	0.75	0.35*
SOILS WITHOUT PAU AMARELO/*solos sem Pau amarelo*												
238	RP-KYL, CR (Mãe do Rio)	km 43.8	21.9	55.6	9.29	3.31	4.7	4.5	1.98	0.24*	0.84	0.24*
205	RP-KYL, CR (Paragominas)	km 175.6	17.1	52.7	12.82	3.65	4.1	4.7	1.39	0.24*	1.00	0.24*
201	KYL-RP*rh*	km 117.0	13.7	32.2	5.83	2.72	4.1	4.7	0.46	0.20*	0.36	0.20*
197	KYL-RP*rh*	km 136.0	33.1	63.2	11.01	3.15	3.9	3.9	0.33	0.20*	0.10	0.20*
210**	KYL*vh*	km 247.0	74.6	88.5	14.86	4.56	4.0	4.7	0.87	0.25*	0.98	0.25*
230**	KYL, C*vh*	km 178.8	60.3	84.5	9.99	4.25	4.4	4.8	1.11	0.26*	0.80	0.26*
208**	KYL, C*vh*	km 69.0	77.2	90.3	19.46	2.92	4.0	4.7	2.52	0.25*	0.69	0.25*
194	KYL, C*rh*	km 63.0	14.9	35.3	4.16	2.94	4.3	5.0	0.27*	0.48*	0.27*	0.48*
242	RP-KYL*rh*	km 256.6	13.2	48.1	6.08	2.42	4.1	4.6	0.31*	0.16*	0.31*	0.16*
237	RP-KYL*rh*	km 205.8	14.6	42.9	5.51	2.15	4.3	4.5	0.21*	0.29*	0.21*	0.29*
233	KYL*m*	km 12.7	6.7	19.8	4.20	1.99	4.6	4.5	0.24*	0.14*	0.24*	0.14*
231	KYL*m*	km 58.0	17.9	23.9	4.90	2.14	4.6	5.1	0.15*	0.15*	0.15*	0.15*
206	KYL*m*	km 201.0	7.3	19.8	5.40	2.33	4.0	4.3	0.32*	0.32*	0.32*	0.32*

* ½ (Ca^{++} + Mg^{++}) the half of jointly determinded bivalent cations
a metade dos cations bivalentes determinados em conjunto
** cover of cipoal or 'cipoalic forest'/*cobertura de cipoal ou floresta cipoálica*

Any special soil qualities related with very heavy texture cannot be the conditioning factors for the occurrence of the species because the RP-KYL, CR soil sometimes falls into other texture classes. Special rooting possibilities are unlikely to be involved, because both the RP-KYL, CR-Ipixuna and the RP-KYL$_{vh}$ have a rather firm and compact subsoil, whilst the KYL$_{vh}$ is deeply friable and porous. Probably, the species requires a high content of a certain (micro) nutrient, or a specific balance of nutrients. Comparison of analytical data does not give a congruent difference between *Pau amarelo* bearing and non-*Pau amarelo* bearing soils (*cf.* Table 12). It is, however, quite possible that a more refined and elaborate chemical analysis, and/or mineralogical analysis, would reveal a correlation. The plinthite concretions themselves may provide the specific chemical qualities of the soils, or the fossil soft plinthite often associated. As discussed in I.4.5. both are related to a land surface of Late Pliocene age, composed of the upper strata of the Barreiras or Alter do Chão beds. The Belterra clay, which forms the parent material of the non-concretionary very heavy textured soils, was deposited right on top of this, in a time immediately following (Plio-Pleisto-

Tabela 12 Comparação de dados químicos de solos com e sem Pau amarelo (Euxylophora paraensis)

Exchangeable metallic cations *bases trocáveis* (m.e./100 g)				Active acidity *acidez ativa* (m.e./100 g)		Available P_2O_5 *assimilável* (mg/100 g)		P_2O_5 total		Org. C		N total		C/N		P-total / 100 N		P-total / C	
K^+		Na^+		$(Al)^+$		P-Bray													
a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
0.25	0.08	0.11	0.04	1.20	0.24	1.5	0.1	60	50	3.44	0.13	0.32	0.03	10.8	4.3	1.87	16.6	17.5	384
0.22	0.08	0.08	0.04	0.29	0.33	0.9	0.1	60	50	3.60	0.50	0.34	0.07	10.6	7.1	1.76	7.0	16.7	100
0.21	0.10	0.10	0.03	1.74	0.66	1.9	0.1	60	40	2.99	0.50	0.26	0.05	11.5	10.0	2.30	8.0	20.0	80
0.17	0.07	0.07	0.07	1.55	0.41	3.1	0.2	40	40	2.78	0.37	0.23	0.05	12.1	7.4	1.74	8.0	14.4	108
0.25	0.11	0.08	0.08	0.53	1.59	3.4	0.2	50	50	2.75	0.17	0.25	0.02	11.0	8.5	2.00	25.0	18.2	294
0.17	0.10	0.06	0.03	1.10	0.73	3.7	0.2	50	80	3.63	0.29	0.25	0.04	14.9	7.3	2.00	20.0	13.8	276
0.11	0.06	0.05	0.03	0.89	0.49	2.7	0.2	30	30	1.20	0.16	0.11	0.03	11.0	5.3	2.71	10.0	25.0	188
0.10	0.06	0.05	0.02	2.16	1.54	1.4	0.2	30	30	2.45	0.29	0.22	0.06	11.1	4.8	1.36	5.0	12.3	103
0.26	0.12	0.07	0.03	2.16	1.07	1.2	0.2	50	30	3.61	0.69	0.33	0.08	10.9	8.6	1.52	3.8	13.8	44
0.12	0.13	0.08	0.06	0.95	1.03	2.5	0.2	80	60	2.59	0.63	0.30	0.08	8.6	7.9	2.76	7.5	30.8	95
0.33	0.11	0.10	0.05	2.37	0.62	2.5	0.1	70	60	5.17	0.42	0.44	0.07	11.8	8.4	1.46	8.5	13.5	146
0.11	0.09	0.08	0.08	0.72	0.24	1.2	0.2	30	30	0.65	0.25	0.06	0.03	10.8	8.3	5.00	10.0	46.2	120
0.06	0.07	0.04	0.04	0.89	0.52	2.2	0.1	30	30	1.37	0.38	0.12	0.04	11.4	9.5	2.50	7.5	21.9	79
0.08	0.08	0.03	0.03	0.93	0.36	1.7	0.1	30	30	1.39	0.20	0.11	0.02	12.6	10.0	2.72	15.0	21.3	150
0.06	0.07	0.03	0.03	0.72	0.64	1.1	0.2	30	30	0.88	0.18	0.06	0.02	14.7	9.0	5.00	15.0	34.0	167
0.08	0.07	0.04	0.03	1.08	0.53	1.2	0.4	30	30	0.87	0.22	0.09	0.03	9.7	7.3	3.32	10.0	34.4	136
0.10	0.08	0.03	0.02	0.81	0.56	1.7	0.1	20	20	1.23	0.19	0.08	0.03	15.4	6.3	2.50	6.7	16.3	105

a = topsoil (A_1 horizon, or A_{11} when the former is subdivided)
solo superficial (horizonte A_1, ou A_{11} quando o primeiro está subdividido)
b = subsoil (B_2 horizon, or B_{21} when the former is subdivided)
subsolo (horizonte B_2, ou B_{21} quando o primeiro está subdividido)

cene). A peculiarity in parent material, related with these geologic times, is probably responsible for the uneven occurrence of the *Pau amarelo* in the Guamá-Imperatriz area.

THE ECO-SITE OF MAHOGANY

It is to be expected that detailed studies outside the Planície part of Amazonia, where the soils vary considerably both chemically and physically, will result in the establishment of more and more definite coincidences between soil and occurrence of individual tree species than in the Planície itself. DUCKE and BLACK (1954), for instance, report that on patches with 'Terra Roxa-like' soil, developed from diabase, the forest cover has a floristic composition distinctly different from that on adjacent soils. On this relatively rich soil, more soft wooded tree species would be present.

The growing site of one tree species of the non-Planície part of Amazonia, namely the very valuable *Mahogany (Mogno: Swietenia macrophylla)*, was studied in some detail, namely in the so-called Araguaia Mahogany area (*cf.* Appendices 2 and 6). This area is located in the transition zone between the Amazon hileia and the savannahs of North-Eastern Brazil. It has a tropical humid climate with a pronounced dry season (*Aw* in Köppen's classification, *cf.* Fig. 2). In the western part of the area, the Pre-Cambrian crystalline basement outcrops; east of this, strips of Palaeozoic and Mesozoic deposits occur (Devonian, Carboniferous, Permean, Jurassic, Triassic), which belong to the sedimentary basin of Maranhão (*cf.* Appendix 8). Locally, Quaternary sediments are present.

The following summarizes the field data of the combined forest inventory – soil survey executed in this area:

1. Mahogany is absent in the areas of the mapping units with savannah cover, being L, QU and KLS, S. Also the mapping units L, SS and KLS, T, covered with low and high shrub vegetation respectively, lack mahogany.
2. The species is very sparsely present in the area of mapping unit DL, S + AF, G, as well in that of mapping unit L, CH.
3. Low, thin and stunted mahogany trees are found scattered in the area of the mapping unit with Hydromorphic Grey Podzolic soil, with high base saturation, Shallow phase (HP_{hb}, S; Profile 46) which has a general vegetative cover of hydromorphic deciduous shrub.
4. Small quantities of mahogany are present in the area of mapping unit KLS, F, which is under forest cover. Here, the tree is found in the transition strips between the dry-land and the bottom lands, which usually have deep Ground Water Humus Podzol (GP). It is also found on the narrow strips of lowland along the rivulets included in the mapping unit and having Low Humic Gley soil (LHG). The tree does not occur regularly on all sites with these soils, but only locally. The impression is that these localities have relatively rich ground water, namely that coming from nearby calcareous deposits (cherts with lime-stone).

The mahogany trees found in the area of this mapping unit can become very big, namely up to diameter class 15[1].

5. The floodplain and lowland soils of considerable extent are mapped under unit F. Those along the river Araguaia proper, which are either Alluvial soil (A) or Low Humic Gley soil (LGH), have no mahogany in their vegetative cover, which is often a creeper forest. Those along the tributaries, which are Low Humic Gley soil (LHG), have mahogany only locally. As in the case of those mapped under KLS, F (see 4), the impression is that these localities have relatively rich ground water, in this case coming from nearby located cherts with lime-stones, and calcareous and gypsiferous silt and clay-stones.
6. Mahogany is found in rather small quantities in the area of mapping unit RP_{rhb}. Within this area, the tree is growing predominantly in the narrow strips of lowland along the rivulets, with Ground Water Laterite soil, intergrade to Hydromorphic

[1]) Diameter class 0 stands for 0–4 cm DBH (diameter at breast height), diameter class 1 stands for 5–14 cm DBH; diameter class 2 for 15–24 cm DBH, 3 for 25–34 cm DBH, etc.

Fig. 25 Tipos de floresta e solos na área Araguaiana de Mogno; levantamento 100% do Mogno num blôco de 200 ha (para a legenda veja página 205 e seq.)

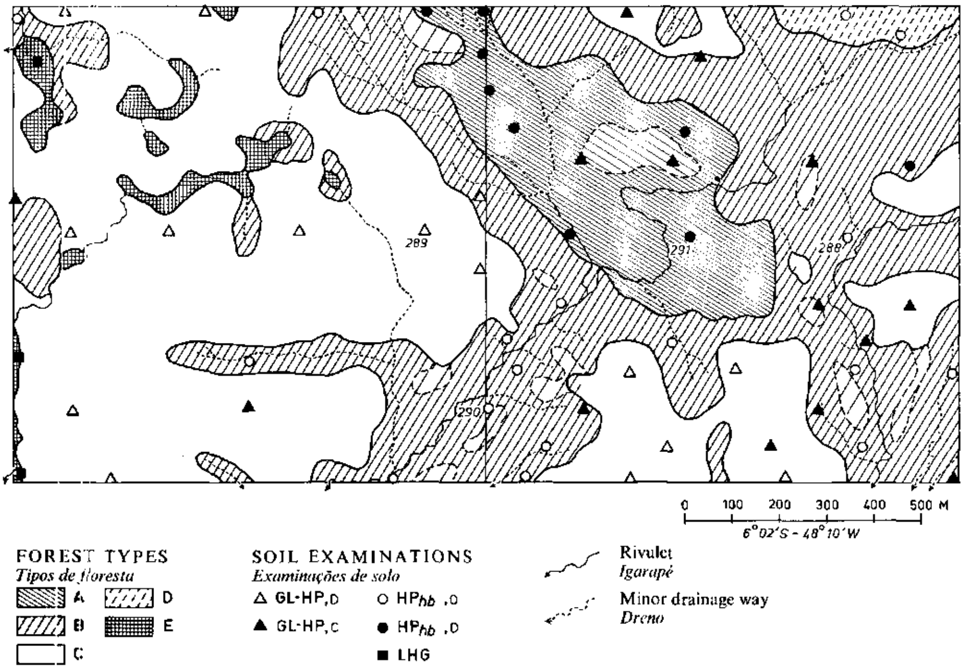


Fig. 25 Forest types and soils in the Araguaia Mahogany area; 100% survey of mahogany in a 200 ha block (for the legend see page 205 seq.)

Grey Podzolic soil, Micaceous phase (GL-HP, M; Profile 16). The tree is found also where greenish-black, hard schists (epidote and biotite schists) outcrop or nearly outcrop, whether on the strips of lowland or on the undulating to rolling upland. The size of the mahogany trees in this area can be very large, up to diameter class 15.

7. The bulk of the mahogany of the survey area is found in the area of mapping unit H, Hydromorphic soils undifferentiated, where the land is extensively flat. The mahogany is not spread regularly over all the land concerned, but concentrated in large patches where the tree is often the predominant constituent of the canopy: *canteiros de mogno*. A detailed survey of a 200 ha block within this area was executed to determine which of the various hydromorphic soils support mahogany (*cf.* Fig. 25; for the mahogany inventory map of this block, *cf.* GLERUM and SMIT, 1961; or SOMBROEK and SAMPAIO, 1962). The results of this survey are as follows:

A. *Forest of small-sized mahogany.* Low, rather open canopy, consisting almost exclusively of low, thin (largely diameter classes 2, 3 and 4) and stunted mahogany trees; high, fairly dense undergrowth, with many thin creepers or climbers; rather closed field layer. This is found on Hydromorphic Grey Podzolic soil, with high base saturation, Dark phase (HP_{hb}, D; Profile 45, see also Photo 23).

Foto 23 O micro-relêvo de canaletes e a zona herbácea e subarbustiva dos solos em que ocorre freqüentemente o Mogno. Os terrenos relativos são extensamente planos e de drenagem imperfeita. O solo è 'Hydromorphic Grey Podzolic', *com saturação de bases alta. À direita e ao centro no fundo há dois mognos pequenos. Além das palmeiras, estas espécies formam pràticamente as únicas que constituem o dossel (área Araguaiana de Mogno, Bloco Piranha)*

Photo 23 The micro relief of canaletes *and the field layer of the soils on which mahogany is of frequent occurrence. The terrains concerned are extensively flat and imperfectly drained. The soil is a Hydromorphic Grey Podzolic soil, with high base saturation. On the right and at centre-background are two stunted mahogany trees. Apart from palms, this species forms practically the only constituent of the canopy (Araguaia Mahogany area, Bloco Piranha)*

B. *Forest of normal-sized mahogany.* High, almost closed canopy, consisting for a good part of medium-sized (diameter classes 4 to 7) mahogany trees, in a much more open pattern than in the forest type A; high, only fairly dense undergrowth, with rather few creepers or climbers; open field layer. This vegetation is found predominantly on Hydromorphic Grey Podzolic soil, with high base saturation, Ortho (HP_{hb}, O; Profile 44)[1], but also on Ground Water Laterite soil, intergrade to Hydromorphic Grey Podzolic soil, Clay-stone substratum phase (GL-HP, C; Profile 15). The latter soil however is commonly found on the edges of the terrain with this forest type, or on small, encircled patches with less mahogany (interrupted shading on the map; also applying to a central patch within the area of forest type A).

[1]) A patch of this soil, at a corner of the surveyed block, has a coverage of dense shrub forest without mahogany (D). It is supposed that former fires and/or very imperfect drainage is the cause for this deviating vegetation type.

C. *'Cipoalic' forest.* High, rather open canopy, consisting of several tree species and comparatively many palms, but rarely with mahogany; high, fairly dense undergrowth with common and rather thick creepers or climbers, and a frequent occurrence of high *Sororoca (Ranavalia guianensis)*; open field layer. This is found on Ground Water Laterite soil, intergrade to Hydromorphic Grey Podzolic soil, Deep phase (GL-HP, D; Profile 14), and also on Ground Water Laterite soil, intergrade to Hydromorphic Grey Podzolic soil, Clay-stone substratum phase (GL-HP, C; Profile 15).

E. *Cipoal* (creeper forest). Little or no canopy, and without mahogany; dense undergrowth, largely consisting of thin creepers or climbers; open field layer. This vegetation type is found on poorly drained patches, with Low Humic Gley soil (LHG).

From these data it becomes evident that in the surveyed area, mahogany grows very predominantly on terrains with an imperfect drainage, with well developed hydromorphic soils. The occurrence of mahogany is not general on these terrains, but concentrated on a few specific hydromorphic soils, on which the species occurs either scattered or in a dense pattern, remains either low, thin and stunted, or attains medium and in some parts large diameters.

The tree occurs scattered in the strips of lowland, with GL-HP, M soil, of the area where the Pre-Cambrian crystalline basement (serie Araxá) outcrops. The tree occurs in a dense pattern on extensively flat terrains with HP_{hb}, O and HP_{hb}, D soils. These soils have developed from gypsiferous and calcareous silt and clay-stones which belong most probably to the Motuca member of the Pastos Bons beds, of Jurassic-Triassic age (Piauí beds of the Upper Carboniferous according to other geologists). Where the tree occurs outside these terrains it is usually where the ground water is rich (high pH), or where rich rock (epidote and biotite schists) outcrops.

The frequented hydromorphic soils (Profile 16, and especially the profiles 44 and 45) are all relatively rich. They have silicate clay minerals of the 2:1 lattice structure; the base exchange capacity is relatively high (25–35 m.e./100 g clay, after correction for the organic matter content); the base saturation is medium, and in the subsoil high; Ca^{++} is the predominant exchangeable cation, but also exchangeable Mg^{++} is present in considerable quantities, especially in the GL-HP, M.

The HP_{hb}, O and HP_{hb}, D soils have a high pH in their deeper subsoil (6–8). In this subsoil, free anions, namely sulphates, carbonates, and/or chlorides are present. It is quite possible that these anions, especially the sulphates, are the conditional factor for the peculiar abundancy of mahogany on the soils. But the field and laboratory data on mahogany and non-mahogany soils of the area are too few to allow definite conclusions.

The differences in size and density of the species, particularly of the mahogany on the HP_{hb}, O and HP_{hb}, D soils respectively, warrants discussion. A likely explanation is that on the HP_{hb}, D soil, with its rich subsoil near the surface, the conditions for regeneration are better, but full development of the trees is hampered by the very poor physical qualities of the soil, which restrict root penetration. Support for this supposition is found in the scattered occurrence of small sized mahogany on the Hydromorphic Grey Podzolic soil, with high base saturation, Shallow phase (HP_{hb},). The rich subsoil of this is also rather shallow, and it possesses extremely poor physical qualities, resulting in a general cover of hydromorphic deciduous shrub. That the scattered mahogany in the areas of mapping units RP_{rhb} and KLS, F can attain a bigger size than on the HP_{hb}, O is probably explained by taking into account that in these areas the physical qualities of the soils concerned are generally better.

PALMS

The occurrence of palms in the Amazon forests seems to be, in general, more related with the variations in climatic and soil conditions than that of many dicotylenous tree species. AUBREVILLE (1958) obtained the impression that every region, and every milieu of the hileia, has its characteristic large palms. Since most palm species are comparatively easily noticed and identified, they may therefore be suitable indicator plants for vegetation types and soil units. Quantitative data on occurrence of palms are not available. The growing sites of several species of the uplands, particularly *Tucumá*, *Babaçú*, and *Bacaba* have however been examined to a degree.

The *Tucumá (Astrocaryum vulgare)* seems to be concentrated on sandy, low uplands where a shallow ground water level occurs. The palm is, for instance, characteristic of the sandy Ground Water Laterite soils of the eastern part of Marajó-island, whether under savannah or forest.

The commercially valuable[1] *Babaçú (Orbignia speciosa)* is often a main constituent of the palm forests in the transition zone between the hileia and the savannahs of North Eastern Brazil. The southern most part of the Guamá-Imperatriz area contains an extremity of this *zona de cocais*. The *Babaçú* there was found to be concentrated, in a dense pattern, on comparatively fertile soil. This is the Red Yellow Mediterranean-like soil, (RM; *cf.* Appendix 1 and Profile 41) which has developed on silt-stones and shales of the Cretaceous Codó beds. Also in the Araguaia Mahogany area the *Babaçú* is encountered. The palm occurs there, fairly frequently, on Red Yellow Podzolic soil, with rather high base saturation (mapping unit RP_{rhb}; *cf.* Appendix 2). It is also frequent on the highest parts of the floodplain of the Araguaia river proper (mapping unit F), which have Alluvial soil (A) consisting of very micaceous silty sands. The palm has a scattered occurrence in the area of the association of Dark Red Latosol, Shallow phase and Acid Brown Forest-like soil, Gravelly phase (DL, S + AF, G). On Lithosol, Quartzite substratum phase (L, QU) and Lithosol, Sand-stone substratum phase (L, SS) the species only occurs locally. The species is absent in the areas of the other mapping units, where the soils are well-drained but poor (Kaolinitic Latosolic Sand, Forest phase; KLS, F), or imperfectly drained and relatively rich (Hydromorphic soils, undifferentiated; H). The palm therefore is confined to the western part of the survey area. It occurs on soils developed on the Pre-Cambrian crystalline basement

[1]) Stands of *Babaçú* are often denser where under human influence, owing to repeated burning of the vegetation between the palms, which themselves are fire-resistant, and to some enrichment planting.

(mica schists, quartzites) or on Devonian-Carboniferous deposits (shales, sand-stones, silt-stones), as well as on young, moderately well-drained soils from recent sediments (micaceous silty sands).

The above data suggest that the *Babaçú* predominates on relatively fertile soils with free or almost free drainage, which may vary in depth and structure. It is, however, quite possible that in the area of maximal occurrence of the species, which is the northern part of the State Maranhão, the palm is less exacting as to soil conditions.

Contrary to the *Babaçú*, the *Bacaba* palm *(Oenocarpus bacaba)* seems to grow predominantly on well-drained, poor sandy soil, in particular on Kaolinitic Latosolic Sand. In the Araguaia Mahogany area at least, this palm is fully confined to the Kaolinitic Latosolic Sand, Forest phase (KLS, F; *cf.* Appendix 2). In the axial part of Amazonia also, this palm species is found particularly on the same type of soil. A palm species not selective as regards soil conditions seems to be the *Inajá (Maximiliana regia)*. In the Araguaia Mahogany area the species is found on practically all encountered soils, except those of the savannahs proper.

IV.2 The Uplands with Savannah or Savannah-Forest Cover

A number of places on the uplands have a coverage of savannah or savannah-forest, instead of forest. These vegetation types are defined and described in I.5.2. As possible causes of the occurrence of the savannahs and savannah-forests the following should be considered:

1. Local unfavourable climatic conditions, especially as regards relatively low total annual rainfall and/or a relatively long and pronounced dry season.
2. Local marked influence of man, especially as regards repeated felling, repeated burning, and animal husbandry.
3. Local unfavourable edaphic conditions. This applies especially to the effective soil moisture reserve for the period of the year that the evapo-transpiration from a forest coverage would exceed the precipitation (dry season or less rainy period).

Effective soil moisture reserve can be insufficient for various reasons:

1. There may be a very low moisture storage capacity per unit of soil material. For this reason very sandy soils, even when they can be deeply penetrated by roots, can be short of a sufficient soil moisture reserve for forestgrowth.
2. The rooting space may be small, because of a small amount of soil material. On very stony soils, and on very shallow soils upon impermeable bedrock, the total stored moisture may be too small to carry a forest coverage through the dry period, even when the storage capacity per unit of earth is high.
3. There may be intermittently imperfect drainage. A shallow ground water level during the rainy season greatly restricts the depth of penetration of the roots. If on such a site the ground water level drops considerably during the dry season, then the short roots loose contact with it, and the moisture reserve in the rooted layer alone is too small to sustain forest growth.

Table 13 The savannahs and savannah-forests of Amazonia, in their dependence upon edaphic and non-edaphic factors

Land form *constituição da terra*	Drainage condition *condição de drenagem*	Soil *solo*
Parts of Early Pleistocene terraces *partes de terraços do Pleistoceno Inferior*	excessively drained *drenagem excessiva*	White Sand Regosol (Giant Podzol) *Regosolo de Areia Branca (Podzol Gigante)*
Undulating or mountanous terrains outside Planície *terrenos ondulados ou montanhosos fora da Planície*	well-drained *bôa drenagem*	Lithosol *Litosolo*
Pleistocene terraces *terraços do Pleistoceno*	well-drained *bôa drenagem*	Kaolinitic Yellow Latosol Kaolinitic Latosolic Sand *Latosolo Amarelo Caolinítico* *Areia Latosólica Caolinítica*
Flat watershed parts of Pleistocene or Early Holocene terraces; Cretaceous or Early Tertiary peneplanation levels *partes planas, nos divisores de água, de terraços do Pleistoceno ou do Holoceno Inferior; superfícies peneplanadas do Cretácio ou Terciário Inferior*	intermittently imperfectly drained *drenagem intermitentemente imperfeita*	Ground Water Laterite soil *solo Laterita Hidromórfica*
Elongated patches, often along rivers, of Late Pleistocene sandy terraces *faixas, muitas vezes ao longo dos rios, de terraços arenosos do Pleistoceno Superior*	imperfectly drained *drenagem imperfeita*	Ground Water Podzol *Podzol Hidromórfico*
idem	imperfectly drained *drenagem imperfeita*	Ground Water Podzol *Podzol Hidromórfico*
Floodplains and lowlands, of Holocene age *várzeas, de idade Holocena*	poorly drained *má drenagem*	Low Humic Gley soil Humic Gley soil Saline or Alkali soil *solo Glei Pouco Húmico* *solo Glei Húmico* *solo Salino ou Alcalino*

Tabela 13 As savanas e floresta-savanas da Amazônia, em sua dependência de fatores edáficos e não edáficos

Vegetation type, in dependence upon the degree of human influences →
tipo de vegetação, em dependência do grau de influências antropogênicas

PATCHY SAVANNAH-FOREST *CAMPINA-RANA* (edaphic/*edáfico*)						
SAVANNAH *CAMPO* (edaphic/*edáfico*)						
HIGH FOREST *Mata alta*	felling, burning → *derrubação, incendimento*	SECOND. FOREST *Capoeira*	felling, burning → *derrubação, incendimento*	SHRUB *Arbusto*	felling, burning, grazing → *derrubação, pastação e incendimento*	SAVANNAH *CAMPO* (non-edaphic/ *não edáfico*)
EXTENSIVE SAVANNAH-FOREST *CAMPINA-RANA* (edaphic/*edáfico*)	burning → *incendimento*	EXTENSIVE SAVANNAH *CAMPO* (masked edaphic/ *edáfico encoberto*)				
PATCHY SAVANNAH-FOREST *CAATINGA AMAZÔNICA* (edaphic/*edáfico*)						
PATCHY SAVANNAH *CAMPINA* (edaphic/*edáfico*)						
LOWLAND SAVANNAH *CAMPO DE VÁRZEA* (edaphic/*edáfico*)						

4. Impermeable layers may occur in the subsoil (Ortstein; dense soft plinthite). These layers restrict root development and thus the layer of effective soil moisture reserve.

Actually, the above soil conditions often occur together and are interdependent. For instance, an impermeable subsoil layer can give a shallow, perched ground water level during the rainy season. On the other hand, intermittent imperfect drainage results often in a very sandy topsoil and a dense clayey, or cemented, subsoil. Other soil factors which might be considered as hampering forest growth are: a restricted ground support, and a low natural fertility. In Amazonia, however, these can be ruled out as causes of savannah or savannah-forest. As regards a restricted ground support there is the example of the igapó. Although it has a very shallow rooting, nevertheless a high forest coverage occurs. As regards a low natural fertility there is the fact that practically all forested Planície soils have a very low base saturation. And even soils with an extremely low cation exchange capacity, also in their topsoil, often have forest coverage (Kaolinitic Latosolic Sand, White Sand Regosol). The closed-nutrient cycle of the tropical forest coverage, once established, does apparently not depend upon fertility of the soil.

With the above considerations in mind, the origin of the various savannahs and savannah-forests of Amazonia will be discussed, as far as this is possible with the limited amount of available data. Their origin is schematised, very tentatively, in Table 13.

IV.2.1 Primarily Non-Edaphic Upland Savannahs

In this subchapter the upland savannahs within the hileia are discussed, which are believed to have originated primarily by local adverse climatic conditions or human influence. Many notes on the upland savannahs of eastern Amapá, of southeastern Marajó, and of the northbank of the Lower Amazon river are compiled in the study of SUTMÖLLER *et al.* (1963). The savannahs of the northern part of Rio Branco Territory are not discussed because the area concerned falls outside the hileia.

IV.2.1.1 *The Upland Savannahs of Eastern Amapá Territory*

The upland savannahs *(campos)* of eastern Amapá Territory are located on flat or gently undulating terrains which are between 5 and 50 m above local river level. Except for narrow strips of bottom land, the soils of these savannahs are well-drained. They are commonly of rather heavy texture, but very heavy textures and very light textures respectively are also found. A number of them contain plinthite concretions. The soils with relatively heavy texture have often compact subsoils. In their general characteristics the soils are identical to forest supporting soils nearby, for instance those of Porto Platôn, and elsewhere in the Planície. They are classified as Kaolinitic Yellow Latosol, of various texture (KYL), Kaolinitic Yellow Latosol, Compact phase of various texture (KYL, C), Kaolinitic Yellow Latosol, Concretionary phase (KYL, CR) and Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol, Concretionary phase (RP-KYL, CR) respectively. Detailed analytical data are given in Chapter V.

For southeastern Amapá Territory, there is a greater amount of climatical data than for many other parts of Amazonia. Weather recording stations are installed at Macapá, Santana, Porto Platôn and Serra de Navio. The first three are located in the savannah area. They each have on an average 3 months per year with each less than 50 mm, and 5 months with less than 100 mm rainfall. Of Serra de Navio, well in the forested part, only one year's recordings are available. During that year, only one month had less than 50 mm rainfall, and two months less than 100 mm each.

A distinct difference in climate is likely to exist between the savannah area and the forested area. But the dry season of the savannah area is not more pronounced than that of many other parts of eastern Amazonia which have a forest coverage (*cf.* the Figs. 3 and 4, and Fig. 12). Adverse climatic conditions can therefore not be a main cause of the savannahs. But even when the present day climate in the savannah area would have been unfavourable for forest growth, a climatic origin of the savannahs could not have been taken as proven. A distinct dry season may be the result rather than a cause of savannah coverage. On extensive open terrains, the air becomes more heated at day time, resulting in less rainfall from air with the same absolute humidity as that carried to forested areas (dry season showers in Amazonia usually fall in the afternoon).

The Amapá savannahs reportedly already existed in 1600. Patches of Terra Preta, sure indicators for former Indian settlements, are frequent. At present, the Amapá savannahs are grazed fairly intensively, and burned repeatedly. The boundaries with the forested part are often very well defined, for instance at Porto Platôn. With every new fire, and helped by shifting cultivation and grazing, the savannah area increases slightly. This process was observed in the headwater region of Igarapé do Lago.

In summarizing these data, it is concluded that the upland savannahs of eastern Amapá are due primarily to long-lasting human influence.

IV.2.1.2 *The Upland Savannahs of South-Eastern Marajó Island*

The upland savannahs of south-eastern Marajó are located on flat terrains, and on small ridges *(tesos)* within the central lowlands, both 1 to 3 m above the level of flooding or submergence. The soils of these terrains are often slightly imperfectly drained, constituting sandy Ground Water Laterite soil (GL). The highest parts have Kaolinitic Latosolic Sand (KLS). Only a few of the savannah terrains, for instance those west of Mariahi at the medium course of the river Afuá, have a thick surface layer of bleached sand, which belongs to the so-called Ground Water Laterite soil, Low phase.

Portions of the described low uplands, with the same soils, have a forest coverage, though of rather poor quality. An example is the surrounding of Soure. The dry season is distinct in eastern Marajó, although the annual rainfall is high (Soure has a total rainfall of 2900 mm, 3 months with less than 50 mm each, 4 months with less than 100 mm each). These climatical conditions apparently do not prevent forest growth and are anyhow not inferior to those of many other parts of eastern Amazonia.

It is known that in pre-Columbian times, relatively many Indians were living on the island. Their settling sites were the above mentioned low uplands (patches of Terra

Preta, *cf.* III.3.4). At present, the savannahs are repeatedly burned and intensively grazed. The boundaries with the forested parts of the same uplands are often sharp. Locally, deforestation is purposely effected for converting the land into pasture.

It is concluded that the origin of the upland savannahs of south-eastern Marajó is largely anthropogenic, both from former Indians' and present farmers' practices. Edaphic conditions are marginal.

IV.2.1.3 *The Upland Savannahs at the Northbank of the Lower Amazon River*

The soils of the upland savannahs at the Northbank of the Lower Amazon river were studied in a number of places. The narrow strip of savannah on high upland (about 60 m above river level) right alongside the Amazon river, from Prainha to Monte Alegre, has well to excessively drained, very sandy soil. This soil is, however, very similar to that of the 'flanco' areas southeast of Santarém that are largely under forest cover. Both are Kaolinitic Latosolic Sand (KLS)[1]. In the grass covered, approximately flat centre of the Dome of Monte Alegre, the soils are shallow, while drainage conditions are often imperfect. Ground Water Laterite soil, intergrading to Lithosol (*cf.* Profile 17) is rather frequent. The savannahs at about 20 km N of Prainha (Desterro) where the country is partially very broken, are for a part located on shallow and imperfectly drained soil, classified as Ground Water Laterite soil (*cf.* Profile 2). Kaolinitic Latosolic Sand (KLS) and Kaolinitic Yellow Latosol, medium textured (KYL_m) are however also found.

The data of the only weather recording station located in the region (Óbidos) point to a relatively dry climate. On climatical maps (*cf.* Fig. 2) often a connection is drawn with the northern part of Rio Branco Territory which has a pronounced dry season (*Aw* type of Köppen). DUCKE and BLACK (1954) report the occurrence of dry and low forests in the region. In comparison with other parts of Amazonia, the relief is greatly varied (Dome of Monte Alegre; table lands between Almeirim and Prainha). Already BOUILLENE (1926) observed that the savannahs in the district between Almeirim and Óbidos are largely found at the western feet of the elevated parts. He supposed that, with the prevailing eastern winds, a smaller amount of annual rainfall at the lay-side is, besides conditions of soil, one of the determining factors for the savannahs.

All these savannahs are more or less regularly burned. Cattle grazing during the dry season is of importance in many parts. The presence of many and large patches of Terra Preta indicate a comparatively strong former Indian influence.

It is concluded that a combination of adverse climatic conditions and human influence is largely responsible for the occurrence of upland savannahs at the Northbank of the Lower Amazon river. In several parts adverse soil conditions are a contributing factor.

[1]) Directly around Santarém this soil is also covered with savannah.

IV.2.2 Upland Savannahs and Savannah-Forests of Edaphic Origin

IV.2.2.1 *Savannahs and Savannah-Forests of the Planície*

INTRODUCTION

The above discussed savannahs are all located in the north-eastern part of Amazonia. A considerable percentage of the other upland savannahs, and of the savannah-forests, are located in the Planície (Fig. 12 – on which only the extensive savannahs and savannah-forests are indicated –, *cf.* Fig. 17). They are all encircled by high forest. The relief is normally flat. From the weather recording stations, although they are few, it can be deduced that the climate is approximately uniform over large areas. It can therefore be said that these savannahs and savannah-forests are not due to adverse climatic conditions *in loco*[1].

In contrast to the majority of the savannah-forests *(campina-ranas, caatingas amazônicas)* and the savannahs of small extent *(campinas)*, all studied savannahs of large extent *(campos)* show traces of burning, of varying frequency. It is however supposed, in agreement with DUCKE and BLACK (1954), that burning is not the cause of these savannahs. High forest adjacent to them does not get burned unless felled, and then secondary forest emerges. Only under long-lasting and pronounced human influence this latter may degenerate into savannah. But the dwelling sites of the present population, as well as those of the former Indians, are concentrated on the main river banks, while the campos are found in watershed areas for a good part. Of course, some slow increase in the area of a savannah, at the expense of the adjacent forest, may have taken place, but their centres must have had an original vegetative cover that is liable to burning. The present day vegetation of the campina-ranas, caatingas amazônicas, and campinas may be still the original one, but that of the campos certainly has changed considerably, under influence of burning. The original vegetation of the campos terrains was probably a kind of savannah-forest. At present, however, the sparse woody plants are of fire-resistant species, with xerophytic leaves and thick bark *(Curatella americana*, and others). Because they easily regenerate after fire, tufted grasses are frequent.

Most of the campos terrains are not grazed by cattle, or very infrequently. Grazing is absent in the campinas, campina-ranas and caatingas amazônicas.

It is concluded that neither adverse climatic conditions, nor anthropogenic factors are causes of the existence of the areas with vegetation types inferior to the surrounding high forest. The present-day character of these vegetation types may be a modified one, which is conditioned by fire. But the origin of both the savannahs and the savannah-forests in the Planície, except those discussed in IV.2.1, is to be found with adverse *edaphic* factors, notably imperfect drainage, impermeable subsoil layers, and/or very sandy and bleached topsoils. In the following, all known data about the extent, topo-

[1]) This does however not contradict the fact that the present-day micro and soil climate of the savannah terrains may be distinctly different from that of adjacent forested terrains. Very interesting data in this respect are recorded by SCHULZ (1960) in the coastal region of Surinam, for sites with rain-forest, savannah-forest, and large clearings respectively.

graphy and soils of the savannahs and savannah-forests of the Planície that are of edaphic origin are brought together. The main criteria for the classification of the soils concerned are summarised first (for full description of the soils *cf.* III.2):

A more or less sandy, non-bleached topsoil (A horizon) over a subsoil (B horizon) of soft plinthite (*i.e.*, dense, normally heavy textured material with many, coarse and prominent mottles of red in a white or light grey matrix) is a *Ground Water Laterite soil.*

A sandy, bleached topsoil over a subsoil of soft plinthite constitutes the so-called *Ground Water Laterite soil, Low phase.*

A sandy, bleached topsoil over a subsoil containing an Ortstein (*i.e.* a more or less indurated, homogenous dark brown layer) is a *Ground Water (Humus) Podzol.*

A very deeply bleached sandy soil is usually called *White Sand Regosol*, although actually the very thick A horizon of a deep Ground Water Podzol, or of a deep Ground Water Laterite soil, Low phase, may be involved.

FIELD OBSERVATIONS

The soils of the campinas of some extent in the Bragantina area, for instance the one of Vigia, are mapped by FILHO *et al.* (1963) as 'Regosol – Ground Water Podzol'.

DAY (1959) gives data on the region the lower Gurupí river, which is part of the Caeté-Maracassumé area (*cf.* Fig. 19 and Photo 24). In this region, savannahs and savannah-forests are very frequent. The terrains concerned consist of relatively low upland, largely submerged with rain water during a part of the year. DAY found Ground Water Laterite soil (the 'Ortho' type) and especially Ground Water Laterite soil, Low phase to be the common soils.[1] Ground Water Podzol and White Sand Regosol were found also, but mostly in small patches. They were seen for instance along the river Maracassumé in the southern part of the survey area, where frequently they occur as a narrow band along the river. It may be noted that the profile studies in this area normally went to 120 cm depth only.

In the upper part of the Guamá-Imperatriz area there occurs a narrow terrace along the rivulets and at 1–3 m above their level (Epi-Monastirian level). The original vegetation on this terrace is largely destroyed at present, but indications are that it was savannah-forest. The soil is a Ground Water Humus Podzol (*cf.* Profile 47).

The savannahs and savannah-forests east of the lower Tocantins are indicated on Appendix 7. HEINSDIJK (1958b), who describes the region concerned as 'very slightly undulating, 5 to 10 m above local river level', reports that the patches with savannah or savannah-forest directly alongside the Mojú river have a white sandy soil surface. West of the river Mojú, and to a lesser extent east of it, large areas in the watershed regions are covered with 'grass and/or shrubs' and have a white sandy soil surface. One such a plain with grasses, some shrubs and palmlets, located 2 km east of Curuçumbaba, was studied by a pedologist. It proved to be submerged by rain water during a part of the year, and to have a Ground Water Laterite soil, Low phase profile (SAMPAIO, field-notes).

[1]) Apart from these, Grey Hydromorphic soil occurs on the terrains concerned (DAY and BENNEMA, 1958).

Foto 24 Savanas abertas de relva (campos) que ocorrem entre a floresta alta em pedaços de extensão variável. Esta savana é de origem edáfica. O solo é de drenagem imperfeita, com uma camada superior de areia alvejada e um subsolo denso e argiloso de mosqueados vermelhos prominentes numa matriz branca. Solo Laterita Hidromórfica, fase Baixa (área Caeté-Maracassumé; 1°40′ S., 45°.52′ O. fotografia TH. DAY)

Photo 24 Open grass savannah (campo), occurring in patches of varying extent between high forest. This savannah is of edaphic origin. The soil is imperfectly drained, with a bleached sandy topsoil, and a dense clayey subsoil with prominent red mottles in a white matrix: Ground Water Laterite soil, Low phase (Caeté - Maracassumé area; 1°.40′S., 45°.52′ W. photo TH. DAY)

All savannahs and savannah-forests between the lower Tocantins and the Bahia de Pracuí are mapped on Appendix 7. It can be seen that most of them are located in watershed parts, while small patches may occur alongside the rivers. HEINSDIJK (1958a) notes that between the Tocantins and the Camaraipí the land is 'flat, only slightly above river level', and partially submerged during a part of the year. Between the Camaraipí and the Bahia de Pracuí, the land is 'slightly undulating, maximally 5 to 10 m above local river level'. The vegetation of the savannahs varies, according to HEINSDIJK, from nearly bare sand with here and there some grass, to a mixture of grass, shrub and patches of trees. The soil surface under both coverages is often white sandy. The area around Anauerá river (2°30′ S; 49°45′ W) was visited by DAY (*cf.* notes in HEINSDIJK, 1958a). He reports that in this area practically all savannahs and the surrounding bands of savannah-forest have soils with a bleached, white sandy top. They were moist in their upper part at the time of examination, and often wet or saturated within 1 m depth. DAY called the soils preliminary 'White Sands'. Although his profile studies went to 1 m depth only, one of his field profile descriptions shows the presence of soft plinthitic material in the subsoil. The soil concerned is therefore believed to be a Ground Water Laterite soil, Low phase, the same as was found on the other side of the Tocantins (see above). This is the more probable because of the presence of imperfectly drained soils, preliminary classified as 'Gray Latosols', under nearby average to poor forest. For a strip of shrub savannah, probably a campina, alongside the river Tocantins itself (49°.35′ W; 2°.25′ S), where the terrain is at a level of about 10 m above the river, SAMPAIO (field notes) described a profile with more than 3 metres of bleached white sand: a White Sand Regosol. More upstream, namely near Tucuruí, the author studied the soil of an interior large patch of shrubby savannah with palmlets, which occurs on flat terrain (6 km from the river; extension unknown; possibly identical with the 'campina de Breu Branco' of DUCKE and BLACK, 1954). The profile consisted of white dry sand to 2 m depth, below which grey bands occurred in white wet sand. Probably a deep Ground Water Podzol is concerned.

The broad strip of savannahs and savannah-forests on the watershed between the Bahia de Pracuí and the lower Xingú also have white sandy topsoils (HEINSDIJK, 1958a).

In contrast to the situation in the regions discussed above, savannahs or savannah-forests are sparse in the region between the lower Xingú and the lower Tapajós. HEINSDIJK (1957) reports the occurrence of only a few small patches, on the lower parts of the sandy 'flanco' terrains. The soil of these patches is 'covered with pure white sand'.

In the western half of the region between the lower Tapajós and the lower Madeira, comprising the areas of forest inventory units Canhumá and Maués, the forest inventory maps show the occurrence of patches of savannah-forest on the flat watershed terrains. These are 5–8 m above local low river water level in the northern half, 20 to 30 m above low river water level in the southern half of the area (HEINSDIJK, 1958c). This author's superficial description of the soils of these patches suggests that Ground Water Laterite soil is involved. In the region directly south-west of the inventory area, namely around Manicoré on the Madeira river, savannahs and savannah-forests are more frequent. The former are mapped in Fig. 26. It can be seen that they are concentrated on watershed terrains. They partly form large irregular patches and partly elongated stretches. No field data are available on their vegetative composition or their soils. A number of the elongated savannah areas have however on AAF (1942) maps the notes 'old streambeds with patches of white sand' or 'white sand with scattered trees'.

The very extensive open savannahs (campos), and the surrounding broad fringes of savannah-forest, between the middle courses of the Madeira and the Purús (Humaitá-Lábrea-Porto Velho triangle), were studied by BRAUN and RAMOS (1959). They occur on flat watershed areas with imperfect drainage. The soil profile descriptions of BRAUN and RAMOS show that all subsoils, often already from about 20 cm depth onwards, have strong, reddish mottling in a light grey or white matrix. There can be little doubt that these subsoils, and the upper section of the underlying material which is described as *argilas mosqueadas da Formação Barreiras*, are soft plinthitic in character. Ground Water Laterite soils, developed from relatively heavy textured parent ma-

Fig. 26 Savanas naturais na região do baixo rio Madeira. Dos mapas básicos da AAF (1942)

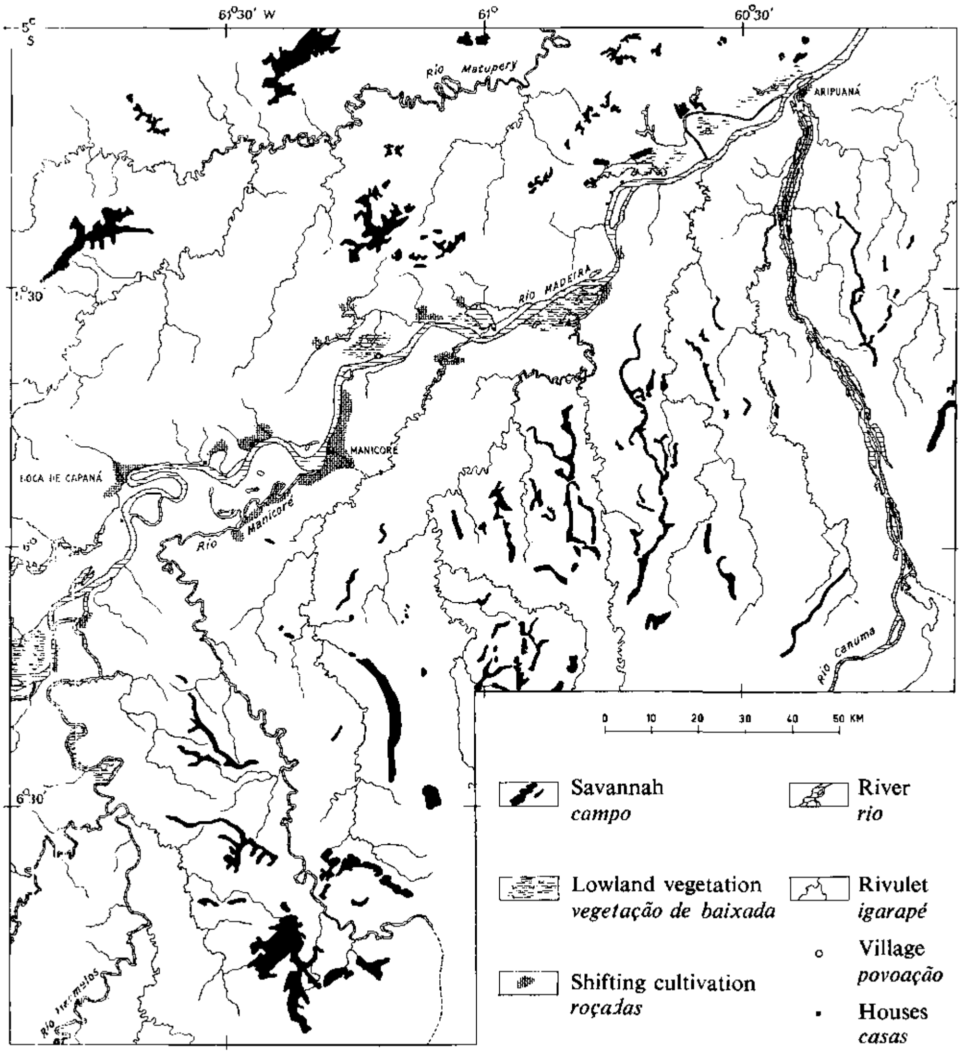


Fig. 26 Natural savannahs in the region of the lower Madeira. From AAF preliminary base maps (1942)

terial, must be involved. That this is the case, is already suggested by Braun and Ramos themselves in writing about '*lateritas hidromórficas*'.

The numerous small savannahs (campinas) on the uplands between the Trombetas and the Rio Negro have all, according to Ducke and Black (1954), a surface of black humus and white sand. The author studied those near Itacoatiara (Photo 25) and especially those north of Manaus. They occur as irregular strips along the rivulets, at a height of 1 to 5 m above them. At all studied sites the soil profile constitutes a Ground

Water Podzol with a well defined Ortstein. This Ortstein occurs sometimes at great depth, giving the soil the appearance of a White Sand Regosol.

As to the extensive natural clearings south of Barcelos on the Rio Negro, no field data exist. Their large extent and their location on supposedly flat terrain suggest that Ground Water Laterite soil predominates.

The soil of the elongated patches of savannah-forest, known as caatinga amazônica, of the upper Rio Negro has been studied by VIEIRA and FILHO (1961). It has a bleached sandy top and an Ortstein. The mentioned authors suggest that former riverbeds are involved, on the bottoms of which the Ortstein developed before the beds were filled with white sand. They therefore classify the soils as Regosol. In the author's opinion however, real Ground Water Podzol is involved. SIOLI and KLINGE (1961) collected 'Podzol' profiles near São Paulo de Olivença, on the Solimões near Peru. These profiles are presumably located on sites with a cover of caatinga amazônica, and the Podzol is probably a Ground Water Podzol.

Tiny patches of savannah-forest within normal high forest may occur on relatively high upland in a freely draining position. On these sites, the soil consists often of bleached sand deeper than augering reached (3 m depth). They seem to be widely distributed on the sandy parts of the Planície, including the north-eastern section of it. Such patches were seen, for instance, in the Manaus-Itacoatiara area, at 10 km north of Oroximiná (*cf.* Profile 48), and at Porto Platôn in Amapá Territory (for the latter *cf.* DAY's description in PITT, 1961).

It may be mentioned in passing, that in the bleached A_2 horizon of the Ground Water Laterite soil, Low phase, the formation of a secondary B horizon or even of an Ortstein, just above the soft plinthite, may take place. This phenomenon is reported by DAY (1959) for the Caeté-Maracassumé area. The author observed it on the low uplands of south-eastern Marajó island. In the latter area, there are indications that such secondary profile development has taken place only after clearing of the natural vegetative cover (*cf.* Photo 14).

It is still noted that the edaphic characterisation of the campina by DUCKE and BLACK (1954), as having a topsoil of white sand and black humus, does not hold good generally. This is because of the above mentioned fact that campos, through the presence of Ground Water Laterite soil, Low phase, may also have a bleached sandy top.

CONCLUSIONS

From the above observations it is evident that all savannahs and the majority of the savannah-forests of the Planície, outside the north-eastern belt, are found on terrains of imperfect drainage, with hydromorphic soils. They are, for a part, Ground Water Laterite soil, and then often the so-called Low phase of this soil, and for the other part Ground Water (Humus) Podzol. Ground Water Laterite soil seems to be associated predominantly with extensive savannahs and surrounding savannah-forests on watershed areas with flat relief (the campos; a part of the campina-ranas). Ground Water Podzol, in contrast, seems to be predominantly associated with savannahs or savannah-forests on strips of sandy, relatively low upland along the rivers and on sand-filled

Foto 25 Savana de areia branca com coberta de fetos e palmeiras pequenas (campina), que ocorre em faixas estreitas ao longo de arroios em área que de resto é florestada. Também esta savana é de origem edáfica. Por baixo de uma camada de uma espessura de um metro de areia alvejada encontra-se um subsolo duro de castanho escuro homogêneo (Ortstein): *Podzol Hidromórfico. Neste lugar a areia alvejada foi excavada para fins de construção. O* Ortstein *constitui a base da excavação (AM-1, km 10 m. ou m. de Itacoatiara)*

Photo 25 White sand savannah with a cover of ferns and palmlets (campina), occuring as narrow strips along rivulets in otherwise forested area. This savannah is also of edaphic origin. Below a layer, about one metre thick, of bleached sand, a homogeneous dark brown hardpan (Ortstein) occurs: Ground Water Podzol. The bleached sand at this spot is excavated for construction purposes. The Ortstein forms the floor of the excavation (AM-1, 10 km ca. from Itacoatiara)

former riverbeds (the campinas; a part of the campina-ranas; the caatingas amazônicas).

Some patches of savannah-forest occur on relatively high, freely draining terrains, where the soil is deeply white sandy. Such profiles are called White Sand Regosol, although most of them actually seem to have been very deeply and intensively bleached *in situ*, and 'Giant Podzol' therefore might be a more adequate classification (*cf.* III.3.4).

The caatinga amazônica and the campina apparently occur on comparable types of terrain and have identical soils. It is likely that the difference in composition of the vegetative covers is due to a difference in climate. Caatinga amazônica is reported only for the northwestern part of Amazonia, with *Af* climate; campinas, on the other hand, occur apparently throughout the other parts of Amazonia, which have *Am* climate predominantly (*cf.* Fig. 2).

IV.2.2.2 *Savannahs and Savannah-Forests outside the Planície*

Forest encircled savannahs or savannah-forests outside the area of the Planície are not uncommon. They are the following (*cf.* I.5.2):

1. the savannahs and savannah-forests on the Brazilian shield at about 7° S latitude. They are found along the lower Araguaia, along the Xingú in the region of the confluence of the Rio Fresco, and along the Tapajós in the region of the junction of the São Manuel and the Juruena (Campos de Cururú, Campos de Mucajazal).
2. The savannahs and savannah-forests on the Guiana shield, between the rivers Trombetas and Jarí up to the frontier with the Guianas. To these belong the Campos de Ariramba, the Campos gerais de Óbidos, and the campos of the upper Paru.

Very little is known about the climatic conditions in the regions of these savannahs and savannah-forests. Local variations in climate are not to be expected, since pronounced differences in topography do not occur; the terrains concerned are at maximally 600 m altitude, and ore often practically flat.[1] It can therefore be said that the existence of the savannahs and savannah-forests under discussion is not due to local adverse climatic conditions. It may, however, be that the general climate in the regions involved has contributed to their extent. This may apply in particular to parts of the Guiana shield where the rainfall is believed to be comparatively unfavourable (*cf.* Figs. 2, 3 and 4).

That anthropogene factors acted as the prime cause is unlikely, because the regions concerned are far from the navigable waterways, where the former Indian tribes were concentrated (*cf.* III.3.4). Human influence may, however, have helped locally in establishing the present day composition and extent of the savannah-forests and particularly of the savannahs concerned. SIOLI and KLINGE (1961), for instance, refer to activity of Indians in the area of the Campos de Cururú. As regards the savannahs of the upper Paru river, the data of DOST (1962) are of interest. He describes the Sipaliwine savannahs, which are the continuation, in the south-western point of Surinam, of the upper Paru savannahs. DOST found artefacts of former Indian occupation, and noted that the terrains are still frequently burned.

While little can be said with certainty concerning the climatic conditions and the degree of anthropogene influence, the same is true for the edaphic conditions of the majority of the savannahs and the savannah-forests outside the Planície. Definite soil data are only available for the forest encircled savannahs or savannah-forests along the lower Araguaia, *viz.* the *campo*, the *campo com arbusto*, the *arbusto* and the *floresta com arbusto* west of the 48°. 10′ W. latitude, as described and mapped by GLERUM and SMIT (1962b). As is shown on Appendices 2 and 6, they occur largely on undulating to mountainous terrain, where the soils are Lithosols of one type or another, *viz.* the mapping units Lithosol, Quartzite substratum phase (L, QU), Lithosol, Sandstone substratum phase (L, SS) and Lithosol, Cherty substratum phase (L, CH). A part of the savannah-forests is found on flat and imperfectly drained terrain, namely in the

[1]) Except for a part of the lower Araguaia savannahs.

area of mapping unit Hydromorphic Grey Podzolic soil, with high base saturation, Shallow Phase (HP_{hb}, s).

The extent of the savannahs along the middle courses of the Xingú and Tapajós is unknown. In part, even their existence is doubtful. Their geographic position suggests they are located on an Early Tertiary peneplanation surface (*cf.* I.4.1). Their soils are therefore apt to be largely Lithosols and imperfectly drained soils (Ground Water Laterite soils, Ground Water Podzols), but this is little more than a guess. Sioli and Klinge (1961) collected 'Podzol' profiles from campo along the Cururú (a small river somewhat north of the São Manuel). This campo forms probably part of the extensive savannah area in this region. Descriptions of the profiles, of their position, and of the degree to which they are representative, are however not given by the mentioned authors.

No field data exist as to the extensive savannahs on the Guiana shield. They are believed to be located for the main part on a peneplanation surface supposedly of Early Tertiary age. Katzer (1903) described the region of the upper Trombetas-upper Paru as flat plateau land with numerous lakes.[1] It seems likely that the main soils on such extensive, flat, and imperfectly drained terrains with a savannah coverage, are Ground Water Laterite soils of one type or another. Dost (personal communication) studied soil profiles of the part of these savannah areas which is located in Surinam (Sipaliwine savannahs). The profiles are either Lithosolic, or show signs of imperfect drainage, with strong, reddish mottling in the subsoil. Ground Water Laterite soil and intergradings of this soil to Lithosol are believed to be involved. Guppy (1958, related by Heyligers, 1963) saw a small, isolated patch of savannah in the region of the upper Trombetas near Serra Irikoumé, which had a white sandy topsoil.

In summarising these few indications, it seems that the forest-encircled savannahs and savannah-forests on the Brazilian and Guiana shields have predominantly Lithosol or Hydromorphic soils as a substratum.

IV.3 The Lowlands with Forest Cover

The relationships between lowland forests and lowland soils are often distinct. Soil conditions on the lowlands are determined directly by the character of flooding or submergence. There are many variations in the chemical composition of the water, and the quantity and quality of the mineral material in suspension (*água preta*, *água branca*, *água limpa*, *cf.* I.4.4). The frequency, length and depth of flooding vary from place to place (*igapó; várzea da chuva*, *-do rio*, *-do maré*, *-do mar*, *cf.* I.5.1.1). For the influence of these variations on the composition of the forest coverage please refer to the short

[1]) Quote: '*eine Hochebene die von zahlreichen Seen und Lagunen bedeckt wird und so wenig ausgesprochene Abdachungen besitzt dass zur Regenzeit Verbindungen zwischen den nach Norden abfliessenden guyanischen und den nach Süden abfliessenden brasilischen Flüssen bestehen*' (Katzer 1903, p.2).
It is in the region of the upper Paru – upper Trombetas that the early maps of South America show the presence of a huge lake or interior sea, as well as of the legendary El Dorado and the tribe of the Amazonas.

Foto 26 Um dos tipos de vegetação que ocorrem nas faixas estreitas de baixada permanentemente mal drenada, ao longo de arroios em áreas de terra firme (igapó). Neste tipo predominam o Guarumá (Ischinosiphon aruma), *a alta erva no fundo, e a Paxiuba* (Iriartia exorrhiza), *a palmeira com as raízes estiradas à direita. O solo é esponjoso e a sua camada superior turfosa: Solo Meio-Turfoso (BR-14, km 110 m. ou m.)*

Photo 26 One of the types of vegetation that occur on the permanently poorly drained narrow strips of lowland along rivulets in upland areas (igapó). In this type, Guarumá ((Ischinosiphon aruma), *the tall herb at the back, and Paxiuba* (Iriartia exorrhiza), *the palm with the stilt-roots on the right, are predominant. The soil is spongy, and has a peaty top: Half Bog soil (BR-14, km 110 ca.)*

description of the lowland forests in I.5.1.1, which is based largely on notes of DUCKE and BLACK (1954). No forest inventories were executed in the lowlands, except for an area in the lower Tocantins river (GLERUM, 1962; area 25 of Fig. 22). This inventory had as a specific purpose to determine the quantity and the growing site of the *Ucuuba branca (Virola surinamensis)*. The timber of this tree species is used in the plywood industry, and the floating seeds are collected to serve as a raw material for the local soap industry. The majority of the *Ucuuba* trees of the várzeas in the studied area were found on the older islands in the river, between Baião and Curuçumbaba. These islands, which have Low Humic Gley soil, are flooded to a shallow depth with river water *(água branca)* in the rainy season, and the action of tides causes a daily variation in water level of 1 to 2 m *(várzea do maré)*. *Buriti* palms *(Mauritia flexuosa)* are in this area an associate of the species. *Ucuuba* is however also found in igapó stretches, where the soil is often peaty (Bog soil or Half Bog soil). Dense stands of the species were seen in the lowlands along the lower courses of the tributaries of the river Capím that are crossed by the BR14-highway. These lowlands are intermediate between várzea and igapó *(meio-igapó)* and their soil was classified as Humic Gley soil, intergrade to Ground Water Podzol.

In many of the lowland forests, palms constitute a prominent feature. *Açaí (Euterpe oleracea)*, *Buriti (Mauritia flexuosa)*, *Ubuçú (Manicaria saccifera)* and *Paxiuba (Iriartia exorrhiza)* are some of the palms that, alone or in varying combinations, give significant appearances to lowland forests (*cf.* Photo 26 and 27).

IV.4 The Lowlands with Savannah or Savannah-Forest Cover

SUTMÖLLER *et al.* (1964) give many data as to the soils and the vegetation on the lowlands with savannah or savannah-forest coverage in eastern Amazonia. Therefore only a few aspects will be discussed here.

IV.4.1 The Lowland Savannahs of the Lower Amazon Region

Many discussions have been made as to the cause of the extensive natural floodplain pastures *(campos de várzea do rio)* along the lower Amazon river between Parentins and the mouth of the Xingú river (*cf.* SIOLI, 1956). Both upstream and downstream of this stretch there is a forest coverage, although the soils in the whole stretch are similar when classified to no great detail, namely Low Humic Gley soil or Humic Gley soil. DUCKE and BLACK (1954) suggest that the comparatively dry climate in the stretch concerned, accounts for the savannah coverage. The author is, however, convinced that its presence is determined only by an adverse length and depth of annual flooding; thus by edaphic factors. The savannahs are 'hydrological' savannahs. Upstream of the savannah stretch, the annual flooding is not long enough, and downstream the flooding is not deep enough to impede forest growth. A strong argument for this point of view is the fact that on the highest parts of the floodplain in the savannah stretch (the levees and point bars) the vegetation is savannah-forest or forest.

Next to the savannahs on lowlands proper in the Lower Amazon region, there are also savannahs on terrains that are slightly above the normal high water level, namely in the area between Oroximiná and Faro (Terra Santa, campos on Early Holocene massapé terrains, *cf.* I.4.4.) Adverse soil conditions (Ground Water Laterite soil; *cf.* Profile 3) are the cause of these savannahs. Frequent burning, however, conditions their present-day vegetative composition.

IV.4.2 The Lowland Savannahs of Eastern Marajó Island

There can be little doubt that the extensive natural grasslands on the lowland parts of eastern Marajó *(campos de várzea da chuva)* are of edaphic origin. Patches of sandy

Fote 27 Açaizal. Neste tipo de igapó a peça constituinte quase única de vegetação é a palmeira Açai (Euterpe oleracea), *que cresce em grupos compactos. Uma camada de folhas palmeiras cobre o solo úmido e esponjoso, que é profundamente turfoso (Solo Turfoso)*

Photo 27 Açaizal. In this type of igapó the nearly sole component of the vegetation is the palm Açai (Euterpe oleracea), *here growing in big clumps. A layer of dead palm leaves covers the wet, spongy soil, which is peaty to a considerable depth (Bog soil)*

low uplands *(tesos)* within the area of the lowlands have a forest coverage, when its vegetative cover is not artificially altered.

These lowlands, of presumably Early Holocene age, are submerged with rain water during several months of the year, in some parts up to 2 m in depth. The soils are heavy textured and have a bad structure. In part, they have an adverse chemical composition, Na^+ and Mg^{++} being predominant on the exchange complex. The soils with a predominance of Na^+ and Mg^{++}, which often are the most deeply submerged by rain water (Solonetz, Coastal phase; *cf.* Profile 52; solonetzic Humic Gley soil, intergrade to Ground Water Laterite soil, *cf.* Profile 18), lack even shrubs in their vegetative cover *(campo limpo)*. The soils with more regular ratios of the exchangeable cations and shallow submergence (Ground Water Laterite soil, heavy textured phase, *cf.* Profile 11) have a coverage of savannah in which shrubs have a scattered occurrence, and *Buriti* palms *(Mauritia flexuosa)* may be present in fairly high quantities.

A situation similar to that in eastern Marajó, prevails in at least a part of the natural grasslands on the lowlands in eastern Amapá Territory.

V Chemical and Physical Qualities of the Main Amazon Soils, and their Agricultural Occupation

Introduction

The Federal Republic of Brazil, seen as a whole, still has vast areas of virgin land available for its rapidly growing population. This population has hitherto been concentrated in some south-eastern States and in a broad strip along the Atlantic seaboard. With the foundation of the new capital Brasília, in the interior, and the construction of highways radiating from this capital in all directions, conditions are being created to permit the occupation of the interior virgin lands. At present, several schemes for such occupation are being drafted by federal and regional development boards. Particularly urgent is the procuring of new land for a part of the rural population of the North-Eastern region, where periodically recurring severe droughts and floods are a serious drawback for sound rural development. Among the outlet areas for the population of this region, parts of Amazonia are being given much consideration. It is therefore of immediate importance to evaluate the capabilities of the Amazon soils.

At many agricultural experiment stations in Brazil, trials were and still are being executed on new agricultural methods, such as the application of chemical fertilizers, animal, farm-yard, or green manures, and the planting of cover crops. The manner of implementation however, and the economics of such methods are still largely unknown for many of the Brazilian soils. In some areas, modern techniques are already being largely applied by the farmers, for instance in many parts of São Paulo State. But for a large part of the rural population, the stage of development as an agricultural community is still relatively low. This many apply particularly to that section of the Brazilian people which is predominantly of Indian descent, as is the case with the inhabitants of Amazonia. This is because the Amer-Indians were, and still are, essentially hunters, fishermen and foragers. In many parts of Brazil, chemical fertilizers are expensive, due, among other reasons, to the costs of transporting them over the vast distances. Animal manure is scarse owing to the grazing of cattle over wide, often unfenced areas.

For these reasons, the present-day agriculture of Brazil is found predominantly on soils with high natural fertility (*cf.* Barros, Drumond, Camargo *et al.*, 1958; Lemos, Bennema, Santos *et al.*, 1960). The shifting cultivation system is also, for that matter, essentially a utilization of temporarily high 'natural' fertility.

In view of the above, it is understandable that, in selecting new settlement areas, soils with a high natural fertility are much more sought after by individual pioneer farmers, than soils that have a potentially high fertility owing to good physical qualities. For large-scale settlement schemes, however, the expanse, the homogenity and the

Foto 28 Arroz de terra firme cultivado em solo de 'plinthite' fóssil. Mais da metade do material de solo é constituida de pedras de 'plinthite' fóssil. Mesmo assim colheitas comumente são satisfatórias nestes solos, visto que o 'plinthite' só excepcionalmente constitui um carapaço impenetrável e a terra própria provàvelmente é um pouco mais rica que aquêle de solos comparáveis sem 'plinthite' (Fazenda Oriboca, perto de Belém)

Photo 28 Dryland rice growing on soil with fossil plinthite. More than half of the soil material consists of stones of fossil plinthite. Crops are nevertheless doing well on these soils, since the plinthite rarely forms an impenetrable cap and the interjacent earth is probably slightly richer than that of comparable non-plinthitic soils (Oriboca Estate, near Belém)

means of access to the area to be selected are of importance, while socio-political factors are also involved.

In Amazonia, soils with relatively high natural fertility are found on parts of the lowlands, and locally on the uplands outside the Planície. Generally speaking, such soils are therefore sparse, often small in area, of difficult accessability, or expensive to reclaim. The terrains of the Planície, on the other hand, constitute large tracts of predominantly flat or gently undulating land which is largely in a freely draining position. These tracts of land are near the main waterways and the existing roads. The forests on these terrains have supposedly the greater gross timber volumes of Amazonia, and the present-day Amazon agriculture is concentrated here. It is for these reasons that the Planície part of Amazonia, although the natural fertility of its soils is low, shows promise for large-scale settlement schemes. Special attention will therefore be devoted to the chemical and physical qualities, the adequate soil management measures and the agricultural capabilities of the Planície soils with an unhindered external drainage.

V.1 The Soils of the Lowlands

As described in III.3.5, the soils of the terrains with Holocene deposits are rather diverse. The igapó soils (Bog soil, Half Bog soil a.o.) are more or less peaty, of spongy consistency, and usually very acid. They occur in narrow stretches and are permanently poorly drained. These properties make the soils generally unsuitable for agriculture, or for cattle herding. Silviculture adapted to these soil conditions may be the most appropriate, cultivating a valuable oil bearing and/or timber producing tree, such as the *Ucuuba (Virola surinamensis)*. The same may be said of the bottom lands within grass-covered uplands, although here, cattle herding may be a feasible proposition too.

The várzea soils (Low Humic Gley soil, Humic Gley soil, a.o.) are generally non-peaty, heavy textured soils. The natural fertility varies considerably. The cation exchange capacity is usually much higher than that of the surrounding upland soils, but the base saturation is low, to very low, on many sites and considerable amounts of aluminum are often present (*cf.* page 236). A portion of the várzea soils is saline and/or has a very unfortunate predominance of Na^{+} and Mg^{++} in the subsoil. The structure of the soils is often unfavourable; heavy textured, sticky and compact subsoils are rather frequent.

After the second world war, because with some crops and with cattle herding favourable results were obtained on some várzea areas, Government agencies paid much attention to promoting várzea agriculture and grazing (Camargo, 1950; Lima, 1956). In this respect may be mentioned the growing of jute in the Lower Amazon region, of rice and sugar cane in the region west of Belém, and of cocoa along the lower Tocantins river. Also notable is the herding of cattle and buffalos in the Lower Amazon region and in the eastern part of Marajó island. Erroneously, a popular impression has grown that *all* of the várzeas are much more favourable for occupation than the surrounding uplands. Actually, land capabilities vary much with the type of várzea. The main criteria for its evaluation will have to be the chemical qualities of the soils, (*c.q.* the richness of the flooding water), and the length and depth of flooding. Except on narrow, relatively high stretches *(várzeas altas, restingas)* and for some especially adapted crops such as jute, a large scale, all year cultivation on the várzeas of eastern Amazonia is possible only after artificial drainage and reclamation. This requires considerable investigation, organization and capital investment. Favourable conditions for pasturing may be obtained more easily and in some parts already exist naturally (*cf.* Sutmöller *et al.*, 1964).

V.2 The Soils of the Uplands Outside the Planície

The uplands outside the Planície are the undulating terrains of outcropping crystalline basement and Paleozoic, Mesozoic or Early Tertiary deposits, as well as the peneplanation areas of Cretaceous or Early Tertiary age. These terrains are largely located far from the population centres. Their accessibility is difficult, due to the rough topography, the occurrence of rapids in the rivers, and the presence of dangerous wild Indians. These are reasons why hitherto little agricultural use has been made of the land concerned. As discussed in III.3.1, III.3.2 and III.3.3, the soils are, according to indications, very diverse. They vary much in natural fertility, in texture, structure, depth, stoniness and in drainage condition. Each individual soil is probably present either rather scattered or in complexes, and the relief can be broken. Only a few parts, which are of comparatively easy accessibility, are occupied. Examples are the Alenquer-Monte Alegre area, Fordlândia on the lower Tapajós river, and some parts around Rio Branco do Acre. These are all areas where soils occur with a comparatively high natural fertility.

The principal criterion for land capability evaluations of the vast unoccupied expanses must be that of high natural fertility of the soils. This is owing to the high cost of transportation, which make it necessary to obtain maximum returns from the minimum of effort.

V.3 The Freely Draining Kaolinitic Soils of the Planície

The terrains of the Plio-Pleistocene Amazon planalto and of the Pleistocene terraces, together called Planície (*cf.* I.4), are largely in a position of free drainage. Comparatively many and consistent data are available as to the soils on these freely draining terrains. The soils concerned are:

Kaolinitic Yellow Latosol (,Ortho)	KYL
Kaolinitic Yellow Latosol, Compact phase	KYL, C
Kaolinitic Yellow Latosol, Concretionary phase	KYL, CR
Kaolinitic Yellow Latosol, intergrade to Dark Horizon Latosol	KYL-DHL
Kaolinitic Yellow Latosol, intergrade to Red Yellow Podzolic soil	KYL-RP
Kaolinitic Red Latosol	KRL
Kaolinitic Latosolic Sand	KLS
Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol	RP-KYL
Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol, Concretionary phase	RP-KYL, CR

(For texture classes *cf.* Table 9).

The chemical characteristics of these soils are similar to a large extent. The soils have in common a total or nearly total absence, even in the deeper subsoil, of primary minerals that are easily weatherable, which would function as a nutrient reserve. The cation exchange capacities are small, and the base saturation percentage is practically always low. The clay fraction is strongly kaolinitic; the Ki values are normally between 1.8 and

2.0, only sometimes as low as 1.5 or as high as 2.3; the Kr values are normally between 1.5 and 1.8, only sometimes as low as 1.4 or as high as 2.0.

Together, the soils will be called *freely draining kaolinitic Planície soils.*

V.3.1 Chemical and Physical Qualities of the Freely Draining Kaolinitic Planície Soils

In the following, the chemical and physical qualities will be discussed of the freely draining kaolinitic Planície soils, under their natural vegetative cover or varying degree of human influence. It is largely a compiling of all relevant field and laboratory data available at present, as to enable a tentative assessment to be made of the agricultural potential of the soils and their adequate management, and to provide a basis for later, detailed research. For this purpose, extreme and mean values are given for each soil component, and the correlation with other components is shown, partly in graphs.

The causal factors for these correlations are not discussed. Such a discussion would not well fit in the context of the present chapter. The available data are, moreover, often too elementary for that purpose.

V.3.1.1 *The Soils under Primeval Forest Cover*

CHEMICAL QUALITIES

For study of the chemical qualities of the freely draining kaolinitic Planície soils under primeval forest cover, IQA analytical data of 35 relevant profiles are available. Half of them are of the Guamá-Imperatriz area. The others are from places scattered over the Planície in eastern Amazonia.

Organic Matter. Analysis shows that the easily available plant nutrients are highly concentrated in a thin superficial layer of the soil which contains the bulk of the organic matter.

For all horizons of the profiles there is a tendency for the percentage of organic matter to increase at a higher percentage of clay.

This is illustrated in the Figs. 27, 28, and 29 (the data for Figs. 27 and 28 were obtained mainly by graphical interpolation from the analytical data of the horizons involved).

The increase of percentage of Carbon with increase in percentage of clay is greatest in the upper part of the profile. At 10 cm depth, for instance (Fig. 27), the increase comprises roughly 0.16% Carbon per 10% clay. The variations, at equal percentages of clay are, however, fairly large. This is because (1) the graphical interpolation of the data does not give an accurate picture of the actual situation in the soil, (2) the sampling of the upper, sometimes very thin horizon was often carried out inaccurately, (3) no mixed sampling, to compensate for the horizontal variations in organic matter, was made and (4) the dispersion of the clay fraction on analysis may not have been complete, due to the comparatively high organic matter content. Apart from these, the variation is also caused by differences in organic matter content which are due directly to the composition of the forest coverage (*cf.* cipoal, IV.1.2).

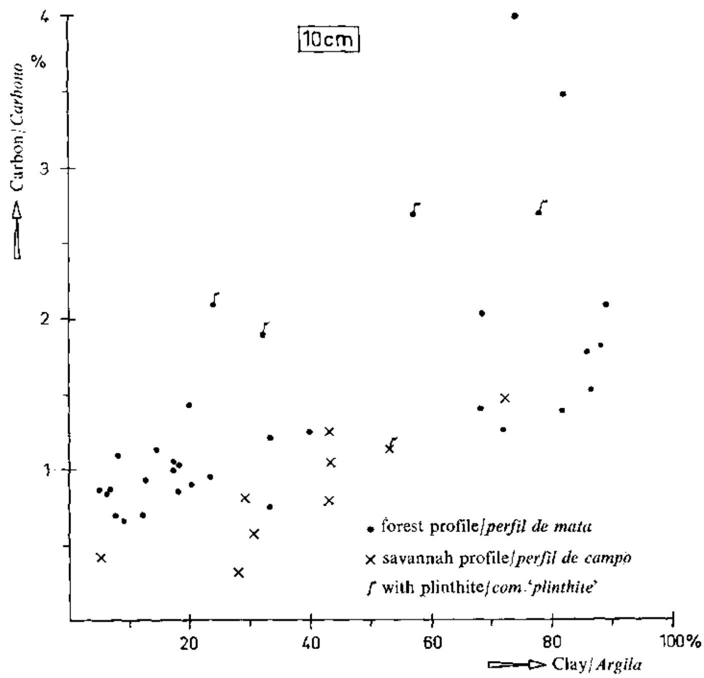


Fig. 27 Relação entre a percentagem de Carbono e a percentagem de argila a 10 cm de profundidade, em perfis de solos caoliníticos da Planície de drenagem livre

Fig. 27 Relation between percentage of Carbon and percentage of clay at 10 cm depth, in profiles of freely draining kaolinitic Planície soils

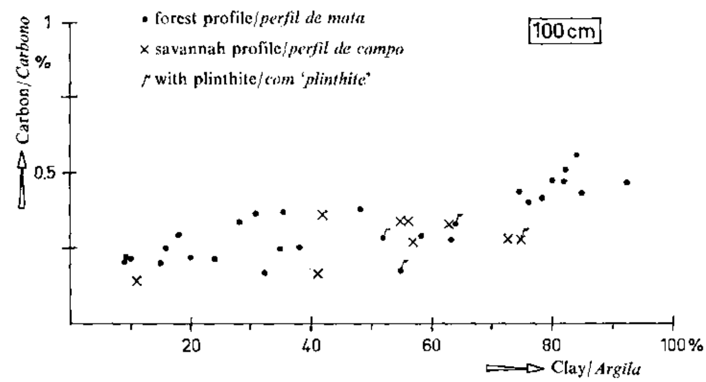


Fig. 28 Relação entre a percentagem de Carbono e a percentagem de argila a 100 cm de profundidade, em perfis de solos caoliníticos da Planície de drenagem livre

Fig. 28 Relation between percentage of Carbon and percentage of clay at 100 cm depth, in profiles of freely draining kaolinitic Planície soils

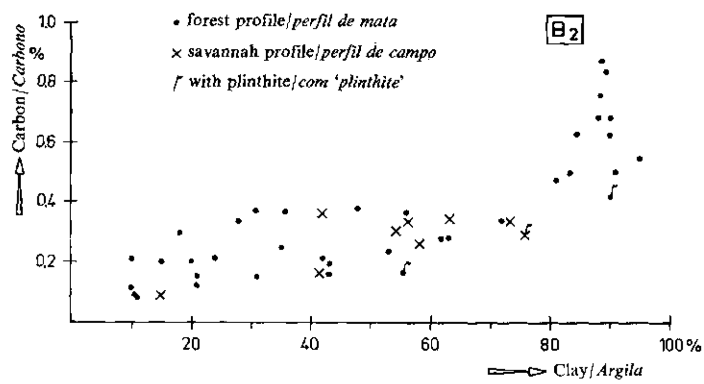


Fig. 29 Relação entre a percentagem de Carbono e a percentagem de argila no horizonte B_2 de perfis de solos caoliníticos da Planície de drenagem livre

Fig. 29 Relation between percentage of Carbon and percentage of clay in the B_2 horizon, of profiles o freely draining kaolinitic Planície soils

Fig. 30 Relação entre a percentagem de Carbono e o valor T para perfis de solos caoliníticos da Planície de drenagem livre

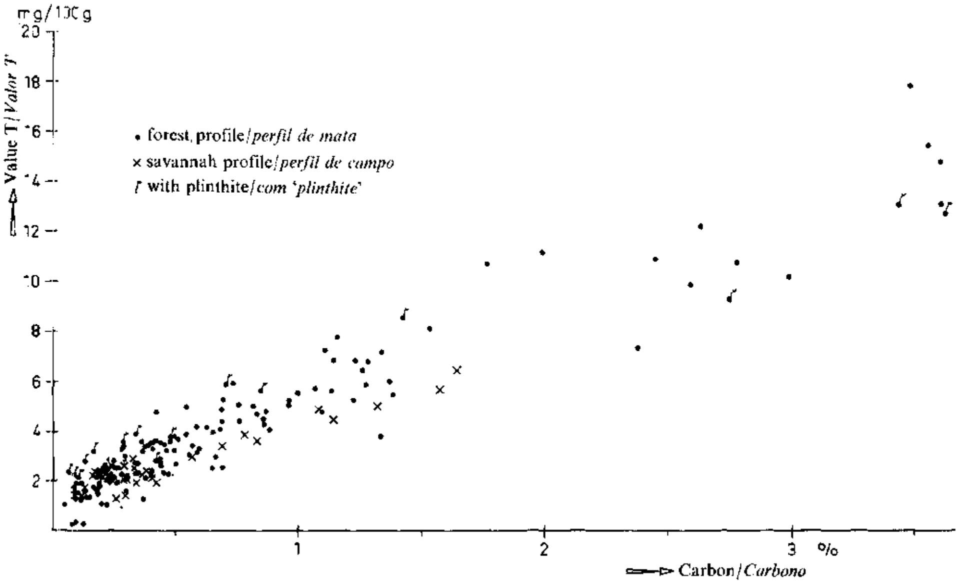


Fig. 30 Relation between percentage of Carbon and value T, for profiles of freely draining kaolinitic Planície soils

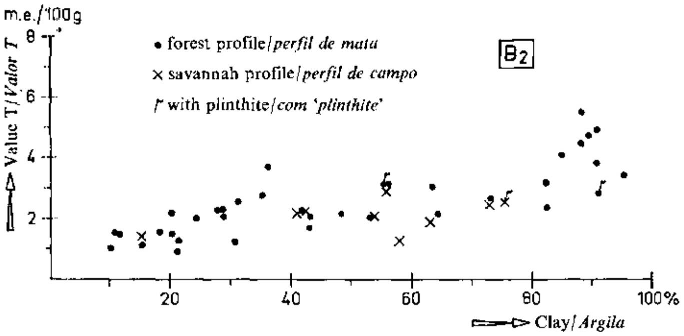


Fig. 31 Relação entre a percentagem de argila e o valor T nos horizontes B_2 de perfis de solos caoliníticos da Planície de drenagem livre

Fig. 31 Relation between percentage of clay and value T, in B_2 horizons of profiles of freely draining kaolinitic Planície soils

Probably more reliable, and anyway more clear is the trend at some depth in the profile, for instance at 100 cm (Fig. 28). The increase of percentage of Carbon with increase in percentage of clay is here much slower, namely roughly 0.035% Carbon per 10% clay. The small increase is due, in part, to the fact that in sandy soils the percentage of organic matter decreases more gradually with increasing depth than in clayey soils. The former have generally deeper profiles, which shows up in the depth of the horizon of maximal clay content, *i.e.* the B_2 horizon. More interesting therefore, in some respect, is the situation for the B_2 horizons of the profiles (Fig. 29), where the increase is roughly 0.06% Carbon per 10% clay.

Table 14 Cation exchange complex of freely draining kaolinitic Planicie soils, under primeval forest cover (18 profiles; Guamá Imperatriz area) or under anthropogenic savannah (6 profiles; Amapá Territory)*

Horizon *horizonte*	T Potential cation exchange capacity *capicidade total de troca* m.e./100 g)	Exchangeable metallic cations, in % of T *bases trocáveis, em % de T*			
		Ca^{++}	Mg^{++}	K^{+}	Na^{+}
FOREST PROFILES/*perfis de mata*					
A_1	(3.9–14.8)[1]	8.6 (3.0–23.0)[1]	8.0 (3.0–17.2)[1]	1.6 (0.9–2.6)[1]	0.7 (0.4–1.9)[1]
A_3–A_2	(2.2–6.9)	6.8 (3.5–16.8)**	6.8 (3.5–16.8)**	2.4 (1.2–6.3)	1.0 (0.5–3.0)
B	(1.4–4.6)	9.2 (5.0–20.0)**	9.2 (5.0–20.0)**	2.9 (1.0–6.2)	1.6 (0.5–5.5)
C***	(1.4–3.6)	11.1 (6.7–19.5)**	11.1 (6.7–19.5)**	3.1 (1.9–4.5)	1.5 (0.8–2.3)
SAVANNAH PROFILES/*perfis de campo*					
A_1	(2.2–5.7)	6.7 (4.5–10.8)**	6.7 (4.5–10.8)**	1.4 (0.3–4.3)	0.8 (0.3–1.0)
A_3–A_2	(2.1–3.5)	7.1 (4.5–9.7)**	7.1 (4.5–9.7)**	0.9 (0.8–1.0)	0.6 (0.2–1.0)
B	(2.1–2.9)	8.1 (5.2–10.9)**	8.1 (5.2–10.9)**	1.5 (0.3–3.5)	0.9 (0.4–2.2)

[1]) Data within brackets: range of values
dados entre os parênteses: variações dos valores
Data before brackets: main values
dados em frente dos parênteses: médios dos valores

* Kaolinitic Red Latosol profiles not included
Perfis de Latosolo Vermelho Caolinítico não incluídos

In Fig. 30 the potential cation exchange capacity at pH 7 (value T) is compared with the organic matter content, using the relevant data of all horizons of the thirty-five profiles. The trend is very clear; the increase of T is about 3.9 m.e. per 1 % Carbon. The T value shows also a positive correlation with the percentage of clay. In the topsoil, with its concentration of the organic matter, the T values is always considerably higher when the soil is heavier. For the B_2 horizon, the increase of T with the increase of percentage of clay is only moderately high, as shown in Fig. 31. In horizons with practically no organic matter (C horizons), T is always very low, even when the percentage of clay is high. This means that practically all the existing cation exchange capacity is due to the organic matter in the soil. The chemical activity of the clay-sized mineral particles themselves is very low (an estimate of the latter may be obtained by the combination of the Figs. 29, 30, and 31; the potential cation exchange capacity per 100 g pure, *i.e.* organic matter-free, clay-sized mineral material, is between 1.8 and 4.0 m.e. approximately). It is apparent that with regard to chemical qualities, *the main advantage of the clayey over the sandy soils is their ability to create a better milieu for preservation of the comparatively very active organic matter.*

The C/N values, which are often an indicator of the type of organic matter, are very regular in the profiles. In the A_1 horizon they are highest. The average value in this horizon is about 10.5 in the relatively heavy textured profiles. The relatively light textured profiles have an average ratio of 13.5 in their A_1 horizons. In the subsurface and subsoil horizons there is no difference in average C/N value between the relatively heavy textured and the relatively light textured profiles. At 50 cm depth, the C/N value

Tabela 14 Complexo de troca catiônica de solos caoliniticos do Planície de drenagem livre, sob cobertura florestal primitiva(18 perfis; área Guamá-Imperatriz) ou savana antropogênica (6 perfis; Território do Amapá)*

Hori-zon *hori-zonte*	S Sum of met. cations (% of T) *soma das bases (% de T)*	$(Al)^+$ Active acidity (% of T) *acidez ativa (% de T)*	H^+ pH-dep. activity (% of T) *acidez pH-depend. (% de T)*	$(Al)^+ + H^+$ Potential acidity (% of T) *acidez potencial (% de T)*	$S + (Al)^+$ Act. cation exch. cap. (% of T) *cap. de troca ativa (% de T)*	S Sum of met. cations (% of S + $(Al)^+$) *soma das bases (% de S + $(Al)^+$)*
FOREST PROFILES/*perfis de mata*						
A_1	19 (9–43)[1]	15 (2–24)[1]	66 (50–73)[1]	81 (57–91)[1]	34 (27–50)[1]	56 (28–95)[1]
A_3–A_2	17 (10–37)	23 (11–37)	60 (46–76)	83 (63–90)	40 (24–54)	43 (21–77)
B	23 (14–39)	23 (6–59)	54 (23–76)	77 (61–86)	46 (28–73)	50 (24–87)
C***	27 (18–56)	13 (3–39)	60 (39–74)	73 (44–82)	40 (28–77)	68 (45–95)
SAVANNAH PROFILES/*perfis de campo*						
A_1	16 (10–24)	21 (9–27)	60 (41–69)	81 (67–90)	37 (31–45)	43 (29–69)
A_3–A_2	16 (10–21)	25 (21–30)	59 (55–63)	84 (79–90)	41 (38–44)	37 (24–51)
B	19 (16–25)	18 (10–35)	63 (49–68)	81 (75–84)	37 (32–51)	52 (31–71)

** $\frac{1}{2}(Ca^{++} + Mg^{++})$ The half of jointly determined bivalent cations
A metade dos cations bivalentes determinados em conjunto
*** Data of 10 profiles only
Dados de 10 perfis sòmente

averages 9.0, at 100 cm depth 8.0 and at 200 cm depth 6.5. Variations from these averages are up to 4.0 unit.[1] For the deeper layers, the value of the ratio as an indicator of the type of organic matter may however be limited, because of the possibility that N-in-mineral-form constitutes there a more than negligible part of the total determined N (see below).

Exchangeable cations and acidities. With the exception of the Kaolinitic Red Latosol profiles, the sum of the exchangeable cations (value S) comprises only a small part of the T value. The base saturation percentage (value V) is always below 40%. In the topsoil (A_1 horizons), the variation of V is between 5% and 40%, with an average of 15%. In the subsurface soil (A_3 or A_2 horizons) the variation is between 5% and 35%, with an average of 14%. In the subsoil (B horizons) the variation of V is between 10% and 40%, with an average of 23%. The deeper subsoil (C horizons), insofar it was sampled, shows a variation between 15% and 50%, with an average of 29%.

In agreement with the low base saturation, the soils show an 'extremely' or 'very strongly' acid reaction (terminology of SOIL SURVEY MANUAL, 1950). The pH-H_2O slightly increases with increasing depth. The variation of this value in the topsoil (A_1 horizons) is from 3.7 to 4.7, in the subsurface soil (A_3 or A_2 horizons) from 3.8 to 5.2,

[1]) KLINGE (1962) gives higher values for Amazon forest soils. In two *Braunlehm* profiles under high forest, the ratios are as high as 20. Other methods of sample storage and analysis may account for this difference.

in the subsoil (B horizons) from 4.0 to 5.4, and in the deeper subsoil (C horizons), insofar sampled, from 5.0 to 5.5.

The pH-KCl is generally less than one unit below the pH-H_2O, namely on the average 0.6 in the upper part of the profiles, and on the average 0.8 in their lower part.

The cation exchange complex was analysed in detail for the relevant profiles of the Guamá-Imperatriz area. The data are given in Table 14.[1] Because it is suggested by COLEMAN *et al.* (1959), among others, that base saturation percentages calculated on the active cation exchange capacity are of more value for the study of the chemical qualities of the soil, in relation to the plant growth, than those calculated on the potential cation exchange capacity, the former percentages are also given.

In the A_1 horizons, the percentage of Ca^{++} is usually slightly higher than that of Mg^{++}. Topsoils in which Mg^{++} slightly predominates over Ca^{++} are however also found. Whether the same applies for the other horizons of the profiles is not certain, because there the bivalent cations were determined collectively. The absolute amount of K^+ in the topsoil rarely exceeds 0.15 m.e./100 g of soil.

It can be seen that the exchangeable[2] $(Al)^+$, or the active acidity (*cf.* III.1), is not remarkably high, especially not so in the topsoil and in the deeper subsoil. The absolute amounts of $(Al)^+$ are between 0.1 and 2.2 m.e./100 g of soil, with an average value of 0.7 m.e./100 g. Mention may be made of the aluminum content of a number of profiles from the centre of the Planície, which were analysed by the Royal Tropical Institute of Amsterdam, Holland. In eight profiles, the 'easily available' $(Al)^+$ (extraction with Na-acetate/acetic acid of pH = 4.8 in a paste with a soil: solution ratio of 1: 2.5, shaking time 30 minutes; MORGAN-VENEMA extract) turned out to be nearly always less than 100 mg/l in the A_1 horizons, and on the average about 60 mg/l in the B horizons.

That $(Al)^+$ values of the freely draining kaolinitic Planície soils are not remarkably high, appears also when they are compared with the data of a number of other Amazon soils. For example, acid hydromorphic soils (those without, or with only little, annual enrichment by material suspensed in water, as there are Ground Water Laterite soils, a part of the Low Humic Gley and the Humic Gley soils) have often 75% $(Al)^+$ in their B_{2g} horizons. This is associated with comparatively large pH-H_2O – pH-KCl differences (average of 17 profiles; *cf.* Appendix 9). The 'easily available' $(Al)^+$ is 150–200 mg/l, in the same horizon of such soils (average of 7 profiles).

Nitrogen and Phosphorus. The IQA analysis data as to nitrogen concern only the *total N* (N-in-organic-complexes + N-in-mineral-form) in the soil. The percentage of total N decreases gradually with increasing depth, in correlation with the decrease of the percentage of organic matter. Apart from this, the percentage of total N is generally lower with lower percentages of clay in the soil.

KLINGE (1962) gives a few data on mineral N in Amazon forest soils, admitting that

[1]) Seen in their entirety, the profiles of this area seem to have a slightly higher base saturation in their upper horizons than those of the centre proper of the Planície.

[2]) With the analysis method used, if soluble $(Al)^+$ is present, it is included in the data.

the values may be incorrect because of possible reactions during the storage of the samples. In two *Braunlehm* profiles under forest coverage, the mineral N decreases from about 5 mg per 100 g of soil in the topsoil, to about 3 mg per 100 g of soil in the subsoil. The litter layer contains about 8 mg per 100 g. The percentage of mineral N compared to total N increases however with increasing depth, namely from about 3% to 8%. With regard to the form of the mineral N, KLINGE gives values for the ratio $N\text{-}NH_4^+ : N\text{-}NO_3^-$ that are between 8 and 25, with 40 in the litter layer.

For eight forest profiles of freely draining kaolinitic soils of the Planície, the 'easily available' N was determined, by the Royal Tropical Institute of Amsterdam, Holland, in the MORGAN-VENEMA extract (see before). In the topsoil (0–20 cm; A_1 horizons), the variation of NH_4 is from 1 to 14 mg/l (average 7) and that of NO_3 from 3 to 30 mg/l (average 15). In the subsurface soil (20–60 cm; A_3 horizons), the variation of NH_4 is from 1 to 12 mg/l (average 3.5) and that of NO_3 from 'traces' to 11 mg/l. In the subsoil (60–100 cm; B horizons), the variation of NH_4 is from 'traces' to 12, and that of NO_3 from 'traces' to 18 mg/l. It can be seen that there is a great variation. This is only associated with textural differences to a minor extent. Apart from seasonal fluctuations in the amounts of NH_4^+ and NO_3^- in the soil, nitrification and denitrification processes are likely to have occurred in the samples before they were analysed. Such processes probably have changed, in an uneven manner, the contents of easily available NH_4^+ and NO_3^- as it was in the soils in their natural position.

It is noted that, in the Forest Inventory areas in the Planície (*cf.* IV.1), normally between 15 and 30% of the enumerated trees belong to the Leguminosae order (the highest percentages are found in the region between the lower Xingú and the lower Tapajós; *cf.* GLERUM, 1960). No data are however available as to the effective root nodulation of these trees.

No data exist on the relative importance of nitrogen fixation, i.e. the conversion of atmospheric N into a combined form and its incorporation into the forest soil. This is so, whether non-symbiotic bacteria *(Clostridium, Beijerinckia)* are concerned, or bacteria that are in symbiosis, via root nodules, with Legumes.

The IQA data on Phosphorus are more interesting. For the thirty-five forest profiles mentioned before, the *available P* was determined according to the TRUOG-method or the BRAY-method, or both (Truog on 25 profiles, often only their upper horizons; Bray on 18 profiles of the Guamá-Imperatriz area). In the Figs. 32 and 33 the data on available P are compared with the depth in the profile. It can be seen that only in the topsoil (0–10 cm) the amounts of available P are appreciable, though the variation is rather large. Below the topsoil, the amounts of available P decrease rapidly, especially when considering the Bray calues, to very low, and approximately constant, values, namely about 0.6 mg P_2O_5 per 100 g of soil (Truog) and about 0.15 mg P_2O_5 per 100 g of soil (Bray). No clear correlation emerges between the amounts of available P and the soil texture.

For the eighteen profiles of the Guamá-Imperatriz area, there are also data on *total P*. Contrary to the situation with the available P, the values for total P are fairly con-

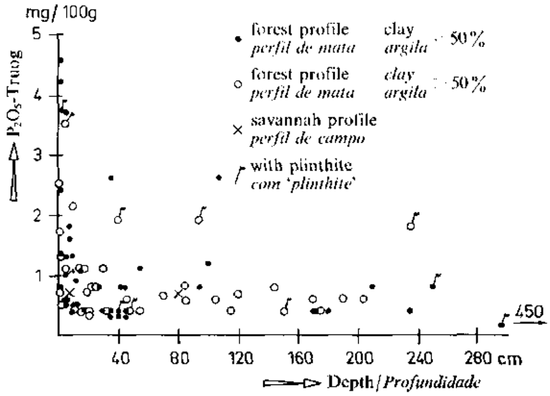


Fig. 32 Relação entre a quantidade de fósforo disponível (método Truog) e a profundidade, em perfis de solos caoliníticos da Planície de drenagem livre

Fig. 32 Relation between the amount of available phosphorus (Truog method) and the depth, in profiles of freely draining kaolinitic Planície soils

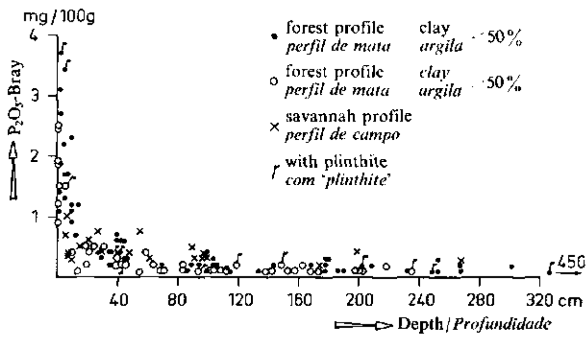


Fig. 33 Relação entre a quantidade de fósforo disponível (método Bray) e a profundidade, em perfis de solos caoliníticos da Planície de drenagem livre

Fig. 33 Relation between the amount of available phosphorus (Bray method) and the depth, in profiles of freely draining kaolinitic Planície soils

stant throughout each individual profile, including the topsoil. It is only in the very heavy textured profiles that a difference may occur in total P between topsoil and subsoil, and this is not more than 20 mg P_2O_5 per 100 g of soil. The total P increases with heavier texture of the soil. For instance, in the medium textured profiles, the amount is about 30 mg P_2O_5 per 100 g of soil, and in the very heavy textured profiles about 55 mg P_2O_5 per 100 g of soil.[1]

A comparison of the data for total P with those for available P gives a picture of the degree to which the P that actually occurs in the soil is fixed. The Bray values are used for the calculation of the ratio P_2O_5-total: P_2O_5-available, for eighteen of the profiles. The ratio generally increases with increasing depth in the profile. In Fig. 34, the ratios of all horizons are compared with the content of organic matter, taking the texture of the horizon concerned into account. It can be seen that the ratio, or the degree of fixation of the soil phosphorus, increases sharply when the percentage of Carbon drops to below approximately 0.5. The fixation, as determined in this way, is greater when the texture is heavier, but the percentage of Carbon the same. For the relatively light

[1]) In eight forest profiles, for the most part of medium to rather heavy texture, the amount of P extracted with 25% HCl was approximately 10 mg/100 g of soil (analysis of Royal Tropical Institute, Amsterdam, Holland).

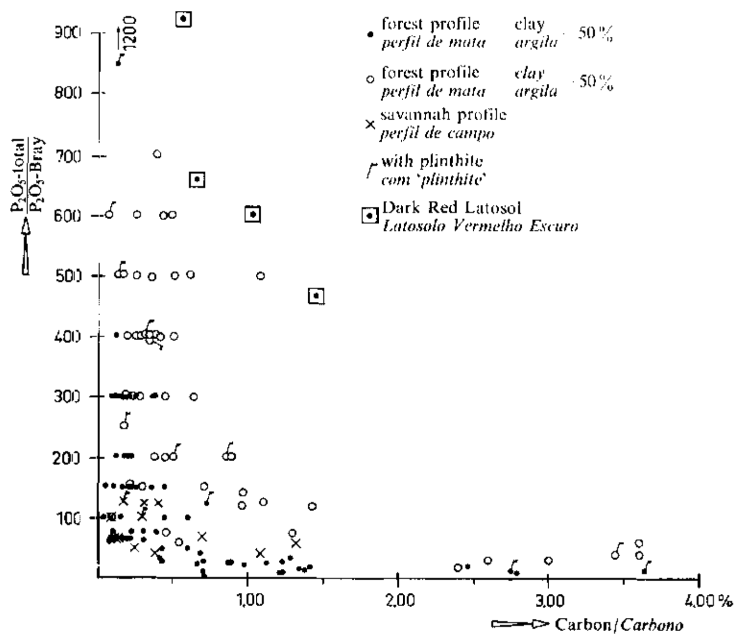


Fig. 34 Disponibilidade do fósforo de solo em relação com a percentagem de Carbono e a percentagem de argila, em perfis de solos caoliníticos da Planície de drenagem livre

Fig. 34 Availability of soil phosphorus in relation to the percentage of Carbon and the percentage of clay, in profiles of freely draining kaolinitic Planície soils

textured profiles the ratio does not exceed 300, while for the relatively heavy textured profiles it can be as high as 600.

Because of their comparatively low percentages of sesquioxides, it may be expected that the phosphorus fixation capacity of the kaolinitic latosolic soils of the Amazon Planície is smaller than that of other latosolic soils, for instance those of São Paulo State (*cf.* Lemos, Bennema, Santos *et al.*, 1960). This can however not be fully verified, since the latter are largely under cultivation, because of which the amount of available P has changed. It is, however, true that the latosolic soils of São Paulo have often higher values for total P. Relevant data are available on a Dark Red Latosol, under primeval forest cover, in a part of Amazonia outside the Planície (*cf.* Profile 35). As can be seen in Fig. 34, the Dark Red Latosol, which contains about 40% clay, has a more unfavourable ratio P_2O_5-total : P_2O_5-available than the kaolinitic latosolic profiles.

Physical qualities

Seen in their entirety, the freely draining kaolinitic Planície soils under forest cover have a 'good' structure, which applies also to those sections of the profiles that are low in organic matter. This structure is usually weakly coherent porous massive, or subangular blocky to granular, of varying strength. The good structure of latosolic soils in general is thought, by many, to be due to the nature of the clay fraction, on the one hand, and to a large activity of the soil fauna, in particular termites, on the other. The author believes that in the Planície soils concerned, with their small amounts of sesquioxides, the soil fauna certainly is of great importance in bringing about, and maintaining, the structure as it is under the primeval forest coverage. The activity of ter-

Foto 29 Cigarras. As construções das larvas de uma cigarra (Cicadidae *fm.) à superfície do solo florestal. As crisálidas no seu último estado, escavam no solo poços de um metro ou mais de profundidade, cobrindo-os com material de solo revestido de 2 dm de altura m. ou m. O capuz de certo modo constitui micromonólito virado para cima do perfil do solo*

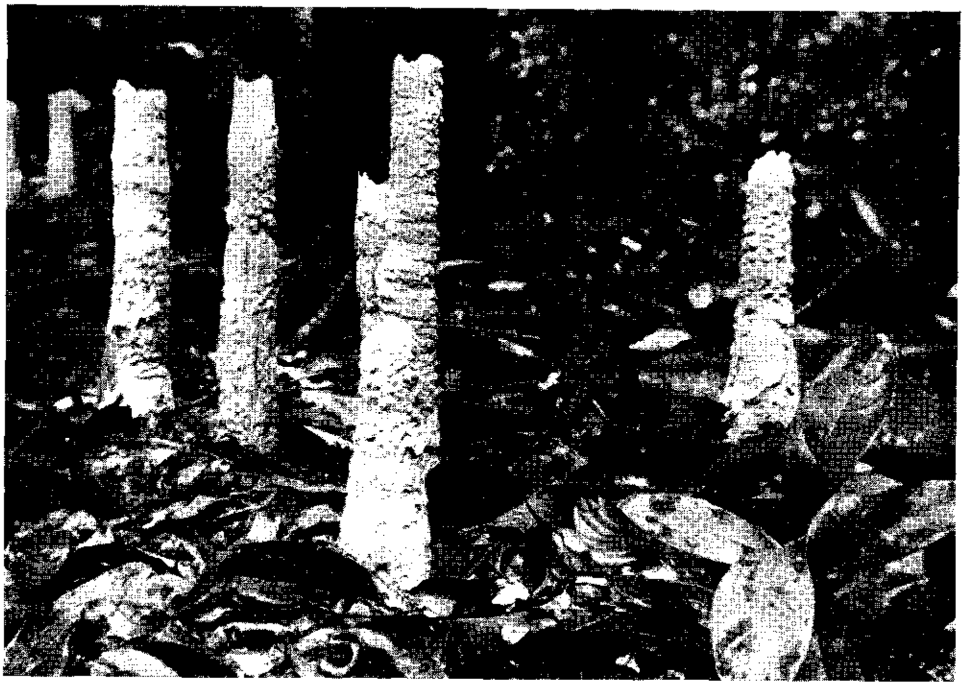


Photo 29 Cigarras. The constructions of the larvas of a cicade at the surface of the forest soil. The larva digs shafts of one metre depth and more and closes this with a hood of coated soil material of about two dm height. The hood forms a kind of upturned micro-monolith of the soil profile

mites and associated fungi, that of ants (notably the parasol ants), of larvas of beetles and crickets, of forest crabs, and also that of rodents, is very apparent everywhere in the forest soils (*cf.* Photos 29 and 30). Their effect on porosity and homogenisation of the soil profile must be enormous. No quantitative data are available regarding this effect. It is, however, noted that in the relatively heavy textured profiles, termites *(Cupins: Isoptera* order) and larvas of a certain cicade *(Cigarras: Cicadidae* family) predominate, while in relatively light textured profiles the activity of parasol ants *(Saúvas: Atta spp.)* and rodents *(e.g.* the *Tatú: Dasypoda sp.*) is most striking. Earth worms seem to be completely absent.

Permeability. The discussion is limited to the freely draining soils, thus those with good external drainage. There are differences in the internal drainage of these soils. The light and very light textured ones (KLS) may have a somewhat excessive internal drainage, due to rapid percolation of the rain water. For several of the soils, namely the KYL, c, the RP-KYL, and the RP-KYL, CR, the subsoil (B horizons) has apparently a somewhat slow permeability for water, resulting in only a moderately good internal

Foto 30 Os montões de terra deitado por uma colônia de saúvas (Atta *spp.*). *Estas formigas manejam hortas de fungos em liteira armazenada em cavidades no subsolo. A atividade das saúvas e demais fauna de solo, é um fator importante na homogenização do perfil do solo sob floresta*

Photo 30 The heaps of earth thrown out by a colony of parasol ants (*saúvas*, Atta spp.). *These ants maintain fungus gardens on litter which is stored in excavated chambers in the subsoil. The activity of the ants, together with that of other soil fauna is an important factor in the homogenisation of the forest soil profile*

drainage. There are no measurements available of the permeability of the various horizons of the soils under discussion.

Moisture equivalents and moisture tension curves. Of great importance is the amount of moisture that can be stored in the soil to be used by the plants during the dry season, since this season is fairly well defined in most parts of the Planície (*cf.* I.2). It is rather common to find, on forested terrain, at the end of the dry season, seemingly very dry subsoils, even when the profiles are relatively heavy textured.

The capacity of soils to retain moisture in available form depends upon the structure and porosity of the soil, the percentage and type of clay-sized particles, and upon the amount of organic matter. The moisture equivalent (M.E., given in grams of moisture per 100 g of soil), which gives an indication of the amount of moisture that can be stored in the freely draining soil, was determined for the disturbed samples of thirty-five forest profiles. In Fig. 35 the M.E. data of the B_2 horizons are compared with the clay content. The trend is very clear. The increase of M.E. with the increase in percentage of clay is not directly proportional for the whole clay-range, but for general dis-

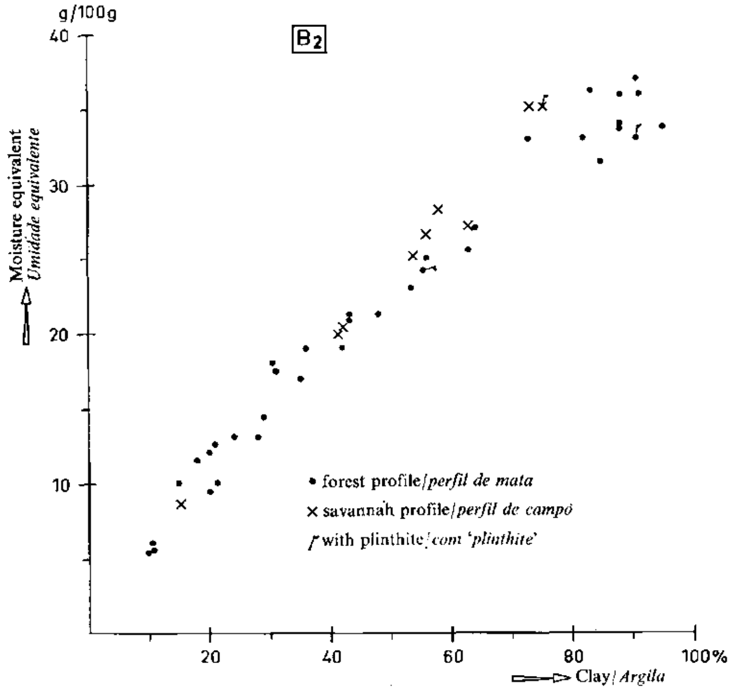


Fig. 35 Relação entre o equivalente de umidade e a percentagem de argila no horizonte B_2 de perfis de solos caoliníticos daPlanície de drenagem livre

Fig. 35 Relation between moisture equivalent and percentage of clay, in the B_2 horizon of profiles of freely draining kaolinitic Planície soils

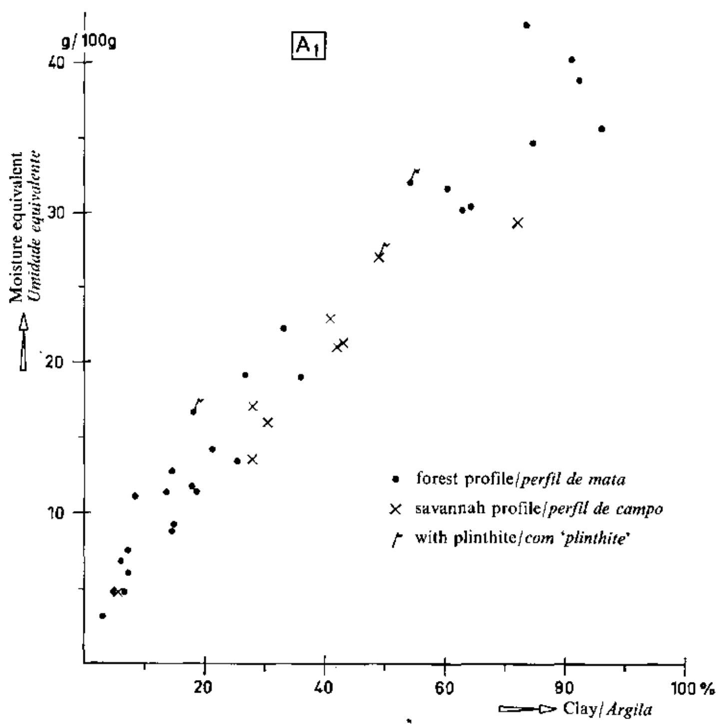


Fig. 36 Relação entre o equivalente de umidade e a percentagem de argila no horizonte A_1 de perfis de solos caoliníticos da Planície de drenagem livre

Fig. 36 Relation between moisture equivalent and percentage of clay, in the A_1 horizon of profiles of freely draining kaolinitic Planície soils cussion it can be said that the increase amounts to 3.6 g/100 g per 10% clay. The M.E. is generally low in comparison with that of less weathered soils, as for instance the Low Humic Gley soil of the Amazon floodplains. The data are still low when compared with those of other latosolic soils rather than the kaolinitic ones of the Planície. For latosolic-B horizons of São Paulo State, it is reported that in the medium range of textures the M.E. value is approximately half of the clay percentage, or 5 g/100 g increase per 10% clay (*cf.* LEMOS, BENNEMA, SANTOS *et al.*, 1960, p. 71).

The M.E. data for the topsoils of the thirty-five profiles are only slightly above the M.E.-% clay curve of the B_2 horizons. In Fig. 36 the situation for the A_1 horizons is given. A calculation, for samples with approximately the same clay content, reveals that 1 % Carbon accounts for about 1.7 g/100 g of the M.E. The part of the M.E. due to the presence of organic matter is therefore small in comparison to the part due to the mineral material, *i.c.* the clay fraction.

M.E. data alone do not give much insight in the availability of soil moisture for the plants, especially since the data are for disturbed samples. The availability is actually determined by the difference between the so-called field capacity (F.C.) and the wilting point percentage (W.P.) respectively. The former is the maximum amount of moisture that can be stored in the freely draining soil, the latter the amount of moisture held by the soil particles with a force larger than the maximally possible suction by the plant roots ('hygroscopic water'). This maximum suction is generally taken to be about 15 atmospheres.

A method much in use for detailed study of soil moisture availability is the determination of a so-called moisture tension or pF-curve of a natural soil sample (pF being the common logarithm of the soil moisture tension in cms water column). The Institute for Land and Water Management Research (I.C.W.) of Wageningen, Holland, kindly determined such curves on a dozen Amazon samples. The ones of subsoils (B horizons) of the soils under discussion are reproduced in Fig. 37. The moisture freed between pF 2.0 and pF 4.2, marking the F.C. and the W.P. respectively, is taken as the amount of available moisture (also called 'capillary water')[1]. This moisture may be taken to be stored in the smaller pores ('effective' pore diameter 20–0.2 micron). The lower part of the curve, below pF 2.0, concerns the water contained only at full saturation of the soil ('gravitational water'), stored in the larger pores ('effective' pore diameter > 20 micron).

Only a few determinations are involved, and the samples not all remained quite natural during transport. The curves of samples 231-3, 219-3 and 303-3 suggest nevertheless that the Amazon kaolinitic Latosols have the following moisture characteristics:

1. A considerable part of the soil moisture is not available for plant growth because it is too strongly held by the soil particles. When the percentage of clay is high, the fixed moisture is up to 35 vol. %.

[1]) Sometimes the M.E., which is at about pF 2.5, is taken as the lower limit, instead of the F.C. of pF 2.0. If this would be adopted for the Amazon soils, then the afore mentioned M.E. data should be converted, via apparent bulk density, to vol. %. It may be recalled that these M.E. data concern disturbed samples, not natural ones.

2. There is a high percentage of larger pores (25 vol. % *ca.*) which will be filled with air when the soil is in freely draining condition, and therefore do not contribute to the effective soil moisture storage.

Fig. 37 Curvas de tensão de umidade de amostras de alguns solos caoliníticos da Planície de drenagem livre e de alguns outros solos amazônicos. Por obséquio do Instituto I.C.W. de Wageningen, Holanda

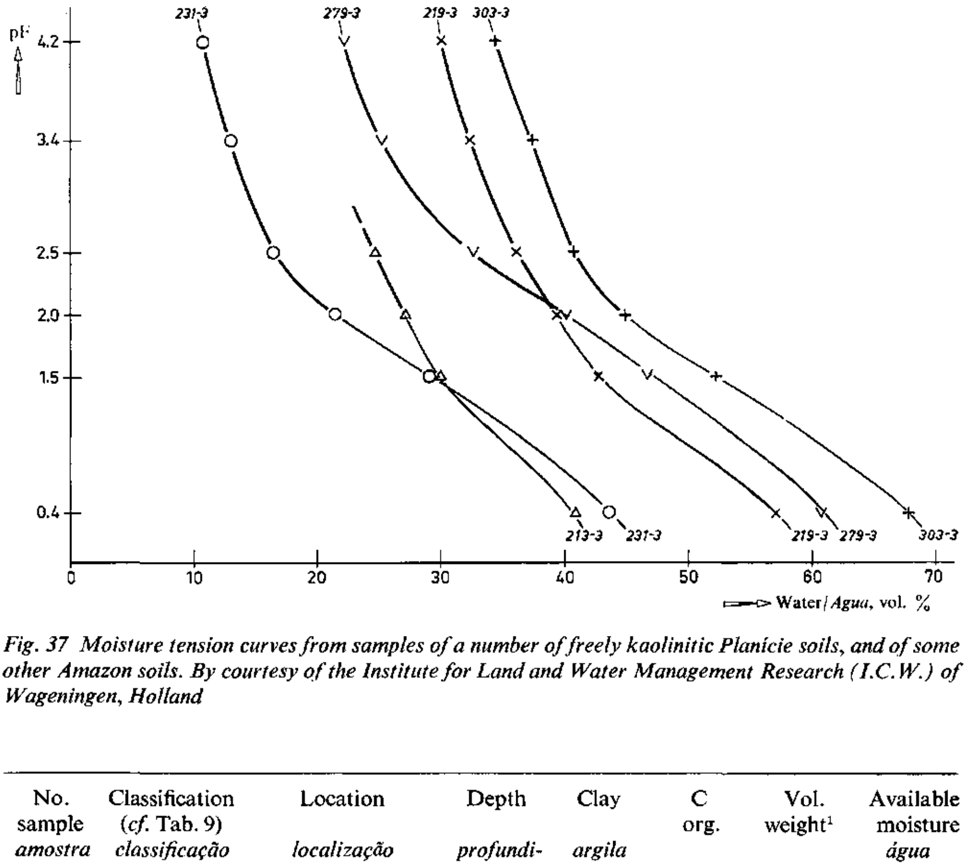


Fig. 37 Moisture tension curves from samples of a number of freely kaolinitic Planície soils, and of some other Amazon soils. By courtesy of the Institute for Land and Water Management Research (I.C.W.) of Wageningen, Holland

No. sample *amostra*	Classification (*cf.* Tab. 9) *classificação*	Location *localização*	Depth *profundidade* (cm)	Clay *argila* (% < 2 μ)	C org. (%)	Vol. weight[1] (g/cm³)	Available moisture *água disponível* (vol. %)
231-3	KYL_m	BR-14, km 58	100	24	0.22	1.34	**10.8**
219-3	KYL_{vh}	BR-14, km 324	80	80 *ca.*	0.45 *ca.*	1.09	**9.3**
303-3	KYL_{vh}	Curuá-una, km 14	80	86	0.50 *ca.*	1.24	**10.5**
213-3	$RP\text{-}KYL_{rh}$	BR-14, km 258	100	40 *ca.*	0.30 *ca.*	1.56	**9.0** *ca.*
279-3	DL, s	Araguaia (Rio Corda)	50	40	0.64	1.54	**20.2**

[1]) Volume weight = weight of 1 cm³ natural sample in completely dry condition (approximately equal to apparent bulk density)
peso de 1 cm³ de amostra natural em condição totalmente seca (aproximadamente igual à massa especifica aparente)

Table 15/Tabela 15 Description of the samples of Fig. 37/Descrição das amostras da Fig. 37

3. The amount of soil moisture available for plant growth (the part between pF 2.0 and pF 4.2) is small. In the samples under discussion it is only about 10 vol. %. A fully rooted subsoil of 1 metre thickness would have an effective soil moisture reserve which is equivalent to 100 mm rainfall. PEERLKAMP and BOEKEL (1960) give available moisture data ranging from 13.5 to 33 vol. %, for a number of Dutch soils of variable clay and humus content. Only for very sandy, humus-poor soils they give values that are the same or smaller than the Amazon ones.
4. Differences in texture have less effect on the amount of available moisture than might be expected considering the very distinctly higher M.E. values at higher percentages of clay, and keeping in mind that also the relatively heavy textured soils have the 'good' structure inherent to Latosols. The two very heavy textured subsoils (219-3, 303-3) even, do not have a greater amount of available moisture whatso-ever than the medium textured subsoil (213-3). Both former subsoils are actually relatively compact (they are both from central sections of planalto stretches, *cf.* IV.1.2) although this compactness is not so outstanding as to classify the soil as KYL, Compact phase. A really compact subsoil would have comparatively high volume weight and a steeper pF-curve, as borne out by the subsoil of the Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol (sample 213-3).

Heavy and rather heavy textured subsoils that are definitely non-compact are likely to have some more moisture available than non-compact medium textured subsoils as is sample 231-3, and non-compact light or very light textured subsoils likewise less available moisture. Preliminary field observations namely, suggest that for non-compact subsoils there is an increase in porosity with increase in clay content. This will apply also to the quantity of smaller pores, which largely determine the soil moisture availability. The field observations are being confirmed by the data on the B horizons of Table 16. Though the porosity data of this table have limited value, because they do not concern natural samples[1], the trend of increasing porosity with increase in clay content seems clear enough (the B_2 horizons of the profiles 216 and 112/42A may still be compared with the A_1 horizon of profile 226, since they have about the same percentage of Carbon).

The influence of the porosity on the soil moisture availability is still illustrated by the pF-curve of sample 279-3, which is of a Dark Red Latosol. This sample has nearly twice the amount of available moisture as those of the kaolinitic Latosols. According to field observations, this Dark Red Latosol profile is strikingly porous.[2] Its pF-curve bears this out, and the difference in porosity is apparently largely because of a higher amount of the smaller pores.

The non-compact subsoils of the kaolinitic Latosols never show as high a porosity as that of the discussed Dark Red Latosol. It seems therefore safe to assume that the available moisture of the former maximally varies between 5 vol. % (for the very light

[1]) Apparent bulk density and real bulk density were determined on only a limited number of samples, to which the ones of Fig. 37 do not belong.

[2]) That the volume weight of the sample is nevertheless high, is probably due to its much higher content of iron oxides.

Table 16 'Natural' porosity of freely draining kaolinitic Planície soils with non-compact subsoil, all under primeval forest cover. 'Natural' porosity is 100 × (1 – apparent bulk density/real bulk density). Determinations on disturbed samples

No. field descr. *número descr. de campo*	Classification (*cf.* Table 9) *classificação (cf. Tabela 9)*	Location *localização*	Depth *profundidade* (cm)	Org. Carb. (%)	Clay *argila* (% < 2 μ)	Bulk density *massa especifica* apparent *aparente* (g/cm³)	real *real* (g/cm³)	'Natural' porosity *porosidade 'natural'* (%)
			A_1 horizon/*horizonte A_1*					
169	KLS	Curuá-una, km 3	0–20	0.73	5	1.55	2.59	**40.2**
226	KRL_m	BR-14, km 429	0–20	0.69	7	1.49	2.63	**43.3**
206	KYL_m	BR-14, km 201	0–15	1.23	7	1.36	2.63	**48.3**
201	KYL-RP_{rh}	BR-14, km 117	0– 5	1.20	14	1.30	2.57	**49.4**
221	KYL_h	BR-14, km 341	0– 5	1.34	19	1.30	2.61	**51.2**
216	KYL_{vh}*	BR-14, km 291	0– 2	3.60	70	1.08	2.49	**56.6**
112/42A	KYL_{vh}*	Curuá-una, km 6	0–40	3.16	81	0.96	2.45	**60.8**
			B_2 horizon/*horizonte B_2*					
169	KLS	Curuá-una, km 3	300–400	0.08	15	1.46	2.65	**44.9**
226	KRL_m	BR-14, km 429	70–120	0.20	15	1.61	2.66	**39.1**
206	KYL_m	BR-14, km 201	130–210	0.19	20	1.49	2.66	**44.0**
201	KYL-RP_{rh}	BR-14, km 117	65–220	0.14	32	1.43	2.66	**46.2**
221	KYL_h	BR-14, km 341	70–140	0.28	64	1.26	2.70	**53.3**
216	KYL_{vh}*	BR-14, km 291	30–80	0.50	91	1.11	2.67	**58.4**
112/42A	KYL_{vh}*	Curuá-una, km 6	100–140**	0.60	82	1.06	2.62	**59.5**

* edge of planalto/*borda de planalto* ** B_3 horizon/*horizonte B_3*

Tabela 16 Porosidade 'natural' de solos caoliníticos da Planície de drenagem livre, com subsolo não compacto, todos cobertos de floresta primitiva. Porosidade 'natural' é 100 × (1 – massa especifica aparente/massa especifica real). Determinação em amostras destorroadas

textured kaolinitic subsoils) and 15 vol. % (for the very heavy, if not the heavy and rather heavy textured kaolinitic subsoils). It should be noted that, for the light textured ones, the fineness of the sand fraction may be of more importance for the soil moisture availability than the percentage of clay (*cf.* PEERLKAMP and BOEKEL, 1960).

The soil moisture availability situation for the topsoils may be different from that of the subsoils because of the concentration of the organic matter there. The influence of the humus on the soil moisture availability is described by several authors. That at higher levels of humus there is generally more moisture available is apparently not so much because of the presence of organic matter as such. BAVER (1956), for instance, shows that the simple adding of organic matter (peat) to soil material, though sharply raising the maximum moisture holding capacity of the mixture, only little raises the for plants available moisture, since most of the water is drained below the pF the of M.E. and also the W.P. percentage somewhat increases. The influence of the organic matter should be largely indirectly, via its positive influence on the structure, *i.e.* the porosity. For the Latosols, with their inherent good structure, this influence cannot be very large. From Table 16 an impression may be gained on the extent of this influence for the Amazon kaolinitic Latosols, under their natural forest cover. There is mostly a fair difference in 'natural' porosity of A_1 horizons and B_2 horizons respectively with about the same clay content, but different percentages of Carbon. The topsoils under discussion therefore, are liable to have somewhat more moisture available than subsoils of comparable clay content. Secondly, for topsoils there is likely to be a more distinct increase in the amount of available moisture at an increase in the clay content than in subsoils, owing to a larger increase of the percentage of organic matter with increase of the percentage of clay (see before). There were no pF curves determined on topsoils and therefore, exact data about their volume percentages of available moisture are lacking. By combining however the relevant data on the part of the M.E. which is accounted for by the presence of organic matter, on maximum percentage of Carbon in topsoils, and on the apparent bulk densities, it is estimated that the addition of available moisture in topsoils, in comparison with subsoils, varies maximally between 1 vol. % (when very light textures are involved) and 5 vol. % (when heavy and very heavy textures are involved). The range in available moisture of topsoils therefore may be maximally between 6 and 20 vol. %.

By way of summary, it may be said that the kaolinitic freely draining Planície soils under forest cover have, as a whole, only small amounts of available moisture per volume unit. The advantage of the clayey above the sandy soils with regard to moisture availability is fairly distinct only for topsoils. For subsoils the difference is smaller, and even non-existent when the clayey ones are compact.

The phreatic level is very deep in practically all freely draining Planície soils. Therefore the ground water does normally not constitute a source of moisture for the plants during the dry season. Only on the youngest Pleistocene terraces (3–4 m$^+$) it may be of some value for the vegetative cover. For the upper part of the Guamá-Imperatriz area, for instance, there are indications that the gross timber volume of the primeval forest on such terraces is slightly higher than on adjoining, higher terraces with soils of the same texture.

Penetration of roots. The bulk of the roots, and especially the rootlets, of the forest vegetation, is found very near to the soil surface. A number of the rootlets are even above the soil, particularly in light textured soils, namely in the litter layer. They collect the nutrients from the decaying litter, and also rainwater. But the deeper roots are also very important, not only in providing ground support for the trees. The available moisture in the soil can only be utilised to the full if the root system is dense and deep. With the low natural fertility of the soils under discussion, a deep rooting system is also of importance for collecting whatever nutrients are still present in the deeper subsoil.

No quantitative data are available on the rooting systems of the components of the primeval forest, on the various freely draining kaolinitic Planície soils. During the reconnaissance soil surveys reported in this thesis it was, however, noticed that on several of these soils the penetration of roots is hampered to a degree. This applies particularly to the RP-KYL, the RP-KYL, CR and the KYL, C. The mentioned soils have B horizons of a comparatively large compactness and considerable resistance to penetration with a soil hammer. These B horizons have a firm or rather firm consistence and the colour transition from the A horizon is often clear.

In profile pits and on recently cut road embankments, the hampering of the root development in these subsoil was easily noticed. Also, fallen trees provided for indications; although the root systems of the various tree species can be very different, the lump of earth thrown out with the roots rarely contained more than one or two dm of such a contrasting B horizon. Notably on the RP-KYL, CR of the northern part of the Guamá-Imperatriz area, on the RP-KYL_{rh} around km 270 of this area and on the KYL, C_{vh} of the km 140–km 190 section the rooting is relatively shallow. For the KYL, C_{vh} moreover, the frequency of fallen trees was observed to be comparatively large. For the rooting situation in the very heavy textured soils in general (Belterra clay soils), reference should be made to the discussion on the cause of the cipoal and the 'cipoalic' forest (IV.1.2).

The soil KYL-RP_{rh} of the section around km 110 of the Guamá-Imperatriz area, in contrast, is deeply rooted. This soil has also a clear colour change from the A to the B horizon, but the latter is friable and has very little compactness.

A deep rooting is a consistent feature of the medium and light textured soils, such as the KYL_m and the KLS. In the latter it may comprise several metres.

V.3.1.2 *The Soils under Influence of Man*

THE SOILS UNDER THE SHIFTING CULTIVATION SYSTEM

For Amazonia, no data are available as to the amounts of nutrients accumulated in the primeval forest cover. It is presumed that these amounts are larger than the nutrient storage in the forest soil itself (*cf.* also NYE and GREENLAND, 1960), if timber volumes are not exceptionally low. It is well known that immediately after felling and burning of the forest, the fertility of the soil increases considerably. This is, because a part of the nutrients accumulated in the vegetation and litter are stored suddenly, via the ash, in the upper soil layer in an easily available form. The temporary high nutrient content of the topsoil and the increased rate of mineralisation of the humus cause a vigourous growth of the first crops (*cf.* Photo 31). However, during the rainy seasons that follow after the burning, the rains, falling on the unprotected surface, cause surface wash ('fertility erosion') and leaching of the soluble salts, that were freed from the ash and the mineralising humus, to deeper soil horizons. Surface wash and leaching, the irretrievable loss of nutrients by crop removal, and the gradual decrease of soil organic matter content, are causes of a fairly rapid decline in fertility of the soil once it is cultivated. Only the planting of fast-growing and deeply rooting perennials may keep such a decline in check. Normally however, cultivated plots are abandoned, also because of the proliferating of weeds, after two or three years, and a new *roça* is started elsewhere. The abandoned plot gradually becomes fully covered with weeds and fast growing, sunloving saplings. This is followed by bush, and ultimately secondary forest:

capoeira when young, *capoeirão* when old. This fallow, besides smothering of the weeds, is thought to be able to replenish the body of stable soil humus. It also regains gradually, by its deep rooting, the nutrients leached to the deeper subsoil and accumulates them again in the vegetative cover. Eventually, the equilibrium of the primeval forest and forest soil will be nearly reached (according to LAUDELOUT, 1962, the replenishment of the soil organic matter is ensured within a few years, whilst a full re-accumulation of the nutrients in the vegetative cover requires much more time). After a varying number of years, the secondary forest is felled and burned anew, and a new cropping cycle starts.

Not enough data is available on freely draining kaolinitic Planície soils under shifting cultivation to ascertain general trends in the changes in soil qualities that may take place under the successive cultivation cycles. An establishment of such trends, and a comparison with the situation under primeval forest cover, may be possible once the data of the reconnaissance soil survey of the Bragantina area (FILHO *et al.*, 1963) are fully known. Reference may also be made to several publications on the effects of

Foto 31 O sistema de agricultura itinerante. Exemplo da cultura do primeiro ano numa roçada dentro da floresta primitiva. Entre os troncos de árvores meio-queimados espalhados pela superfície do solo, plantam-se arroz e milho. No fundo vê-se uma faixa de mandioca. Perto da casa se faz uma queimada

Photo 31 The shifting cultivation system. An example of the first year crops on a plot of agriculture (roçada) within the primeval forest. Between the half-burned tree stems lying strewn on the soil surface, rice and maize is planted. In the background a patch of cassava can be seen. Some burning is taking place near the dwelling

shifting cultivation elsewhere in the tropics, in particular those concerning West and Central Africa, which regions have, for a part, soils comparable with those of the Amazon Planície (*cf.* II.2.3). In particular the previously mentioned, comprehensive studies of NYE and GREENLAND (1960) and LAUDELOUT (1962?) contain many data on the effects of cropping periods, and of fallow of secondary forest or grassland, on the qualities freely draining, usually highly weathered soils of tropical Africa.

If the fallow periods are allowed to last long enough, then the long-range decline in agricultural potential of the soils is apparently very limited. With relatively short fallow periods however, definite degeneration of the land is unavoidable. Re-burning is done too soon to secure full recovery of the land under the fallow, which now reaches only the bush stage. In every new cropping period therefore, lower yields are obtained.

The latter is apparently the case on parts of the Bragantina area, and on the uplands along the lower Tocantins (Cametá), which are both regions where shifting cultivation has been practised for more than fourty years. BIARD and WAGENAAR (1960), for instance, mention that in the Bragantina area much capoeira of six to ten years old is being used at present, although people are aware that much better results would be obtained if felling were delayed until the capoeira is twenty years old. A plot of an eight years old capoeira, in an area where the virgin forest was felled about fourty years ago, would yield only half the crop value of a virgin forest plot.

Although in Amazonia, as a whole, land is still abundant, there is an actual shortage of land around the established rural population centres, such as those of the Bragantina area. This results in a local overcropping of the land under the shifting cultivation system in its present day form.

There seems to be no clearly defined preference for shifting cultivation on one of the various soils discussed. Very light textured ones, however, are avoided, partly because they easily erode.

The majority of the present-day Amazon shifting cultivation is found on light and medium textured soils (KLS; KYL_m). Concretionary soils (KYL, CR and RP-KYL, CR) are also used. The stoniness of the latter is apparently not a major disadvantage. That the relatively heavy textured soils are little used, is largely because they are normally found farthest from the land and water transport routes. For the very heavy textured soils (KYL_{vh}; KYL, C_{vh}), a difficult supply of drinking water, and a slightly less easy tillage, may constitute additional factors accounting for their sparse occupation. Wherever such Belterra clay soils are, however, in agricultural use, for instance south of Santarém, the yields are comparatively very satisfactory.

THE SOILS UNDER ANTHROPOGENIC SAVANNAH

To which changes in soil qualities a repeated burning of the vegetation may lead ultimately, may be ascertained by studying the freely draining kaolinitic Planície soils under savannah. As has been discussed in IV.2.1, the savannahs on such soils are considered to be anthropogenic. They occur in Amapá Territory, in parts of the Lower Amazon region, and locally on the eastern part of Marajó island.

Analytical data are available on nine profiles of freely draining kaolinitic Planície soils under savannah, largely from Amapá Territory[1] (*cf.* Figs. 27 to 36).

The percentages of Carbon in the topsoils are, on the average, about 0.5 % Lower than those of forest topsoils (*cf.* Fig. 27). At 100 cm depth, and in the B_2 horizons respectively, the difference with the forest profiles seems to be less, if it exists at all (*cf.* Figs. 28 and 29). The ratios between T values and the percentages of Carbon, considering all horizons, are equal or only slightly below those of forest profiles (*cf.* Fig. 30). The above implies that, when compared with the ratios of forest topsoils and forest subsoils, the ratios of T: % clay are probably lower in the topsoils of the savannah profiles, but the same, or only slightly lower, in the savannah subsoils (*cf.* Fig. 31).

The C/N value of the savannah topsoils (A_1 horizons) is, on the average, 13.0, both for the relatively light and for the relatively heavy textured ones. At 50 cm depth the average value is 12.0 and at 100 cm depth 10.0. The C/N values of the savannah profiles are therefore 2 to 3 units higher than those of forest profiles[2].

The exchangeable metallic cations comprise a small part of the T value. The base saturation is approximately the same as that in forest profiles.

The savannah profiles are usually slightly less acid than the forest profiles, possibly owing to the repeated burning. The pH-H_2O value in the topsoil (A_1 horizons) of the nine profiles varies between 4.7 and 6.3. In the subsurface soil (A_3 or A_2 horizons) the variation is between 4.8 and 5.9, and in the subsoil (B horizons) it is between 5.2 and 6.2. The difference between pH-H_2O and pH-KCl is slightly larger than in the forest profiles. Both in the upper and the lower part of the savannah profiles it averages 1.0. The variation is however comparatively large.

For six of the nine profiles, the cation exchange complex was analysed in detail (*cf.* Table 14). The relative proportions of the exchangeable metallic cations are approximately equal to those of the forest profiles, except for K^+ which is clearly lower. The absolute amounts of K^+ rarely exceed 0.06 m.e./100 g.

The data for active acidity and pH-dependent acidity (Table 14) do not suggest any consistent difference on the acidity situation with that of the forest profiles.

The few data on available P (mainly Bray method), suggest that there is not such a great difference between the availability in the topsoil and that in the subsoil as in the forest profiles; the amount of available P is comparatively low also in the topsoil (*cf.* Fig. 33). This is probably related with the previously mentioned difference in the distribution of the organic matter. The values for total P are comparable to those of forest profiles. The ratios P_2O_5-total : P_2O_5-Bray do not exceed 150, even in the subsoil with its low level of organic matter content (*cf.* Fig. 34). The few data suggest that the degree of fixation of the soil phosphorus may be somewhat less than in forest profiles (the non-plinthitic savannah samples, indicated in Fig. 34, have all less than 50 % clay, the two plinthitic ones both more than 50 % clay).

[1]) The data of profiles AP_1 and AP_8, described in the study of CARNEIRO (1955) on the Amapá savannahs, might also be used for comparison.

[2]) KLINGE (1962) gives much higher values for C/N ratios of *Braunlehm* or *Podzoliger Braunlehm* under savannah, namely up to 90. See also the note at page 235.

The structure of the savannah profiles is, generally speaking, comparable to that of the forest profiles. However, the surface is sealed owing to rain splash. In the light textured profiles gully erosion may be severe, as can be observed at Santarém and Monte Alegre towns. The very heavy textured ones, on the other hand, may be subject to considerable sheet erosion. With the exception of the very light textured ones, all savannah soils under discussion have a comparatively large compactness, especially in the topsoil. Pores are sparse and fine, and the consistency is often slightly firm, to firm. There is also a somewhat larger textural difference between topsoil and subsoil, when compared with forest profiles of the same over-all texture. The larger textural difference and the compactness is likely to be related to the fact that, possibly termites excepted, the activity of the soil fauna is less than in forest profiles.

No pF-curves for samples of savannah profiles were determined, so that no definite data can be given for the amounts of available moisture. In view of the soil compactness and the lower level of the organic matter content in the topsoil the amounts may be expected to be lower than in forest profiles of comparable texture. In this respect it is, however, noteworthy that the data for moisture equivalent of savannah subsoil (B_2 horizons) are the same or slightly higher, and those of savannah topsoil (A_1 horizons) the same or only slightly lower, than those of forest subsoil and forest topsoil respectively (*cf.* the Figs. 35 and 36).

By way of summary it can be said that the qualities of the freely draining kaolinitic Planície soils under long-lasting anthropogenic savannah are still fairly well comparable to those of forest soils of the same character. The main differences are a somewhat lower organic matter content of the topsoil – and consequently a somewhat lower potential cation exchange capacity (T) and lower amounts of exchangeable cations and anions –, a larger soil compactness, and presumably a lower quantity of available moisture. Slight differences are found in the C/N ratios, the values for pH-H_2O, and the degrees of phosphorous fixation. But the picture changes, of course, much to the disadvantage of the savannah soils if one takes into account the nutrients accumulated in the respective vegetative covers.

The soils influenced by pre-Columbian Indian occupation

Throughout the Planície of Amazonia patches of so-called Terra Preta soil can be found. In III.3.4 it has been described that these patches are a kind of 'kitchen-midden', which have acquired their specific fertility from dung, household garbage, and the refuses of hunting and fishing. The Terra Preta (TP) soil of the Planície is kaolinitic in character and usually freely draining. It gives therefore an excellent opportunity for study of the permanent changes in the qualities of freely draining kaolinitic Planície soils which may take place, under the prevailing warm and wet climate, as the result of soil improvement activities of man over a long period of time.[1]

Although, understandably, there is a great variation in the chemical and physical

[1]) Their study is also of importance because of an allegedly smaller susceptibility of rubber trees, planted on patches of TP, for the notorious fungus *Dothidella ulei*.

qualities of the TP profiles, related with stronger or weaker and shorter or longer lasting Indian influence, some specific trends can be clearly discerned.

Analytical data of five profiles of TP are available. The profiles are all from patches now cultivated but not settled on. Two of the profiles are of the common relatively light textured variant of the soil, having 12 to 20% 'silt + clay'; the other three are of the infrequently found very heavy textured variant, having more than 80% 'silt + clay'. (The silt and clay fractions are taken together, because of the probability that, with the relatively high organic matter content, a good part of the determined 'silt' is actually non-dispersed clay).

The blackish toplayer, containing pieces of ceramics, is normally less than 50 cm thick, sometimes as thick as 100 cm. In the very heavy textured variant, the percentage of Carbon is 4 to 5% in the upper 20 cm of this blackish layer, and 1 to 2% in the part below. In the relatively light textured variant, the percentage of Carbon is 1 to 2% in the upper 20 cm of the blackish layer, and 0.5% in the lower part. Thus, despite the very humic appearance, the present organic matter content of the blackish layer is only moderately high. It is roughly two times the average values for non-enriched freely draining kaolinitic Planície soils of comparable clay content (*cf.* Fig. 27). The blackness of the colour is probably due to a complex formation of organic matter and Ca^{++}, which may form a coating on the soil particles. In the yellowish subsoil of the TP, the percentage of Carbon is nearly identical to that of the B_2 horizons of non-enriched soils (*cf.* Fig. 29). It is about 0.6% in the very textured variant, and 0.3% in the relatively light textured variant.

The C/N values are slightly higher than those of non-enriched profiles. This is true for the whole of each profile, but especially for the lower part of the blackish layer, where it is, on the average, 18. In the upper part of the blackish layer the value is, on the average, 14, and in the yellowish subsoil 13.

The potential cation exchange capacity (T value) is relatively high, even when compared with the higher organic matter content. Fig. 38 shows that the points for the TP are all above the line of the average ratio T:%Carbon of non-enriched forest profiles (*cf.* Fig. 30). It is emphasized that, when there is any decrease of the SiO_2/Al_2O_3 ratio (Ki value) with increasing depth at all, it comprises maximally 0.08 unit. All horizons of all five profiles have Ki data between 1.71 and 1.95, except for one subsoil sample which showed Ki = 2.2. In comparison to this, values slightly over 2.0 less rare in the non-enriched kaolinitic Planície soils. It can therefore be taken as certain that the higher T values of the TP are not due to a presence of small amounts of silicate clay minerals considerably more active than kaolinite. It might be concluded that the chemical activity of the organic matter of the TP is much higher than that of the non-enriched profiles. There are, however, fairly great differences in T value, namely up to 10 m.e., where percentages of Carbon and percentages of clay are identical. It is interesting to note that the T values show a fairly good correspondence with the amounts of phosphate in the TP. The latter are strikingly high, though with a large variation. In figure 39, the 'surplus value' of T (*i.e.* the amount above that of the T-%Carbon line of non-enriched forest profiles) is compared with the 'surplus value' of P_2O_5-total (*i.e.*

the amount of P_2O_5-total of the TP, less the small amount of P_2O_5-total which is present in non-enriched profiles of comparable clay content; the latter is 0.02% for the relatively light textured variant, and 0.05% for the very heavy textured variant; *cf.* V.1.1). It can be seen that, below 0.30%, the 'surplus value' of T increases about proportionally with the 'surplus value' of P_2O_5-total.[1] In this section, one per cent 'surplus value' of P_2O_5-total corresponds with four m.e. 'surplus value' of T. Above 0.30% 'surplus value' of P_2O_5-total, the increase of T is apparently more gradual. It may be wondered how the high amounts of phosphates favourably influence the potential cation exchange capacity. For the topsoils, it seems likely that the phosphorus enlarges the activity of the organic matter, by having entered in a complex formation with it.

For the subsoils, however, which are poor in humus, such a complex forming alone seems no sufficient reason for their higher T values. Reference may be made to the publication of CATE (1960). He studied in detail two freely draining kaolinitic Planície soils from the Curuá-una centre, being a KLS and a KYL_{vh} respectively. He observed that the potential cation exchange capacity increased considerably after equilibration of the soil samples concerned with 0.01N H_3PO_4, for 25 hours. Except for the topsoil of the KLS, the increase was more than 100%, this also being true for the deeper subsoil with its low organic matter content.

The exchangeable metallic cations comprise a comparatively large part of the T value. The base saturation V is between 30 and 85%. In the blackish layer the average percentage is 65%, and in the subsoil 50%. The relative proportions of the exchangeable metallic cations are strikingly different from those of non-enriched soils. For 5 of the 6 profiles (in one of the relatively light textured profiles no detailed analysis of the metallic cations was executed), the Ca^{++} varies between 20 and 77% of the T value, and the average is 55%. In the blackish layer, the percentage is often higher than in the subsoil; the absolute amounts of Ca^{++} in the former layer can be as high as 25 m.e./100 g. For Mg^{++}, the variation is between 4 and 16% of the T value, with an average of 8%. The percentage of Mg^{++} is normally less than one-fifth of the percentage of Ca^{++}. The K^+ and Na^+ together always comprise less than 2% of the T value. Their relative proportions and their absolute amounts are fully comparable with those in non-enriched soils. It can be concluded that the enrichment with metallic cations concerned very predominantly Ca^{++}, to a small degree Mg^{++}, but no K^+ and Na^+.

Understandably, the TP soil is less acid than its non-enriched relatives. The pH-H_2O varies between 4.7 and 6.4. In the blackish layer the average value is 5.8 and in the subsoil 5.3. In both the blackish layer and the subsoil the difference between pH-H_2O and pH-KCL is about 0.9. The active acidity, or the $(Al)^+$, is small, when it exists at all. In the three profiles of the very heavy textured variant, $(Al)^+$ comprises less than 3% of the T value in the blackish layer and less than 15% in the subsoil. In these three profiles the pH-dependent acidity, or the H^+, is about 25% of the T value in the blackish layer, and about 40% in the subsoil.

[1]) The determination of P_2O_5-total for the two relatively light textured profiles is less reliable than the determination for the very heavy textured profiles. The latter were analysed a few years later, when the method for determination of P_2O_5-total was improved.

Fig. 38 Relação entre a percentagem de Carbono e o valor T nos perfis de Terra Preta da Planície

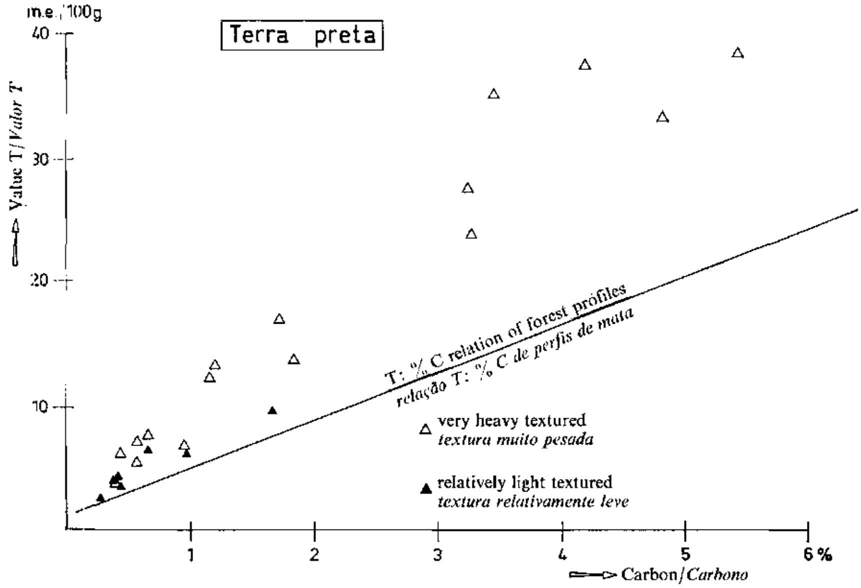


Fig. 38 Relation between percentage of Carbon and value T, in Terra Preta profiles of the Planície

Fig. 39 Relação entre o valor 'excedente' T e o valor 'excedente' de P_2O_5-total em perfis de Terra Preta da Planície

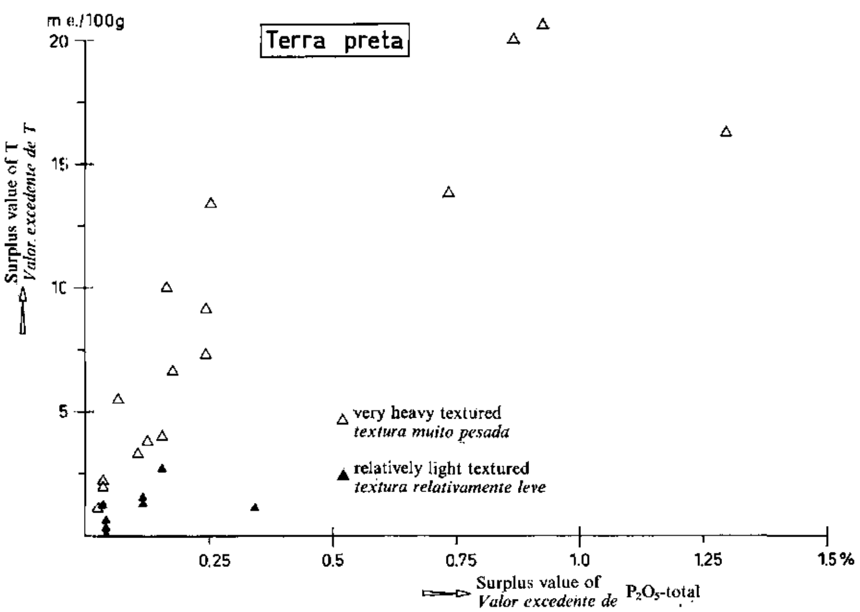


Fig. 39 Relation between 'surplus' value of T and 'surplus' value of P_2O_5-total, in Terra Preta profiles of the Planície

As already mentioned, the amounts of phosphorus are comparatively very high in the TP soil. In the very heavy textured variant, the amount of available P (Bray method) varies between 6.5 and 66.0 mg P_2O_5/100 g of soil (average 40) in the blackish layer, and between 3.8 and 65.1 mg/100 g of soil (average 35) in the subsoil. In the relatively light textured variant, the amount of available P (Truog method) varies between 3.2 and 98.8 mg P_2O_5/100 g of soil (average 40) in the blackish layer, and between 6.7 and 31.2 mg/100 g of soil (average 20) in the subsoil.

The amounts of total P are between 120 and 1.350 mg P_2O_5 /100 g of soil (average 950) in the blackish layer of the very heavy textured variant, and between 80 and 300 mg P_2O_5/100 g of soil (average 150) in its subsoil. In the relatively light textured variant[1], the values for P_2O_5-total are between 60 and 370 mg/100 g of soil (average 150) in the blackish layer, and between 70 and 140 mg/100 g (average 100) in the subsoil.

To assess the degree to which the phosphorus is fixed in the TP soil, the P_2O_5-total : P_2O_5-Bray ratios were calculated for the three profiles of the very heavy textured variant. The values are below 25 in all horizons, even in the subsoil where the percentage of Carbon may be lower than 0.5%. Hence the values for the TP soil do not agree with the curves for non-enriched kaolinitic soils (*cf.* Fig. 34). It seems that the total amount of phosphorus of the TP soil is considerably greater than the fixing power of the humus-poor soil material.

The relatively high C/N values imply that the nitrogen may be in short supply. It is noted that Klinge (1960), who determined Carbon and Nitrogen data for two TP profiles, gives values for mineral N (in percentage of the total N) that are comparable to those of non-enriched forest profiles. The ratios $N\text{-}NH_4^+ : N\text{-}NO_3^-$ are however lower, especially in the TP topsoil, due to higher values for $N\text{-}NO_3^-$.

The moisture equivalent data for the three very heavy textured profiles vary from 36 to 41 g/100 g and from 34 to 37 g/100 g, for topsoils and subsoils respectively. In the relatively light textured profiles, the range is from 8 to 12 g/100 g and from 7 to 9 g/100 g respectively. These values are comparable to those of topsoils and subsoils of non-enriched forest profiles (*cf.* the Figs. 35 and 36). The amount of available moisture in the TP is likely to be slightly larger than that of non-enriched forest soils. As regards other physical qualities, the TP seems comparable with its non-enriched relatives.

The soils under manuring and fertilizing

Chemical fertilizers and animal and green manures are applied locally to the freely draining kaolinitic Planície soils, namely on the limited acreage with permanent agriculture. The latter involves the growing of vegetables and fruits on plots near the towns, of pepper mainly by Japanese small farmers, and of rubber on recently established smallholdings and a few commercial estates (Pirelli, Goodyear). A systematic collection of data concerning the responses to, and the economy of, the applications of fertilizers and manures is badly lacking.

Fundamental experiments on the effects of fertilizers or manures with annual or

[1]) *Cf.* note page 254.

perennial crops, on the various soils, and with different rotation systems, were completely lacking until a few years ago. However, after the establishment, in 1939, of the *Instituto Agronômico do Norte* (IAN) at Belém, with several Experimental Substations throughout Amazonia, research in this respect has gradually been taken up. The data obtained so far are still piecemeal and little conclusive. Future fully fledged research will certainly provide for more definite data on the best systems for fertilizing and manuring.

The IAN trials on freely draining kaolinitic Planície soils concern mainly those on the *terra firme* area of the IAN terrains on the outskirts of Belém. The soils concerned are relatively light textured (KYL_m) predominantly, while a small part is concretionary. Much of the area was cleared of its primeval forest cover many years ago. The following data are partly summarised from expositions at the *Primeira Reunião de Agronomia do Norte do País*, Belém 1962 (the full descriptions of these trials are being published in the *Boletins Técnicos* of the Institute).

Beans *(Feijão: Phaseolus vulgaris)*, were fertilized with powdered lime one month before planting. Statistics did not reveal any significant differences in yields of the control plots and those with 2, 4, 6 or 8 ton/ha of lime. The application of N, P and K (100 kg/ha of chili saltpetre, 500 kg/ha of super phosphate, 200 kg/ha of potassium chloride), in various combinations, did not show any significant increase in yield.

Corn *(Milho: Zea mais)*, planted on plots just cleared from forest, was treated with 2 ton/ha of lime. The liming resulted in a highly significant increase in yield. On the other hand, the application of N, P and K (300 kg/ha of chili saltpetre, 400 kg/ha of super phosphate, 100 kg/ha of potassium chloride), in various combinations, did not result in any significantly higher yields. The same crop was planted on a plot that already had been cultivated for three years, now being added 15 ton of animal manure, 1 ton of lime, 300 kg of chili saltpetre, 400 kg of super phosphate and 100 kg of potassium chloride per ha. The yield compared very favourably with the low yields of corn normally obtained on such exhausted plots, but the cost of the fertilizing was almost as high as the gross revenue.

Oil palm *(Dendê)* is not indigenous, and not commercially cultivated as yet in Amazonia. At IAN however, various plots have been planted with the palm *(Elaeis guineensis, Elaeis melanococca,* and the various varieties and hybrides of these). From the manner of the growth of the plants it has been concluded by technicians of Unilever Cie and of IRHO[1], among others, that the palm adapts itself well to Amazon conditions. Dura × Dura crossings, for instance, have given fairly high yields, although foliar analysis, at the Royal Tropical Institute in Amsterdam, Holland, showed a deficiency of K^+ and probably also of Ca^{++}. Fertilizer trials on these plots are at present in execution.

[1]) *Institute de Recherches pour les Huiles et Oléagineux*, Ivory Coast.

Though the planting of rubber *(Borracha: Hevea brasiliensis* and crossings) in Amazonia has been greatly stimulated, there is no exact data on which to base fertilizing schemes for this perennial. On IAN terrains the fertilizing takes place according to the formula N : P : K = 8 : 12 : 10. At Pirelli Estate near Belém, where the soils are largely concretionary (KYL, CR) the formula applied is 10 : 10 : 10; at Goodyear Estate, which is located 100 km east of Belém and has sandy soils (KYL_m; KLS), the fertilizer application is on a 8 : 16 : 9 basis (HUFFNAGEL, 1964).

Pepper *(Pimenta do reino: Piper nigrum)* was introduced in Amazonia in the thirties, by Japanese colonists. In recent years, this crop has rapidly expanded, notably at Tomé-Açú, and in the surroundings of Belém. Fertilizing is essential for this intensive crop; without it only 1 kg yield per plant may be obtained, while with liberal application of fertilizers 8 kg can be reached. At Tomé-Açú colony, where the soils are rather heavy textured mainly (KYL_{rh}), the avarage yield of full grown plants is 4 kg when both inorganic fertilizers and manures are applied. Manuring in the colony comprises the mulching with grass fodder *(Capim-da-colônia: Panicum nimidium)* as well as the application of refuses of oil rendering palm fruits. No use is made of legumes, because of associated dangers such as contamination of the soil with nematodes (by *Indigofera pascuorum)* and strangling of the pepper plants (by *Pueraria phaseoloides)*. DAY (1961) estimates yields of 2 to 3 kg per full grown pepper plant, on relatively light textured soils near Belém (KYL_m or KLS), with an application of 0.5 kg of mixed chemical fertilizer per plant per year.

For silviculture, the application of fertilizers is being tried too. PITT (1961) reports on the effect of phosphate addition on the artificial regeneration of several tree species. The application of 'half a dessert spoon' of rock phosphate or super phosphate did not show any effect on plots at Curuá-una centre. The plots had just been cleared from their primeval forest cover, and were located either on the planalto with its very heavy textured soil (KYL_{vh}), or on the lower terrains with their light textured soils (KLS). The application of the same amount of these phosphates was, however, essential for the growth of tree seedlings on plots in the upland savannah area of Amapá territory, with heavy textured soil (KYL_h).

As regards pasturing the following can be said. Data as to the mineral imbalances in Amazon cattle and the nutrient content of the soils on which they graze, are given in the combined veterinary – pedological study of SUTMÖLLER *et al.* (1964). The study reveals that the soils of the upland savannahs in Amapá territory, in the Lower Amazon region and on eastern Marajó island are deficient in several micro nutrients (Cobalt, Manganese), as well as in phosphate and potassium. The soils concerned mainly are freely draining kaolinitic Planície soils (*cf.* IV.2.1). As to the improvement of pastures on kaolinitic Planície soils, trials may be mentioned on *teso* terrains[1] at the

[1]) The soils concerned are not quite freely draining (*cf.* DAY and SANTOS, 1958).

artificial insemination station of São Salvador, near Soure (NIEUWENHUIS, 1960). Introduced *Pangola grass (Digitaria decubens)*, *Elephant grass (Pennisetum purpureum)*, *Mucunã (Stizolobium deeringianum)* and *tropical Kudzu (Pueraria phaseoloides)* were growing well on these terrains, and responded favourably to the addition of chemical fertilizers.

An interesting example of mixed farming on freely draining kaolinitic Planície soils is practised locally in the Bragantina area. Tobacco is planted in this area on plots used previously as temporary pens for cattle which graze on nearby lowlands (*cf.* SOARES, 1956).

Reference may be made to the favourable results of additions of chemical fertilizers on the growth of sugarcane and other crops on the *taboleiro* uplands near Campos, in Rio de Janeiro State. These uplands have soils that are much comparable to the Amazon soils under discussion.

V.3.1.3 *The Soils with Horizons of Fossil Plinthite*

The freely draining kaolinitic Planície soils with horizons of fossil plinthite, hard or soft, are KYL, CR, and RP-KYL, CR. Seen as a whole, their chemical and physical qualities are comparable with these of non-plinthitic freely draining kaolinitic soils.

It is especially noteworthy that plinthitic soil horizons do *not* have a higher degree of fixation of the soil phosphorus present (*cf.* Fig. 33). Analysed plinthitic topsoils under forest cover have a base saturation which varies from 34 to 20%, and is therefore slightly above the average value for non-plinthitic topsoils. For plinthitic subsurface and subsoil horizons, no consistent difference in this respect appears. Plinthitic topsoils seem to have a comparatively high percentage of organic matter (*cf.* Fig. 27), plinthitic subsoils however have a relatively low percentage (*cf.* the Figs. 28 and 29). The potential cation exchange capacity (T value) of these subsoils is nevertheless not consistently different from what may be expected at a given percentage of clay (*cf.* Fig. 31). In other words, plinthitic horizons with low percentages of organic matter have T values which are slightly higher than the average for non-plinthitic horizons with similar percentages of organic matter. This seems to indicate that, although Ki data is approximately the same as that of the other Planície soils, the clay fraction of the plinthitic horizons is slightly less chemically inactive. In this respect it may be mentioned that on a large rubber estate near Belém, the stripping of the non-plinthitic surface layer (which contains most of the organic matter!) from the plinthitic soils has been found to be advantageous for the growth of rubber saplings.

Owing to their compactness, horizons of fossil soft plinthite, such as the B horizon of the RP-KYL, CR, are not favourable for rooting. Horizons of fossil hard plinthite however, such as the A horizon of the RP-KYL, CR and the A and B horizons of the KYL, CR, normally are excellent rooting media. Such horizons consist very predominantly of concretions in friable earth (*cf.* Photo 28); exceptionally the segregates of sesquioxides form slag-like, impenetrable masses.

Reference may be made to the remarks in Chapter IV on the natural vegetative cover of the freely draining plinthitic Planície soils. The timber wealth is certainly not lower than on non-plinthitic freely draining kaolinitic Planície soils, and at least one valuable tree species predominates on one of the plinthitic soils.

V.3.2 Agricultural Land Capability Evaluation for the Freely Draining Kaolinitic Planície Soils, and their Adequate Management

V.3.2.1 *Agricultural Land Capability Evaluation*

The main conclusion from the foregoing discussion is that the natural fertility is low in all freely draining kaolinitic Planície soils (except the Terra Preta). In such a situation, the differences which occur in soil qualities such as organic matter storage, available moisture reserve, and root penetrability, become very important. Agricultural land capability evaluation in the Planície will have to be based largely upon the differences in the latter qualities. Such external factors as the topography and drainage pattern of the land, its accessability, and the degree of geographical coherence of the individual soils, play a part. Apart from this however, and the soil preferences of individual crops, it may be stated that the most favourable conditions for crop production are to be found on those relatively heavy textured forest soils that have non-compact and friable subsoils.

The Kaolinitic Yellow Latosol (,Ortho), and Kaolinitic Yellow Latosol, intergrade to Red Yellow Podzolic soil which are of rather heavy, or heavy texture (KYL_{rh} and KYL_{h}; $KYL\text{-}RP_{rh}$ and $KYL\text{-}RP_{h}$) meet these requirements best. On these soils the highest gross timber volumes of the primeval forest are found (*cf.* IV.1.2).

Where the above soils are used for shifting cultivation they often have a smaller potential because of the tendency of the small farmers to gradually reduce the length of the fallow period.

The soils under savannah coverage have definitely less agricultural potential than those under primeval forest, because of the near absence of a nutrient reserve in the vegetation, less organic matter in the topsoil, and some degradation in the soil structure which affects unfavourably the available soil moisture and the root penetration.

The soils with horizons of fossil plinthite have about the same potential, when hand culture methods are applied, as non-plinthitic soils of the same degree of anthropic influence. Only when machinery is to be used do they obviously become much less suitable, because of their stoniness.

V.3.2.2 *Soil Management*

The preceding examination of the chemical and physical qualities of the freely draining kaolinitic Planície soils, under forest or under human influence, enable an assessment to be made as to the best ways for management of these soils after clearing of the primeval forest cover, as well as for their recuperation after adverse human influence.

MAINTENANCE OF SOIL ORGANIC MATTER

It is evident that the organic matter in the soils is of paramount importance. It is practically the sole bearer of the available plant nutrients, determines the nutrient storage capacity (T value) to large extent, is the main source of nitrogen, and makes the phosphorus of the soil easily available. The soil organic matter also has a favourable effect on the soil moisture availability.

In forest soils, the soil organic matter is concentrated in a thin superficial layer. Therefore, at the commencement of agricultural activities on these soils, great care has to be taken to leave intact, as much as possible, the original superficial layer. Any effort to improve the fertility of the forest soils, and to recuperate the soils under savannah and those under long-lasting shifting cultivation with short fallow periods, will have to take the maintenance, and if possible the enlargement, of the soil organic matter has a basis.

Theoretically, it would be possible to attain gradually a level of soil organic matter which is comparable to that of the Terra Preta soil. It has been shown before that already under the natural cover the percentage of organic matter is higher, both in topsoil and in subsoil, with increasing percentage of clay. In the relatively light textured forest soils, the layer in which the organic matter is concentrated is often up to 40 cm thick. A relatively large mass of soil is involved in storing this organic matter. In the heavy textured soils however, a very thin superficial layer, often only 2 to 5 cm, suffices to store a good part of the naturally present organic matter. In the latter soils it will not be very difficult to maintain, under permanent cultivation, the natural organic matter level. This will be possible by arranging that the organic matter becomes about equally distributed in the total tilth layer, through increasing the sub-surface section with the same amount of organic matter which is lost in the thin superficial layer. Even an absolute enlargement of the organic matter level in such soils seems feasible, namely by securing an organic matter level in the total tilth layer which is as high as in the superficial section of forest profiles. In fact, some of the heavy and very textured profiles under forest, notably those with very high timber volumes, have remarkably thick A_1 horizons. An example of this is shown by the profile at the planalto edge of Curuá-una centre (112 of Fig. 11). This profile, having 80% clay, contains about 3% Carbon down to 40 cm depth, resulting in a T value of 15 m.e. per 100 g of soil throughout this layer!

Whether an increase in the organic matter level in the relatively heavy textured soils can be realised under non-intensive agriculture, and whether it will be economically justifiable, is questionable. It is, however, evident that the heavier the texture of the soil, the better its ability to maintain the level of organic matter in the newly occupied forest soil and to restore it after degeneration of the soil under adverse human influence.

There are several methods of ensuring maintenance, and possibly increase of the level of soil organic matter, such as the planting of cover crops and the application of animal and green manures and compost. Application of some specific green manures seems to be the most effective and economical. There are however hardly any comparative trials available to confirm this belief.

Exploiting of soil moisture reserve

It has been mentioned that a large part of Amazonia has a climate with a dry season, in which the rainfall is too small and too irregular to provide for unhibited plant growth. The soil moisture has to be exploited in such periods. The total effective soil moisture reserve depends upon the amount of available moisture per unit of soil, as well as upon the intensity and depth of rooting. It seems hardly feasible to obtain an enlargement of effective soil moisture reserve by mechanical improvement of porosity and soil penetrability. In topsoils these qualities are normally quite favourable, and breaking of compact subsoil layers will not be economically justified for most crops. Because of the influence of the soil organic matter on soil moisture availability and on root penetrability however, via its influence on the activity of the soil fauna, the maintenance or increase of the organic matter level is an important management measure also for the effective soil moisture reserve.

Strange as it might seem for a region with a 'wet' climate, some irrigation, during a short period of the year, may well be an economic proposition for a number of drought-sensitive crops. In this case, owing to the supplementary character, irrigation with flexible equipment such as sprinklers, seems advisable.

Tillage and erosion control

Normally, the topsoils are friable and easily penetrable, and the dangers of large-scale erosion are very small. Exceptions to this are the very heavy textured and the very light textured soils. The former may be subject to surface sealing and sheet erosion, and on the latter gully erosion can be severe. On these soils, tillage and erosion control measures require special attention.

Fertilizing

Immediately after felling and burning of the forest cover, an addition of chemical fertilizers seems superfluous, owing to the temporary enrichment of the soil by ash from the vegetation, and the rapid rate of mineralisation of the soil humus. Afterwards however, the removal of nutrients from the soil system by crop production or cattle rearing has to be recompensed by new additions, if the nutrient status of the forest soil is to be fully maintained. Such additions, together with measures taken to maintain or increase the organic matter content, will also be required for recuperation of exhausted soils and when general soil improvement is envisaged.

With the foregoing soil data, and the few data of fertilizing trials, it is possible to assess tentatively to what degree applications of chemical fertilizers are necessary and what their effects will be:

The application of large amounts of *lime* is probably not advantageous, at least not in so far as it is intended to lessen the acidity. It is true that the soils are generally very strongly to extremely acid, but the active acidities, or the exchangeable aluminum percentages, are nevertheless only moderately high. A slight increase of the pH (about one unit, to approximately pH-H_2O = 5.5) is probably sufficient to eliminate the unfavourable effect of this aluminum on the availability of other nutrients. Owing to the fact that the potential cation exchange capacities are generally low, such an increase may be effected with moderately small doses of lime (as a rough estimate, 1.5 to 2 tons/ha for a tilth layer of 20 cm, not counting possible leaching). A further raising of the pH is likely to again decrease the availability of several nutrients. This may apply particularly to micro nutrients, of which the total amounts seem to be already naturally low both in forest and savannah soils. The often very gradual effect of liming on crop production has to be kept in mind, when the first year's results of the fertilizing are evaluated.

The available amount of *nitrogen* in the soils is unlikely to be deficient for some time after the clearing of the forest, because of the relatively high rate of mineralisation of the organic matter. On long cultivated plots and on savannah areas however, an addition of N-fertilizers may have considerable effect. It will be necessary to apply nitrogen when green manuring is executed with soil covers other than N-fixating legumes.

It has been shown before that the content of total *phosphorus* is low. The fixation of this element is somewhat larger in clayey soils than in sandy soils, but it is, as a whole, probably less strong than in Latosols other than the main Amazon ones. An enlargement, if necessary, of the content of available phosphorus in the soil, can therefore probably be obtained with only moderate amounts of phosphates, particularly in the sandy soils. This is also true, because the exchangeable aluminum is only moderately high and easily eliminated with some liming. Because of the relation between the availability of phosphorus and the percentage of organic matter, an enlargement of the apparently too low amount of available phosphorus in the savannah soils implies that an enlargement of the organic matter content must be effected at the same time. Without a considerable quantity of organic matter, it will be very difficult to obtain a satisfactory level of available phosphorus (1 mg P_2O_5-Truog per 100 g of soil*??*). It is most probably uneconomical to apply such liberal doses of phosphates that the amount of total phosphorus in the soil becomes greater than the fixing power of the humus-poor soil material, as is apparently the case in the Terra Preta subsoil (more than 100 mg P_2O_5-total per 100 g of soil). Such large additions, however, may have an enlargement of the potential cation exchange capacity as an interesting side effect.

Fertilizing with *potassium* seems to be generally useful, at least when perennials are involved. SUTMÖLLER *et al.* (1964) found that potassium deficiences in Amazon cattle may occur if the amount of exchangeable potassium in the soils concerned is below 0.20 m.e. per 100 g of soil. Reference is made to the evidence from foliar analysis executed for Amazon oil palms. Experiments with the crop on comparable soils in West Africa have shown that for this perennial the level of exchangeable potassium should be at least 0.15 m.e. per 100 g of soil, in the upper 30 to 40 cm of the profile (IHRO-OLLAGNIER, personal communication). Another minimum value estimation is 1.5 to 2 % of the T value. If this is generally true for conditions in the Amazon, then not only are the exhausted savannah soils deficient in potassium for the growth of oil palm, but also the forest soils (the storage in the vegetation not taken into account); even the Terra Preta soil is at, or below, the minimum necessary level.

The nutritional imbalances in cattle, grazing on the savannah soils, suggest that fertilizing with several *meso* and *micro nutrients* will be effective. On non-exhausted soils also, when supporting perennials or sustained cultivation of annuals, deficiencies of meso and micro nutrients are a possibility if no compensation is made with chemical fertilizers or compost.

It is stressed that any fertilizing recommendation, made with the aid of the present-day knowledge of soil – plant relationships in Amazonia, is at best a rough estimate. There are also the different requirements of individual crops. The method of soil tillage and the system of fertilizer application can have a tremendous influence upon the effect, if any, of added materials. Also, a shortage of one element, even when a micro nutrient, may cause an apparent lack of response to a fertilizer application which is totally misleading. With the generally weak buffering of the soils, especially of the sandy ones, it is easy, on the other hand, to unwittingly add an excess of one nutrient, thereby diminishing the availability of other nutrients.

V.3.2.3 *Systems of Crop Production*

At present, the crop production on the freely draining kaolinitic Planície soils is carried out very predominantly by native small farmers, with hand culture methods, and the application of the shifting cultivation system. It has been concluded in V.3.1.2, that this system, as it is practised nowadays in Amazonia, reduces gradually the agricultural potential of the land. In view of the low standard of living of the rural populace, and the envisaged immigration from other parts of Brazil, the expanding of crop production on the Planície soils is a necessity. This must be done both by improvement of the crop production in the present-day agricultural areas such as the Bragantina area, and by creating of agricultural settlements in primeval forest areas. Stimulating of the establishment of commercial agricultural estates, belonging to specialised companies, might be an effective way to achieve higher production and they may be o educative value for the rural population on their peripheries. Government agricultura policies however will aim mainly at improving and enlarging the means of existence o the native small farmers. For this, the shifting cultivation system can not be discarded as 'obsolete'. In general the system secures a living, though on a low level, from tropical soils with a low natural fertility, in areas where land is superfluous. The choice and succession of crops after clearing of the fallow is often the ingeneous result of century-long experience by the native population in tropical areas where animal manures, chemical fertilizers and insecticides were not available in the past, nor are they today an economic proposition. Proposals to introduce 'modern' agricultural practices for peasant farming have to take full account, not only of the economy of the agricultural products themselves, but also of the socio-economic level of the rural populace.

Under the prevailing conditions, the improvement and expanding of peasant farming on the freely draining kaolinitic Planície soils of Amazonia has to take the shifting cultivation as a basis. There seem to be several ways in which the system, as practised nowadays, may be improved, and gradually transformed in to a system of settled agriculture.

One of the first and easiest measures would be to allot more land to original settlers, to strictly control the area of forest felled each year, and to allow only the felling of sufficiently old (15 to 20 years) fallow. Secondly, a stimulating of the growth of the fallow may be feasible, as has been tried for instance at Yangambi station in Congo, with the *corridor* system.

A main gap in Amazon agriculture is believed to be the practical absence of perennials such as rubber, cocoa and oil palm. Such crops are a firm step to settled agriculture. They will provide for considerable and stable cash without requiring much technical skill, form a good protection against degeneration of the land, and are likely to react the most favourably to applications of manures and chemical fertilizers. To give an encouragement to the planting of such perennials, on a percentage of the plots allotted for ordinary shifting cultivation, seems to be an inherent part of a sound agricultural policy. In fact, this has been propagated in recent years, for the agricultural colonies established by the *Instituto Nacional de Imigração e Colonização* (INIC) in general and for rubber in particular, via the joint project *ETA '54* of U.S. A.I.D., SPVEA and other institutions. However, the strict precautions that have to be taken against the leaf blight *Dothidella ulei* are one of the hindrances to expansion of rubber planting. Both technically and economically it seems quite possible to promote the establishment of small groves of oil palms along similar lines as is being done for rubber. Smallholding of this perennial seems promising even in those parts of the Planície where climatic conditions may not be optimal for the crop. Apart from this, one or more of the many indigenous oil rendering palm species may prove to be a valuable perennial crop.

Also the prospects for increased growing, by small farmers, of specials such as pepper look favourable. Such new crops constitute, in fact, a more intensive use of the land. The use of fertilizers, green manures and cover crops will be justified by higher and more stable profits, and also annual crops may gradually be grown continuously.

It is possible that an adapted system of mixed farming will prove to be a stable base for rural settlement. Besides the profits of livestock husbandry itself, the grass or legume ley may improve soil conditions and the manure of the penned cattle may be fully used for the enlargement of crop production on the same farm. In this case, much attention has to be given to the quality of the grass ley. The application of adequate chemical fertilizers, and the introducing of new and highly productive grasses and palatable legumes, on artificial pastures, seem to be promising.

Another possibility for improvement of the standard of living of the rural population in Amazonia is the combination of crop production with a modern exploitation of the forests. Several forest production reserves on Planície areas are proposed or already established (*cf.* Fig. 22), in accordance with recommendations made after the FAO-

SPVEA forest inventories. The creation of agricultural settlements on the peripheries of such reserves would be a safeguard against uncontrolled cutting and felling, and secure a labour force for the exploitation of the reserve itself; at the same time, it would provide extra cash for the agricultural community.

It is without doubt that the agricultural research, as started by the *Instituto Agronômico do Norte*, must be enlarged and deepened. It should comprise studies on crop rotation and intercropping schemes, grass leys, types of green manures and cover crops; trials on the application of chemical fertilizers, animal manure, compost and the waste from industrial production; trials on cultivation practices such as planting time and spacing; the introduction and testing of new crops, and the selecting of the best varieties of local crops; the assessment of the absolute production capacity of the various soils and the economy of soil management measures. The experiences in these respects in other tropical areas with similar physical conditions, of which particularly West Africa and Congo (Yangambi) must be mentioned, may be utilized to a large extent.

Rural extension work, to a greater degree than being done by the *Fomento Agrícola*, will have to teach the new methods which have proved valuable, and to produce and distribute seeds and other planting material. This may prove to be one of the bottlenecks for the expansion of the Amazon agriculture, because of the preference of the present-day rural population for extractive activities on the natural vegetative cover, and the aversion of trainees from spending a considerable time in the *interior*. In this respect, the establishment of subsidised pioneer and demonstration farms should be highly beneficial.

In fact, most measures in the technical agricultural field for improving Amazonian peasant farming are well understood by Amazon agronomists. Other services however, are equally indispensable. These are the sufficient and regular release of working funds for agricultural research and rural extension work; cheap agricultural credit; promotion of processing industries on the spot; price policies for cheap provision of fertilizers, insecticides and implements; easing of import and export regulations and the restriction of federal, state and municipal taxes on the agricultural products; the promotion of agricultural cooperatives, of transportation, education and other measures in the social field. It is often rather the lack of these services, or their unbalanced or short-term implementation, which is delaying the emergence of a prosperous agricultural community in Amazonia.

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Summary

The present study actually deals with the soils of the Brazilian part of the Amazon region. The boundaries accepted for this region are the transitions from the belt of equatorial forest to the savannahs of North-Eastern and Central Brazil and those of Rio Branco-British Guiana. The eastern half of the region is discussed in particular.

PEDOGENETIC FACTORS

Climate. Only a small, north western section of Brazilian Amazonia has a climate without any dry season (type *Af* in Köppen's classification; Fig. 2). The greater part of the region has a few months per year with little or no rainfall (type *Am*).

Geology. Brazilian Amazonia consists of a low, sedimentary area, the Amazon valley proper, and parts of the crystalline shields of Central Brazil and the Guianas (Fig. 5). The crystalline shields are of Pre-Cambrian age and mainly consists of granites, gneisses and mica schists. The sedimentary part consists of several basins, namely the basin of Acre, of the Amazon proper, of Marajó, and that of Maranhão (Fig. 5 and Appendix 8). The sedimentary part of Amazonia has at its surface only narrow bands of Paleozoic-Mesozoic deposits, of very varying character; the greater part consists of Tertiary unconsolidated sediments which are kaolinitic clays and quartz sands. The Pleistocene sediments, which are similar in character to the Tertiary ones, are thin, and their extent has been reported to be limited. Holocene deposits comprise a small area, much less than was estimated by early explorers of Amazonia.

Geomorphology. In the watershed regions to the north and south of the Amazon river system the following geomorphological units can be distinguished (Figs. 8, 9 and 17):

1. Undulating terrains with outcropping crystalline basement.
2. Undulating terrains with outcropping Paleozoic, Mesozoic or Early Tertiary deposits.
3. Two peneplanation surfaces inside the area designated as crystalline on the geological maps. These surfaces occur at 400–600 and 250–400 m altitude and are assumed to be of Cretaceous and Early Tertiary are respectively. Little can be said with certainty about these surfaces.

The broad axial part of Amazonia consists of:

4. Flat plateau land, known as Amazon planalto, and of Plio-Pleistocene age.
5. Upland terrains at a lower level, fashioned to terraces at various levels, and of Pleistocene age. (The units (4) and (5) are designated together as Planície).
6. Lowlands, of Holocene age.

The height of the Amazon planalto is usually 150–200 m in the eastern part of the valley and somewhat less in the western part. A characteristic of this planalto is that it has at its surface a ten to twenty metres thick layer of uniform, very heavy sedimentary clay. It is supposed that this so-called Belterra clay had its origin in the erosion of uplifted kaolinitic deposits of the Andes area. The clay must have settled very gradually and evenly on the flat bottom of a huge shallow inland sea. A large part of Amazonia was covered by this sea during an age of the Latest Tertiary or Earliest Pleistocene when the general sea level was high (Calabrian; *cf.* Table 1).

The upland terrains in the axial part of Amazonia that were fashioned during the Pleistocene period have a great expanse. A 500 km long section of the upper part of the recently constructed Belém-Brasília highway, allowed for a detailed study of the local geomorphologic constitution (Appendices 4 and 5). Various terraces occur in this stretch. Some of them are coastal-marine, the others fluviatile. All terrace levels must have been formed during times when the existing sea level was higher than at present and therefore they are of interglacial age. For part of the stretch, a comparison of the terrace levels with world wide interglacial sea levels enables the terraces to be tentatively dated in detail (Tables 1 and 2).

It is likely that in other parts of the Amazon valley proper the terrace levels are also of interglacial age.

The very locally occurring, so-called massapé terrains, and parts of eastern Marajó island are presumably of Early Holocene age. The younger Holocene terrains are commonly divided into várzeas and igapós. In this publication, várzea is defined as lowland that is intermittently waterlogged, and the igapó as lowland that is permanently waterlogged. The várzeas, which have the largest extent, are subdivided according to the character of the variation of the water level and to the composition of the water.

Levels of fossil plinthite. Along the afore mentioned upper part of the Belém-Brasília highway detailed observations were made on the occurrence of levels of fossil plinthite (Appendices 4 and 5). Several types of fossil plinthite can be discerned in this area, and each of them has a specific position and area of occurrence. In the stretch traversed by the highway, the main part of the fossil plinthite was formed *in situ*. It must have originated during at least two ages of the Late Tertiary with flat land surfaces of imperfect drainage. An age of the Pleistocene produced plinthite of limited expanse.

It is likely that the fossil plinthite in other parts of eastern Amazonia was formed also largely during the Tertiary and the Pleistocene.

Vegetation. Is is concluded from the geomorphologic constitution of the Planície part of Amazonia and the character of its sediments that both during the Tertiary and the Pleistocene there were several ages with relatively dry climates (interpluvials). During these ages there was no forest coverage over large parts of Amazonia.

The present-day vegetative cover is subdivided into several forest types, on the one hand, and several savannahs and savannah-forests, on the other (Fig. 12).

THE MAIN AMAZON LATOSOL

The concepts on 'latosol', 'laterite' and 'plinthite' have had already an evolution. The national Brazilian Soils Commission has recently given a detailed definition of the Latosol, in an elaboration of the U.S.A. concept. Attention is given to the separation of Latosols from other red and yellow soils of the tropics and subtropics. In particular, the characteristics of the diagnostic horizon of Latosols, the latosolic-B horizon, are contrasted (Table 5) with those of the textural-B horizon, which is diagnostic for Red Yellow Podzolic soils and others.

Many different terms have been applied to the various Latosols found throughout the world. In Brazil, a subdivision of the Latosols is being worked out which takes as its principal criterion the composition of the clay fraction in relative amounts of silicate clay minerals (kaolinite), iron clay minerals (goethite, hematite), and aluminum clay minerals (gibbsite). These amounts are assessed mainly on the molecular ratios SiO_2:Al_2O_3:Fe_2O_3.

It is shown that the well-drained soils of the Planície part of Amazonia have predominantly a latosolic-B horizon as this is defined by the Brazilian Soils Commission. The molecular ratios SiO_2:Al_2O_3:Fe_2O_3 point to a strong predominance of kaolinite in their clay fraction, which is confirmed by several X-ray curves of representative profiles (Tables 7 and 8, and Fig. 14a-e). The soils therefore belong to the subgroup of the kaolinitic Latosols and are named Kaolinitic Yellow Latosol. For the sandy relatives of the soils, with less than 15% clay in their B horizon, the name used is Kaolinitic Latosolic Sand.

The described Amazon soils are comparable with several of the soils in tropical Africa, which are grouped according to other classification systems than used in this publication.

AMAZON SOILS WITH PLINTHITE

The soils that contain plinthite in one form or another are discussed separately. In agreement with the VIIth Approximation, 'plinthite' here replaces the old word 'laterite', and a subdivision is made into hard plinthite (laterite concretions and slabs) and soft plinthite (Buchanan's laterite or mottled clay).

Soils with recent plinthite. At present plinthite in Amazonia mainly develops on flat land surfaces with intermittently imperfect drainage. Soft plinthite is formed at some depth in the soil profile on these sites, *viz.* in the zone of fluctuation of the phreatic level, which is fully in agreement with the classical findings of MARBUT (1932).

In some cases this zone occurs at such a depth that the solum of the soil profile is not affected (*cf.* Profile description 1). Usually, however, the zone is nearer to the surface and clay-sized mineral particles and sesquioxides are carried from the superficial layer downward. An imperfectly drained soil develops with a leached A horizon and a B horizon of soft plinthite, *i.e.* the Ground Water Laterite soil. There is a great variability in characteristics of this soil unit (*cf.* Profiles 2 to 18, and Appendix 9), which is governed by several factors. The ultimate stage of Ground Water Laterite soil development appears to be represented by the profile which has a bleached and light textured, thick A horizon over a heavy textured, dense and slowly permeable, thick B horizon of soft plinthite, whilst at the transition zone of the two horizons some plinthite material occurs that has already hardened (the Ground Water Laterite soil, Low phase).

Soils with fossil plinthite. In Amazonia it is common to encounter layers of soft or hard plinthite on well-drained sites where the phreatic level occurs at a depth of many metres. In view of the described present-day formation of plinthite, and in agreement with most of the recent literature on the subject, such plinthite is considered to be fossil.

Layers of fossil hard plinthite underlain by fossil soft plinthite are likely to have formed *in situ*. The combined layers constitute the relics of a Ground Water Laterite soil which developed on a former land surface with imperfect drainage. After conditions of imperfect drainage ceased to exist, the profile was geologically eroded to the point at which all the light textured and loose A horizon, and possibly part of the plinthitic B horizon, was stripped off. Whilst the lower part of the plinthitic B horizon has remained soft, the upper still present part has become hard plinthite.

Separate layers of fossil hard plinthite are normally of colluvial-alluvial origin. There are several supplementary characteristics that may help to establish whether plinthite is recent or fossil, and whether formed *in situ* or of colluvial-alluvial origin.

If the fossil plinthite is found below the solum, it is not diagnostic for classification of the soil. If, however, the fossil plinthite forms part of the solum, then the classification of the soil depends upon the degree of weathering of the parent material, *i.e.* in this case the plinthite. In Amazonia the final weathering product consists, with few exceptions, of a mixture of hard concretionary elements and loose friable earth of which the clay fraction is kaolinitic in character.

Where there is shallow weathering of the plinthite layer the soil is classified as Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol, Concretionary phase. When the weathering is deep, and in any case when the fossil plinthite is of colluvial-alluvial origin, the soil is classified as Kaolinitic Yellow Latosol, Concretionary phase (*cf.* Profiles 19 to 23, and Appendix 9).

A general scheme for the different soils to be distinguished with the formation, truncation, and burying of Amazon plinthite is given in Fig. 15.

The soil units distinguished, and their geographic occurrence

All discerned Amazon soil units (*cf.* summary in Table 9) are described systematically, by giving a general concept, the range in characteristic, and a representative profile with its analytical data.

The soil maps of two of the areas of which a reconnaissance soil survey was executed (Appendices 1 and 2), give a picture of the geographic occurrence of the various soils. The Guamá-Imperatriz area may be taken as representative of the Planície part of Amazonia with its unconsolidated sediments of kaolinitic clays and quartz sands. The Araguaia Mahogany area may be taken as representative of the non-Planície part of

Amazonia, with its wide variation in geologic age and petrographic constitution. Fig. 17 is a sketch of a provisional soil map for the whole of Brazilian Amazonia.

The undulating terrains with outcropping crystalline basement probably have Red Yellow Latosol as the predominant soil. The presence of Red Yellow Podzolic soil and of Lithosols is established.

The undulating terrains with outcropping Paleozoic, Mesozoic or Early Tertiary deposits have a large variety of soils. Lithosols appear to be common.

Very little soil data is available on the peneplanation surfaces on the crystalline basement.

Most of the soil data of Amazonia relate to the Planície and the Holocene terrains. The soils of the Belterra clay covered Amazon planalto have an uniform profile development over large distances. By far the most common soil is Kaolinitic Yellow Latosol (,Ortho), very heavy textured. Parts of the planalto in the south-western part of Amazonia have imperfect drainage, with Ground Water Laterite soil or Kaolinitic Yellow Latosol, intergrade to Ground Water Laterite soil.

The Pleistocene terraces in the eastern part of Amazonia have Kaolinitic Yellow Latosol (,Ortho), of medium, rather heavy, or heavy texture and Kaolinitic Latosolic Sand as the principal soils. Several aspects of profile development of these soils are related to the texture of the parent material. The terrace level also appears to have some influence (*cf.* Table 10). Other well-drained soils are Kaolinitic Yellow Latosol, Compact phase; Kaolinitic Yellow Latosol, intergrade to Red Yellow Podzolic soil; and Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol; soils which are subdivided according to their texture. In addition, there are the plinthitic soils Kaolinitic Yellow Latosol, Concretionary phase and Red Yellow Podzolic soil, intergrade to Kaolinitic Yellow Latosol, Concretionary phase.

Imperfectly drained soils are Ground Water Laterite soils and Ground Water (Humus) Podzol.

There are many small patches with a peculiar dark and fertile soil which is called Terra Preta. This is a 'man-made' soil, developed on the dwelling sites of the pre-Columbian Indian tribes.

Judging from the data of MARBUT and MANIFOLD (1926) and other informations, the soils of the Pleistocene terraces in the western part of Amazonia are largely comparable with those of eastern Amazonia.

On the várzeas, Low Humic Gley and Humic Gley soils predominate, and on the igapós, Bogs and Half Bogs. Also Ground Water Laterite soils are found on these lowlands. In the coastal area Saline and Alkali soils occur.

For description of hitherto unknown forested areas at which the detailed geographic pattern of the various soils can be shown, the introduction of the concept 'land-unit' is suggested. This denotes a tract of country within which the geologic, topographic and hydrographic elements, the climate, pattern of vegetation and pattern of soils are approximately uniform.

The soils and their vegetative cover

The available data on the vegetative cover are of limited value for the assessment of the relationships between soils and vegetation, because methods of ecological research proper could not be employed. A discussion is nevertheless desirable in view of the near absence of published data on soil-plant relationships in Amazonia.

Among the characteristics of the upland forests, the mean gross timber volume and the occurrence of individual tree species are discussed in particular, because it is on these that the FAO/SPVEA forest inventories provide for data.

The influence of non-edaphic factors on differences in forest growth. The highest timber volumes of the Planície may be found in areas where the total annual rainfall is not excessively high and a short dry season occurs. A number of differences established in the occurrence of individual tree species are likely to be determined by differences in climate as well.

Anthropogenic influences may have affected forests, even seemingly primeval ones, over large areas. An example is the selective cutting of certain very valuable tree species. A peculiar type of forest, which consists largely of short-lived *Guadua* species (tabocal) and is found in an area along the Belém-Brasília highway, is very likely due to the burning practises of Indians.

Edaphically determined defferences in forest growth. Nearly all forest inventory areas are located in the Planície, the soils of which are very similar, at the classification level employed. Established differences in forest characteristics within an area of uniform climatic conditions and non-existent or uniform anthropogenic influences, are therefore apt to show a correlation with lower category soil differences. Among these are the moisture holding capacity, the total available amounts of the various plant nutrients, and the penetration possibilities for roots. These qualities depend on such factors as the soil texture, the compactness of the subsoil and the presence of plinthitic materials. The coincidence of differences in forest characteristics with differences in these latter factors are discussed. It is often uncertain what exactly are the causal factors of the coincidences established.

A relationship exists between soil texture and gross timber volume. The rather heavy or heavy textured soils in particular support forest with high timber volume. Very heavy textured freely draining Planície soils, the soils derived from Belterra clay, have in several parts forest of a low timber volume, because it consists fully, or for a considerable part, of creepers and climbers: cipoal and 'cipoalic' forest. These forest types can be found on the completely flat central sections of planalto parts, as well as on the oldest Pleistocene terraces where these are covered with reworked Belterra clay. Cipoal and 'cipoalic' forest prevail on Belterra clay soils with a compact subsoil and a thin A_1 horizon compared with the soils of the immediate surroundings.

With the aid of a number of examples the problem is discussed of any relationship between soils and individual tree species that have an established variation in occurrence. Acapú *(Vouacapoua americana)*, for instance, is restricted to parts of the region and there found in colonies. These colonies are however found on a variety of soils. One of the species found concentrated on very heavy textured soils is the Angelim pedra *(Hymenolobium excelsum)*. The occurrence of Pau amarelo *(Euxylophora paraensis)* was studied in the Guamá-Imperatriz area. In this area the species apparently has its optimal growing conditions on soil with concretions of fossil plinthite of a specific level and age.

A special study was made on the occurrence of the mahogany *(Swietenia macrophylla)* in a part of the south-eastern transition zone of the belt of tropical forest, the Araguaia Mahogany area. In this area, the species mainly grows on terrains with imperfect drainage and well developed hydromorphic soils that chemically are relatively rich (Fig. 25 and Appendix 6).

The occurrence of palms in the Amazon forests seems to be more often related to the variations in the conditions of climate and soil than is the case with the occurrence of dicotylenous tree species.

Non-edaphic savannahs. Some upland savannahs within the forest belt mainly originated as a result of adverse non-edaphic conditions, usually with a predominance of anthropogenic factors. These savannahs are located in the north eastern part of Amazonia (upland savannahs in Amapá Territory, on south-eastern Marajó island and on the north bank of the Lower Amazon river).

Savannahs and savannah-forests of edaphic origin. The other savannahs, and the savannah-forests, of the Planície are of edaphic origin. All the savannahs concerned and most of the savannah-forests are found on terrains with imperfect drainage. These terrains either have a Ground Water Laterite soil (often the Low phase), or a Ground Water (Humus) Podzol. Extensive savannahs and surrounding savannah-forests, on watershed areas with flat relief (the campos, and part of the campina-ranas), have predominantly a Ground Water Laterite soil. Patchy savannahs and savannah-forests, on narrow strips of low sandy upland along rivers and on sand-filled former river beds (the campinas, the caatingas amazônicas, part of the campina-ranas), have predominantly the Ground Water Podzol as substratum. Some patches of savannah-forest (part of the campina-ranas) occur on relatively high, freely draining terrains, with White Sand Regosol.

Little data is available on the savannahs and savannah-forests of the non-Planície part of Amazonia. They are probably of edaphic origin, with Lithosols and Hydromorphic soils as predominant substrata.

The growing conditions of the various discussed savannahs and savannah-forests are summarised in Table 13.

Soils and vegetation of the lowlands. As regards the lowlands, differences between their forests are often considerable and they can often be correlated with the character of flooding or submergence. The lowland savannahs and savannah-forests of eastern Amazonia are considered to have originated edaphically.

THE SOILS AND THEIR USE

An evaluation of the main Amazon soils from the viewpoint of their agricultural occupation is of immediate importance. Parts of Amazonia are namely being considered as outlet areas for the large rural population of the North Eastern region of Brazil with its periodically recurring severe droughts and floods.

With regard to the soils of the lowlands it is emphasized that land capabilities vary much with the type of várzea. The main criteria for their evaluation must be the chemical qualities of the soils and the depth and length of the flooding. The necessary artificial drainage and reclamation would require considerable investigation, organisation and capital investment.

The soils of the uplands outside the Planície are very diverse. The natural fertility of the soils is certainly a principal criterion for land capability evaluation in these distant and inaccessible areas.

Qualities of the freely draining kaolinitic soils of the Planície. The terrains of the Planície constitute large tracts of predominantly flat to gently undulating land which is largely freely draining. These terrains are near the main water-ways and the existing roads. Their forests have the higher timber volumes, and the present-day Amazon agriculture is concentrated here. For these reasons the Planície part of Amazonia, despite the low natural chemical fertility of its soils, has a potential for large-scale settlement schemes. Special attention is therefore given to the chemical and physical qualities, the agricultural capabilities and the adequate management measures of Planície soils with good external drainage, *i.e.* the freely draining kaolinitic Planície soils.

Qualities of the soils under their natural vegetative cover. For the assessment of the chemical qualities of the freely draining kaolinitic Planície soils under their natural forest cover, analytical data of 35 relevant profiles are available. These are arranged and studied on their relationship (*cf.* Figs. 27 to 34). It is apparent that with regard to chemical qualities the main advantage of the clayey over the sandy soils is their capacity to create a better milieu for preservation of the comparatively very active organic matter.

In their physical qualities the soils can differ distinctly from each other. The moisture holding capacity of the soils is of importance in view of the fact that a large part of Amazonia has a short dry season. From moisture equivalents, some moisture tension curves, and other analytical data (*cf.* Figs. 35 to 37 and Table 16), it is deduced that the soils under forest cover have, as a whole, only small amounts of available moisture per volume unit. Clayey soils have a fairly distinct advantage over sandy soils, with regard to moisture availability, only as regards the topsoil.

Qualities of the soils under human influence. The chemical and physical qualities of the Planície soils change in several ways, when these soils come under influence of man. For the soils under shifting cultivation, only qualitative observations are evaluated.

For those under ancient anthropogenic savannah, however, a number of quantitative data are available. When the difference in the amount of nutrients stored in the respective vegetative covers is not counted, it can be said that the qualities of these savannah soils are still fairly comparable to those of forest soils. The main differences are a somewhat lower organic matter content of the topsoil, and consequently a somewhat lower potential cation exchange capacity and smaller amounts of exchangeable cations and anions, greater soil compactness and presumably less available soil moisture. Slight differences are found in the C/N ratios, the values for pH-H_2O, and the degree of phosphorous fixation.

The permanently beneficial effect of human influence is illustrated by the chemical qualities of the Terra Preta (*cf.* Figs. 38 and 39). The potential cation exchange capacity of this soil is relatively high, also when the organic matter content is low. However, this high cation exchange capacity corresponds with a high amount of phosphates in the Terra Preta. This amount often seems considerable higher than the fixing power of the humus-poor soil material.

The effects of chemical fertilizers and of animal and green manures can be assessed only tentatively, because of the limited number of experimental plots and sites with permanent agriculture.

The most suitable soils. It is evident that land capability evaluations for the Planície should be principally based on such differences in soil qualities as organic matter storage, soil moisture reserve and root penetrability. For large-scale settlements, external factors should be considered, such as the topography and drainage pattern of the land, its accessibility, and the degree of geographic coherence of the various soils. Apart from this, however, and the soil preferences of individual crops, the most favourable conditions for crop production are to be found on relatively heavy textured forest soils that have non-compact and friable subsoils. The Kaolinitic Yellow Latosol (,Ortho) and Kaolinitic Yellow Latosol, intergrade to Red Yellow Podzolic soil which are of heavy or rather heavy texture meet these requirements best.

Soil management. The examination of the chemical and physical qualities of the freely draining kaolinitic Planície soils under forest cover or under human influence, enable an assessment to be made as to the best methods of managing these soils after the primeval forest cover has been cleared, and of recuperating them after adverse human influence. The maintenance and, where possible, enlargement of the soil organic matter content is of paramount importance. At the actual state of research, fertilizing recommendations can only be tentative.

Shifting cultivation must constitute the basis for improvement and expansion of peasant farming on the Planície soils. The present system of shifting cultivation in Amazonia can be gradually improved in several ways. The introduction of perennials, especially oil palms, seems desirable. The combination of crop production with modern management of the forests is a feasibility.

Sumário

Os solos da parte brasileira de região amazônica constituem a matéria do presente estudo.

Como fronteiras daquela região são tomadas as transições do cinturão da floresta equatorial para as savanas do Nordeste e do Brasil Central e para as do território do Rio Branco e da Guiana inglêsa. Em particular é discutida a metade da parte Leste da região.

FATORES PEDOGENÉTICOS

Clima. Apenas ume pequena parte da Amazônia brasileira apresenta um clima sem qualquer estação sêca (tipo *Af* na classificação de Köppen, Fig. 2). Na maior parte da região há pouca ou nenhuma precipitação durante alguns meses do ano (tipo *Aw*).

Geologia. A Amazônia brasileira consiste de uma área baixa e sedimentar sendo o vale amazônico pròpriamente dito, e partes dos contrafortes cristalinos do Brasil Central e das Guianas (Fig. 5). Essas formações cristalinas remontam ao período Pré-cambriano e são constituidas principalmente de granitos, gneisses e micaxistos. Na parte sedimentar encontram-se quatro bacias, nominalmente a do Acre, a bacia amazônica pròpriamente, a da ilha de Marajó e a do Maranhão (Fig. 6 e Apéndice 8). Na superfície apresentam-se apenas faixas relativamente estreitas de depósitos Paleozóicos-Mesozóicos de caraterística muito variável; a maior parte da área sedimentar constitui-se de sedimentos Terciários não consolidados, que se compõem de argilas caoliníticas e areia de quartzo. Os sedimentos Pleistocenos, cuja composição se assemelha aos Terciários, são pouco espessos e a sua extensão, conforme aos dados de literatura, é limitada. Tembém os sedimentos Holocenos apenas compreendem uma área limitada, muito inferior à estimativa dos primeiros exploradores da Amazônia.

Geomorfologia. Nas regiões dos divisores de água ao lado Norte e Sul do sistema fluvial do Amazonas, pode-se distinguir as seguintes unidades geomorfológicas (Fig. 8, 9 e 17).

1. terrenos ondulados de embasamento cristalino aflorante.
2. terrenos ondulados com depósitos aflorantes do Paleozóico, Mesozóico ou Terciário Inferior.
3. dois níveis de peneplanação dentro da área que nos mapas geológicos fica indicada como cristalina. Estes níveis ocorrem a 400–600 m e a 250–400 m de altura respeti-

vamente e é provável que sejam da idade Cretácea e do Terciário Inferior. Destes níveis há, porém, poucos dados certos.

A larga parte axial da Amazônia consiste de:

4. terras planas em platô Plio-pleistoceno, chamado o planalto amazônico,
5. terras firmes mais baixas, modeladas em terraços a níveis diferentes, de idade Pleistocena (As unidades 4. e 5. conjuntamente são indicadas como Planície).
6. baixadas, de idade Holocena.

Na parte Leste do vale, o planalto tem em geral 150 a 200 m. de altura; na parte Oeste é um pouco mais baixo. Uma caraterística do planalto é que ele apresenta na sua superfície uma camada, de dez a vinte metros de espessura, composta de uma argila sedimentar homógena de textura muito pesada. Esta argila, chamada argila de Belterra, há de ter sua origem em depósitos caoliníticos nos Andes, que – após serem elevados – foram expostos a erosão forte. A argila ter-se-á depositado de maneira uniforme e gradativa na base plana de um amplo mar interior de pouca profundidade. Uma grande parte da Amazônia deve ter sido coberta por esse mar durante certo período do Terciário Superior ou do Pleistoceno Inferior, quando o nível geral do mar era elevado (Calabriano).

Os terrenos modelados durante o Pleistoceno, na parte axial da Amazônia, cobrem uma superfície grande. O traçado de 500 kilômetros de comprimento da parte superior da recém-construida rodovia entre Belém e Brasília ofereceu a possibilidade de estudar em detalhes a geomorfologia local (Apéndices 4 e 5). Neste trecho apresentam-se vários terraços. Alguns deles são costeiros, os demais fluviais. Todos devem ter sido formados em tempos em que o nível de mar era mais elevado que atualmente, e portanto devem ser de idade interglacial. Comparando os níveis dos terraços com os níveis glaciais do mar, até mesmo resulta possível determinar provisòriamente em detalhes as idades dos terraços numa parte da área em aprêço (Tabelas 1 e 2).

E' provável que todos os terraços nas demais partes do vale amazônica pròpriamente dito, também sejam de idade interglacial.

Os chamados terrenos de massapé, de ocorrência muito local, e partes da Marajó oriental remontam provàvelmente do Holoceno Inferior. Os terrenos Holocenos mais recentes são comumente subdivididos em várzeas e igapós. Neste estudo a várzea é definida como baixada intermitentemente inundada, e o igapó como baixada permanentemente inundada.

As várzeas, que constituem a maior parte das baixadas, são subdivididas de acôrdo com o caráter das flutuações do nível de água e sua composição.

Níveis do 'plinthite' fóssil. Ao longo da referida parte superior da rodovia Belém-Brasília foi feito um estudo detalhado da ocorrência de níveis de 'plinthite' fóssil (Apéndices 4 e 5). O 'plinthite' fóssil duro nesta área pode dividir-se em vários tipos e cada um dêles tem sua posição e área de ocorrência específicas. Deduziu-se que a maior parte do 'plinthite' fóssil foi formada *in situ*. Deve ter tido sua origem durante pelo menos duas épocas do Terciário Superior, quando nesta área havia superfícies planas de drenagem imperfeita. Durante alguma época Pleistocena também deve ter sido formado 'plinthite', seja em quantidade limitada.

E' provável que também nas demais partes da Amazônia o 'plinthite' fóssil mormente fôsse formado durante o Terciário e o Pleistoceno.

Vegetação. Da composição geomorfológica da Planície amazônica e do caráter dos sedimentos presentes é deduzido que assim durante o Terciário como durante o Pleistoceno havia várias épocas com climas relativamente sêcos (interpluviais), durante as quais grandes partes da Amazônia não tinham cobertura florestal.

A cobertura vegetal atual é subdividida em vários tipos florestais por um lado e várias savanas e florestas-savanas por outro lado (Fig. 12).

O LATOSOLO AMAZÔNICO MAIS IMPORTANTE

Os conceitos 'latosol', 'laterite' e 'plinthite' já têm tido uma evolução histórica. A Comissão de Solos do C.N.E.P.A. há pouco deu uma elaboração extensa do conceito 'latosol' na base usada nos Estados Unidos. Nela se prestou atenção para a maneira de distinguir os Latosolos de outro solos vermelhos e amarelos dos trópicos e subtrópicos. Nomeadamente as caraterísticas do B-latosólico e do B-textural, que são os horizontes caraterísticos de Latosolos, respetivamente de solos Podzólicos Vermelho-Amarelo e outros, são contrastadas.

Os vários Latosolos no mundo têm recebido as mais variadas denominações. Hoje está sendo desenvolvido no Brasil um sistema de subdivisão dos Latosolos, usando-se como principal critério a composição da fração de argila, a saber a mútua relação entre as quantidades minerais-de-argila de silicato (caolinita), minerais-de-argila de ferro (goetita, hematita) e minerais-de-argila de alumínio (hidrargilita). Êsses minerais são avaliados por meio das razões moleculares $SiO_2 : Al_2O_3 : Fe_2O_3$.

Fica demostrado que a maior parte dos solos bem drenados da Planície amazônica têm um B-latosólico conforme à definição da Comissão de Solos. Há nêles uma predominância muito forte de caolinita em sua fração argilosa, o que fica comfirmado por alguns Roentgengramas de amostras representativas de solo (Fig. 14a–e e as Tabelas 7 e 8). Êsses solos pertencem portanto ao grupo dos Latosolos caoliníticos, e nêste estudo são denominados Latosolo Amarelo Caolinítico. Os solos arenosos comparáveis com eles, ou seja os que no seu horizonte B contêm menos de 15% de argila, são denominados Areia Latosólica Caolinítica.

Os solos amazônicos acima descritos são iguais a vários solos da África tropical, agrupados segundo outros sistemas de classificação que o usado neste estudo.

SOLOS AMAZÔNICOS COM 'PLINTHITE'

Os solos que contêm 'plinthite' em qualquer forma são discutidos separadamente. Conforme à *Seventh Approximation*, o 'plinthite' substitui a palavra antiga laterita. O 'plinthite' fica subdividido em 'plinthite' duro (cascalho e pedras de laterita) e 'plinthite' macio (laterita de Buchanan; argila mosqueada).

Solos de 'plinthite' recente. A formação atual de 'plinthite' na Amazônia ocorre quase exclusivamente nos terrenos planos de drenagem intermitentemente imperfeita. Em tais lugares é formado o 'plinthite' macio a pouca profundidade, a saber na zona na qual oscila o nível freático, perfeitamente de acôrdo com as achadas clássicas de MARBUT (1932). Em alguns casos a zona em aprêço ocorre a tal profundidade que não pode afetar o solum do perfil (Perfil 1). Usualmente, porém, a zona acha-se tão próxima à superfície que lixiviam as partículas minerais mais finas e os sesquióxidos da zona superficial. Forma-se então um perfil de drenagem imperfeita com um horizonte A eluviado e um horizonte B que se compõe de 'plinthite' macio: o perfil Laterita Hidromórfica. Há grande variabilidade nas caraterísticas desta unidade de solo (Perfis 2–18 e Tabela 9), regulada por vários fatores. Como condição final da evolução Laterita Hidromórfica pode considerar-se o perfil que se compõe de um horizonte A espesso, alvejado e arenoso e um horizonte B espesso, argiloso e pouco permeável de 'plinthite' macio, com – na zona de transição – algum material de 'plinthite' já endurecido (neste estudo denominado solo Laterita Hidromórfica, fase Baixa).

Solos com 'plinthite' fóssil. Muitas vezes ocorrem na Amazônia zonas de 'plinthite' duro ou macio em lugares bem drenados onde o nível freático apenas se encontra a muitos metros de profundidade. Tendo em vista a formação recente de 'plinthite' como descrita acima, êste é considerado como fóssil, o que é de acôrdo com a maior parte da literatura mais recente sôbre êste assunto.

As zonas de 'plinthite' duro fóssil, que sobrepõem uma de 'plinthite' macio fóssil usualmente têm sido formadas *in situ*. As zonas constituem conjuntamente o relicário de um perfil Laterita Hidromórfica, que se desenvolveu numa superfície anterior, de drenagem imperfeita. Êste perfil, após superados os impedimentos de drenagem, terá sofrido uma erosão de tal magnitude, que desapareceu todo o horizonte A arenoso e sôlto, e talvez parte do B argiloso de 'plinthite'. Enquanto a parte mais profunda do B de 'plinthite' ainda presente permaneceu macia, a parte superior vinha transformando-se em 'plinthite' duro.

Camadas individuais de 'plinthite' duro fóssil são normalmente de origem aluvial-coluvial. Há várias caraterísticas suplementares úteis para esclarecer si o 'plinthite' é recente ou fóssil, e si foi formado *in situ* ou é de origem aluvial-coluvial.

Quando o 'plinthite' fóssil apenas se encontra por baixo do solum, não importa para a classificação do solo. Quando o 'plinthite' fóssil constitui uma parte do solum, a classificação dêsse solo depende do grau de meteorização do 'plinthite', que em tal caso constitui a rocha-mãe. Na Amazônia o material meteorizado final consiste quase sempre de uma mistura de elementos concrecionários duros e terra friável, cuja fração de argila tem caráter caolinítico.

Onde a meteorização da zona de 'plinthite' apenas tem pouca profundidade, o solo é classificado como solo Podzólico Vermelho-Amarelo, 'intergrade' para Latosolo Amarelo Caolinítico, fase Concrecionária. Quando a meteorização da zona é profunda, o solo é denominado Latosolo Amarelo Caolinítico, fase Concrecionária. A última denominação é sempre aplicável quando o 'plinthite' fóssil é de origem aluvial-coluvial (Perfis 19–23 e Apéndice 9).

Na Figura 15 é dada uma esquema geral para os diferentes solos que se podem distinguir na formação, respetivamente a truncação e cobrimentação de 'plinthite' na Amazônia.

AS UNIDADES DE SOLO DISTINGUIDAS E SUA OCORRÊNCIA GEOGRÁFICA

As diferentes unidades de solo da Amazônia conhecidas (veja résumo da Tabela 9) são descritas sistemàticamente, dando o conceito geral, as possíveis variações nas caraterísticas e um perfil representativo com seus dados analíticos.

Os mapas de solo de duas das áreas de levantamento expedito (Apéndices 1 e 2) dão uma idéia da ocorrência espacial das diferentes unidades de solo. A primeira área de levantamento expedito, a área Guamá-Imperatriz, pode ser tomada como um exemplo da Planície, com seus sedimentos não consolidados, compostos de argilas caoliníticas e areias de quartzo. A área Araguaiana de Mogno é exemplo da parte da Amazônia fora da Planície, com sua ampla variação em idade geológica e constituição petrográfica. A Fig. 17 é um esbôço de um mapa de solos para toda a Amazônia.

Nos terrenos ondulados com embasamento cristalino aflorante, ocorre como solo provàvelmente mais importante, o Latosolo Vermelho-Amarelo. Ocorrem também solos Podzólicos Vermelho-Amarelo e Litosolos.

Há grande variedade de solos nos terrenos ondulados de depósitos aflorantes do Paleozóico, Mesozóico ou do Terciário Inferior. Provàvelmente os Litosolos são os que ocorrem com maior freqüência.

Contamos com muito poucos dados sobre os solos dos níveis de peneplanação na área do embasamento cristalino.

A maior parte dos conhecimentos pedológicos sobre a Amazônia são concernentes à Planície e às baixadas Holocenas. Os solos do planalto amazônico coberto de argila de Belterra apresentam um desenvolvimento de perfil uniforme sobre grandes distâncias. Predomina o Latosolo Amarelo Caolinítico (,Orto) de textura muito pesada. Algumas partes do planalto na zona sudoeste de Amazônia apresentam uma drenagem imperfeita, de forma que lá o solo é de Laterita Hidromórfica ou Latosolo Amarelo Caolinítico, 'intergrade' para solo Laterita Hidromórfica.

Os solos principais dos terraços Pleistocenos da parte leste da Amazônia são Latosolo Amarelo Caolinítico (,Orto) de textura média, meio pesada ou pesada, e seu equivalente de textura leve ou muito leve, a Areia Latosólica Caolinítica. Várias tendências no desenvolvimento do perfil desses solos demostram uma relação com a textura dos sedimentos. Também o nivel de terraço faz um papel, o que possibilita uma avaliação da influência do fator tempo na formação de solo (Tabela 10). Outros solos bem drenados são o Latosolo Amarelo Caolinítico, 'intergrade' para solo Podzólico Vermelho-Amarelo; Latosolo Amarelo Caolinítico, fase Compacta e solo Podzólico Vermelho-Amarelo, 'intergrade' para Latosolo Amarelo Caolinítico; solos êsses que são subdivididos de acôrdo com a textura do horizonte B. Em adição há os solos com 'plinthite' fóssil: o Latosolo Amarelo Caolinítico, fase Concrecionária e o solo Podzólico Vermelho-Amarelo, 'intergrade' para Latosolo Amarelo Caolinítico, fase Concrecionária.

Os principais solos imperfeitamente drenados são os solos Laterita Hidromórfica e os Podzols Hidromórficos.

Nos terraços pleistocenos de Amazônia oriental ocorrem ocasionalmente solos que são marcadamente escuros e férteis, denominados Terra Preta. São solos antropogênicos, desenvolvidos nos provoados das tribos de Índios pré-colombianos. Considerando os dados de MARBUT and MANIFOLD e outros sôbre esta área, os solos dos terraços Pleistocenos na parte oeste da Amazônia devem ser por grande parte iguais aos do leste da Amazônia.

Nas várzeas predominam os solos Glei Pouco Húmico e os solos Glei Húmico, e nos igapós, solos turfosos. Também ocorrem solos Laterita Hidromórfica. Na zona costeira ocorrem solos salinos e alcalinos.

Para descrever áreas florestais até hoje desconhecidas, prestando-se atenção para o padrão detalhado dos diferentes solos, é introduzido o conceito de 'unidade de terra'. Como tal é considerada uma área dentro da qual as condições geológicas, topográficas e hidrográficas, o clima, o padrão da vegetação e o padrão dos solos são iguais.

RELAÇÕES ENTRE OS SOLOS E A VEGETAÇÃO

Para determinar as relações entre os solos e a vegetação da Amazônia, os dados disponíveis apenas têm valor limitado, visto que aínda não puderam ser feitas nalguma escala pesquisas de caráter puramente ecológico. Todavia, por faltarem quase inteiramente dados publicados sobre a relação solo e vegetação na Amazônia, é aconselhável uma discussão do assunto.

Entre as caraterísticas da floresta, nomeadamente são discutidos o volume bruto de madeira e a ocorrência de espécies individuais de árvores, pois é sôbre estes elementos que existem dados, devidos a uma série de inventários florestais.

A influência de fatores não-edáficos nas diferenças na vegetação florestal. Os mais elevados volumes de madeira da Planície podem ser encontrados nas áreas onde a precipitação anual não é muito elevada e onde há estação sêca de curta duração.

É provável que parte das diferenças na ocorrência de espécies individuais de árvores também sejam devidas a diferenças climatológicas.

É possível que áreas extensas de florestas aparentemente primitivas podem ser afetadas por fatores antropogênicos. Um exemplo é o corte seletivo de certas madeiras muito valiosas. Um tipo peculiar de floresta constituida em grande parte de espécies *Guadua* de curto ciclo de vida (tabocal) e que ocorre em certo trecho da rodovia Belém-Brasília, com grande probabilidade pode ser atribuido a práticas de incendimento de parte dos Índios.

Diferenças de origem edáfica na vegetação florestal. Quase todas as áreas de inventário florestal acham-se localizadas na Planície, onde os solos de drenagem livre, no nível aplicado de classificação, apresentam um alto grau de semelhança. Assim, diferenças estabelecidas nas caraterísticas de floresta, que ocorrem em áreas de condições climatológicas uniformes e de falta ou ocorrência uniforme de influências antropogênicas, hão de ser estudadas na sua correlação eventual com as diferenças encontradas nas caraterísticas de solos de categoria mais baixa, como a capacidade de retenção de água, a soma total dos vários nutrientes disponíveis para as plantas, e as possibilidades de penetração de raízes. Estas qualidades dependem de fatores tais como a textura do solo, a compacidade do subsolo e a presença de matéria de 'plinthite'. Resulta que diferenças em caraterísticas florestais freqüentemente coincidem com diferenças nêstes fatores. Em geral é difícil, porém, estabelecer quais são os fatôres motivadores destas coincidências.

Existe uma relação entre textura do solo e volume bruto de madeira. Em particular os solos de textura pesada e meio-pesada freqüentemente suportam florestas com alto volume de madeira. Os solos de textura muito pesada da Planície, porém, ou seja os solos desenvolvidos na argila de Belterra, em vários trechos estão cobertos com florestas de baixo volume de madeira, por consistir inteiramente ou por parte considerável de cipós (cipoal ou floresta cipoálica). Êstes tipos de floresta ocorrem no centro completamente plano dos terrenos de planalto, bem como nos terraços Pleistocenos mais antigos nas partes onde êstes estão cobertos com argila de Belterra remodelada. Deduziu-se que o cipoal e a floresta cipoálica prevalescem nos solos de argila de Belterra que, comparados com os solos nas imediações, apresentam um subsolo compacto e um horizonte A_1 delgado. Parece que também em outras partes da Amazônia as florestas ricas em cipós prevalescem em solos de pouca penetração de raízes, bem os de uma baixa como os de uma alta fertilidade natural.

Com alguns exemplos é descutida a relação possível entre solos e espécies individuais de árvores de distribuição desigual. O Acapú *(Voucapoua americana)*, por exemplo, apenas ocorre em algumas partes da região, onde é encontrado em grupos. Êstes grupos, porém, ficam em solos variados. A Angelim pedra *(Hymenolobium excelsum)* é uma das espécies encontrada mormente em solos de textura muito pesada. A espécie Pau amarelo *(Euxylophora paraensis)* na área Guamá-Imperatriz, onde foi estudada sua ocorrência, encontra as suas melhores condições de crescimento em solos de concreções de 'plinthite' fóssil de determinado nível e idade.

Uma investigação especial foi feita dos lugares de crescimento de Mogno *(Swietenia macrophylla)*, em parte da zona de transição sudeste do cinturão do floresta equatorial. Resulta que nesta área a espécie cresce quase exclusivamente em terrenos de drenagem imperfeita com solos hidromórficos bem desenvolvidos, especialmente os que químicamente são ricos (Fig. 25 e Apéndice 6).

A ocorrência de espécies de palmeiras nas florestas amazônicas parece que mais se acha relacionada com as variações nas condições de clima e solo do que é o caso na ocorrência de espécies de árvores dicotilas.

As savanas não-edáficas. Algumas savanas de terra firme dentro do cinturão de floresta principalmente foram causadas por fatores adversos não-edáficos, usualmente com uma predominância de influências antropogênicas. Essas savanas acham-se localizadas na parte nordeste da Amazônia: o território do Amapá, a parte sudeste da ilha de Marajó e a parte ao lado norte do Baixo Amazonas.

Savanas e florestas-savanas de origem edáfica. As outras savanas da Planície e as florestas-savanas são de origem edáfica. Essas savanas e florestas-savanas acham-se em terrenos de drenagem imperfeita. Os solos dêsses são ou solo Laterita Hidromórfica – muitas vezes a chamada fase Baixa dêle – ou Podzol Hidromórfico. Extensas savanas e as florestas-savanas que as circundam, encontradas nos terrenos planos nos divisores de água (os campos; parte das campina-ranas), encontram-se principalmente em solos Laterita Hidromórfica. As savanas e florestas-savanas de pouca extensão, que ocorrem em faixas estreitas de terreno baixo e arenoso ao longo de rios ou sôbre antigos leitos de rios enchidos de areia (as campinas; as caatingas amazônicas; parte das campina-ranas), ocorrem sobretudo em Podzols Hidromórficos. Alguns lugares de floresta-savana (parte das campina-ranas) acham-se em terrenos relativamente altos de drenagem livre, com Regosolo de Areia Branca.

Há poucos dados disponíveis sobre as savanas e as florestas-savanas fora da Planície. É provável que sejam de origem edáfica e ficam mormente em Litosolos e solos hidromórficos.

Na tabela 13 aparece um esquema das condições de crescimento das diferentes savanas e florestas-savanas discutidas.

Solos e vegetação nas baixadas. As mútuas diferenças entre as florestas das baixadas são muitas vezes claras, e é possível relacioná-las com o caráter da inundação. As savanas e florestas-savanas que ocorrem nas baixadas do este da Amazônia são de origem edáfica.

A POTENCIALIDADE DOS PRINCIPAIS SOLOS AMAZÔNICOS PARA FINS AGRÍCOLAS

Uma avaliação dos principais solos amazônicos para fins agrícolas é de importância imediata. Isto é porque partes da Amazônia são consideradas como podendo ser usados de escoadouros para a densa população rural do Nordeste, região esta periòdicamente sujeita a sêcas ou inundações calamitosas.

Com respeito às baixadas há de salientar que seu valor agrícola depende muito do tipo de várzea. Os critérios dominantes para sua avaliação terão de ser as qualidades químicas de seus solos e o caráter da inundação. Os melhoramentos hidráulicos da terra requereriam investigação, organização e investimento de capital numa escala vultosa.

Os solos de terra firme fora da Planície são muito diversos. A fertilidade química natural do solo é certamente um critério essencial para avaliar as potencialidades da terra naquelas áreas remotas e de difícil acesso.

Qualidades dos solos caoliníticos da Planície de drenagem livre. A Planície compõe-se mormente de terrenos planos ou levemente ondulados de drenagem livre. Estes terrenos acham-se nas proximidades dos principais cursos de água e das poucas rodovias existentes na região. As florestas naquelas áreas têm um volume de madeira relativamente alto e as áreas agrícolas amazônicas atuais ficam concentradas nestes terrenos. Assim a Planície amazônica, embora a fertilidade química natural do solo seja baixa, representa uma possibilidade para a colonização agrícola em grande escala. Portanto convém prestar atenção especial para as qualidades químicas e físicas daquêles solos da Planície que tenham boa drenagem externa, os chamados solos caoliníticos da Planície de drenagem livre.

Qualidades dos solos sob sua vegetação natural. Para discutir as qualidades químicas dos solos caoliníticos da Planície de drenagem livre sob sua vegetação florestal natural, contamos com dados analíticos de 35 perfis. Êstes dados são agrupados e estudados em suas mútuas relações (Figs 27–34) E' evidente que a capacidade de criar um meio mais adequado à preservação da matéria orgânica relativamente muito ativa é a principal vantagem dos solos argilosos sôbre as solos arenosos quanto às qualidades químicas. As diferenças entre os diversos solos residem por parte considerável nas suas qualidades físicas. Importa a capacidade de retenção de água dos solos, visto que grande parte da Amazônia tem uma estação sêca de alguma importância. De equivalentes de umidade, algumas curvas de tensão de umidade e outros dados analíticos (Figs. 35–37 e Tabela 16) deduz-se que os solos sob sua vegetação florestal, visto no conjunto, apenas tem pequenas quantidades de água aproveitável por unidade de volume. Apenas na zona em que se acha quantidade considerável de matéria orgânica, os solos argilosos – no que diz respeito à quantidade de água disponível – têm vantagem evidente sobre os solos arenosos.

Qualidades dos solos sob influência humana. Quando os solos caoliníticos da Planície de drenagem livre chegam sob influência humana, vão modificando-se suas qualidades químicas e físicas. Para os solos usados para agricultura itinerante apenas há observações qualitativas. Para os solos das savanas antropogênicas existentes há muito tempo, contamos, porém, com um número de dados quantitativos. Não considerando a diferença na quantidade de nutrientes armazenados nas vegetações respetivas, podemos dizer que, no que diz respeito às qualidades químicas e físicas, os solos das savanas em aprêço ainda se assemelham bastante aos solos sob floresta. As principais diferenças são as seguintes: uma quantidade algo menor de matéria orgânica da camada superior do solo, maior densidade de solo de topo e possìvelmente menor quantidade de água disponível. Pequenas diferenças foram registradas nas razões C/N, nos valores para o pH-H_2O e no grau de fixação de fósforo.

Os efeitos benéficos que a influência humana pode ocasionar, são ilustrados pelas propriedades químicas da Terra Preta (Figs. 38 e 39). A capacidade total de troca dos cations dêste solo é relativamente elevada, mesmo onde o teor da matéria orgânica seja baixo. A alta capacidade de troca dos cations na Terra Preta, porém, vai acompanhada de grandes quantidades de fosfatos, as que parecem muitas vezes ser consideràvelmente maiores que o poder de fixação do solo pobre em humus.

Os efeitos de adubos químicos, estrume e adubos verdes, apenas podem ser aproximados em parte, por ser limitado até hoje o número de quadros de ensaio e terras de agricultura permanente.

Os solos mais adequados. A estimativa do potenticial agrícola dos solos da Planície de drenagem livre há de basear-se principalmente nas diferenças das qualidades dos solos tais como o teor de matéria orgânica, a capacidade de retenção de água e a penetrabilidade por raízes. Para projetos de colonização agrícola em grande escala é natural que também desempenham um papel fatores externos, como a topografia e o padrão de drenagem da terra, sua acessibilidade e o grau de coerência geográfica dos vários solos. Não considerando, porém, êstes fatores e as exigências das culturas individuais, pode-se afirmar que as condições mais favoráveis para a agricultura se encontram nos solos florestais de textura relativamente pesada, de subsolo não-compacto. O Latosolo Amarelo Caolinítico (,Orto) de textura pesada e meio pesada e o Latosolo Amarelo Caolinítico, 'intergrade' para solo Podzólico Vermelho-Amarelo são os que melhor se prestam para aquela finalidade.

Manejo da terra. O exame das qualidades químicas e físicas dos solos sob floresta primitiva ou sujeitos à influência humana, dá indicações para os meios mais adequados para manter a potencialidade dos solos após ser derrubada a floresta primitiva, bem como para seu melhoramento após uma interferência humana adversa. A conservação e – na medida do possível – o aumento do teor da matéria orgânica dos solos é de suma importância. Considerando o estado atual das investigações, apenas poderão ser aproximativas as recomendações relativas à fertilização.

Será preciso tomar o sistema itinerante como ponto de partida para o fomento da agricultura. Aos poucos poderá ser melhorada em muitos respeitos a aplicação que êste sistema tem hoje na Amazônia. Parece recomendável uma ampliação da área com perenes arbóreos, particularmente do dendê. Poderá ter vantagens a combinação da agricultura com uma moderna explotação das florestas.