M.W.H. de Boer

Department of Tropical Soil Science,
Agricultural University, Wageningen

Landforms and soils in eastern Surinam (South America)

Avec sommaire:
Physiographie et sols au Surinam oriental (l'Amérique du Sud)
Con síntesis:
Fisiografía y suelos del este de Surinam (América del Sur)

pudoc

1972 *Centre for Agricultural Publishing and Documentation*

Wageningen

Abstract

De Boer, M.W.H. (1972) Landforms and soils in eastern Surinam (South America). Agric. Res. Repts (Versl. landbouwk. Onderz.) 771, ISBN 90 220 0381 7, (vii) + 169 p., 38 tbs, 49 figs, 136 refs, Eng., French and Spanish summaries. Also: Doctoral thesis, Wageningen.

Quaternary geogenesis in eastern Surinam was studied by field methods and sedimentary-petrographic research. The development of the river valleys was explained in terms of changes in sea level, tectonic movements and changes in climate. A preliminary stratigraphy was established.

Eight soil profiles were selected for a detailed study of pedogenesis. For this purpose the field data were combined with the results of thin-section analysis and chemical research, including X-ray microprobe analysis. To interpret the mechanical data, a rectangular diagram after Doeglas was used. The chemical data were recalculated into the normative mineralogical composition according to van der Plas & van Schuylenborgh and Burri. Thus bioturbation, clay migration, ferrallization, plinthization, podzolization and the genesis of arable soils were studied.

27 soil profiles were classified by the American, the French, and the Brazilian system.

ISBN 90 220 0381 7

De auteur promoveerde op 3 maart 1972 aan de Landbouwhogeschool te Wageningen op een gelijkluidend proefschrift tot doctor in de landbouwwetenschappen.

Contents

1 Introduction

In Surinam, pedological studies have almost completely been restricted to the coastal area. This study gives information on landforms and soils in the interior of the country. Attention has been focused on the drainage area of the Marowijne River, which is situated along the frontier of Surinam and French Guiana. This area will be referred to as the Marowijne area (Fig. 1).

It is expected that the results will be a base for land classification in the future development of the country.

1.1 Methods

Field studies were carried out in ten sample areas which were distributed over the river valleys from the estuary up to the headwaters (Fig. 1). The size of the strips varied from 1900 to 12 000 ha. The sample areas were distributed more or less regularly over the Surinam part of the valley system. The strips represented relatively broad parts of the valleys, where a maximum variation in landforms and soils could be expected. Moreover, the main geological formations (Table 2) occurred in the strips. The choice of the sample areas was based on a preliminary study of literature, geological and topographical maps, and aerial photographs.

Photo-interpretation maps were made of all sample areas and seven to thirteen lines per strip were laid out, which served as a base for the field work. In each strip three to seven lines were levelled.

Deep borings down to a maximum of 8 m and routine borings down to 2.2 m were made with an Edelman auger. Two borings were made with an Empire drill, one to 20 m and another to 7 m.

In all sample areas soil profiles were studied which were considered to be representative of the geomorphological units observed (3.1). The studies were carried out in pits and exposures and the following characteristics were described in the field:

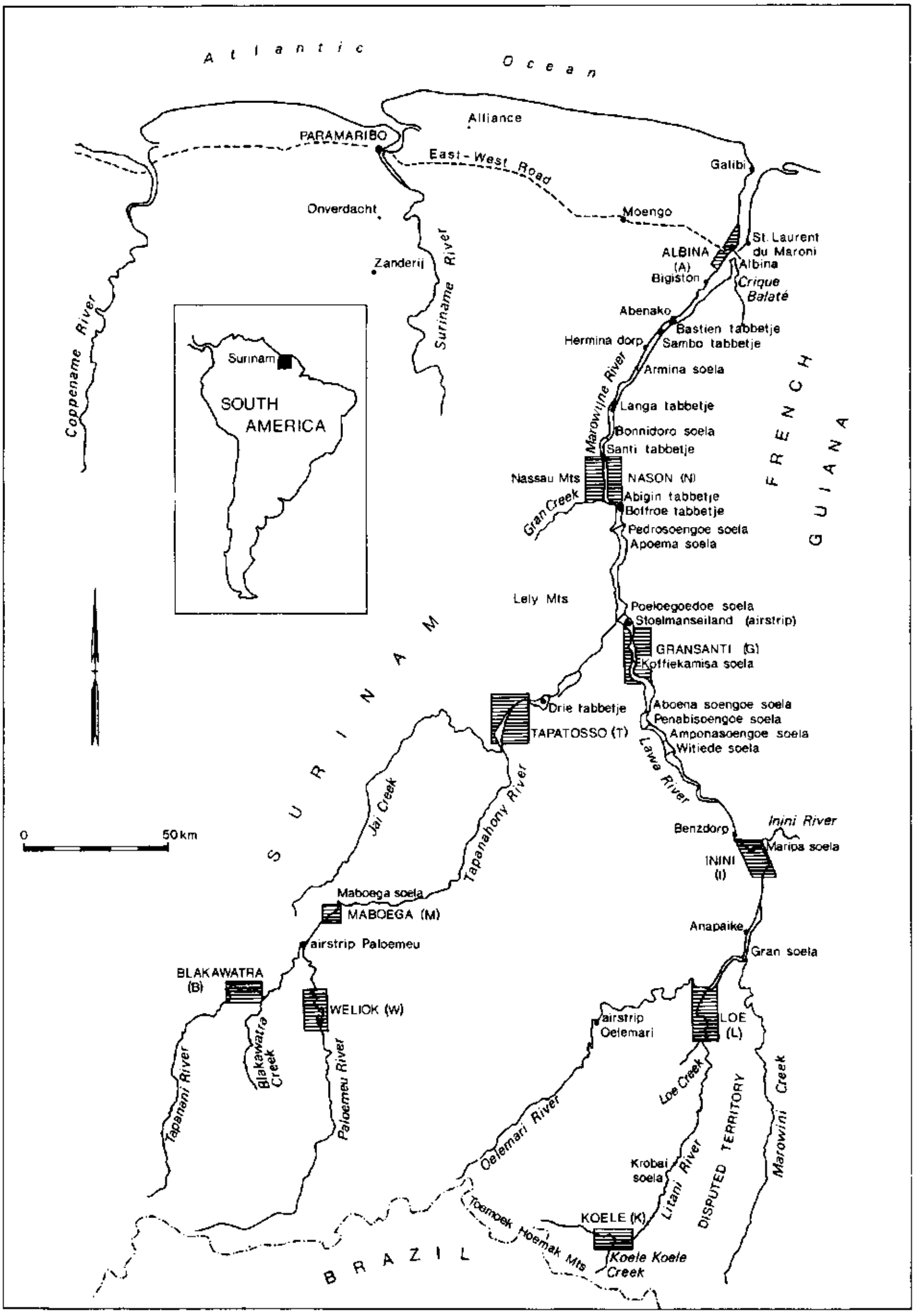


Fig. 1. General map of eastern Surinam and location of sample areas.

(1) Environmental conditions

(2) Texture and sedimentary stratification

(3) Degree and kind of weathering and soil formation as expressed by colour; frequency, size, contrast and colour of mottles; structure, porosity, consistence and pH (Hellige)

From a series of 57 profiles some were selected for more detailed studies. Samples of regolith and sediments were analysed for texture, mineralogical composition and chemical properties. From undisturbed samples thin sections were made for micromorphological analysis. Four ^{14}C estimations were given.

Sampling sites are indicated in figs 2-9. As a rule, samples were encoded by a capital and two ciphers. This code refers to the sample area, the number of the profile and the soil horizon, respectively. When only one sample per location was considered, the second cipher was omitted. Code letters of sample areas are given in Fig. 1.

Some data were derived from other authors. Sample numbers of these authors have been maintained.

Details concerning profile descriptions and laboratory procedures are given in Appendix I.

1.2 Terminology

To avoid misunderstanding, some terms that are still under discussion will be defined below.

Geogenesis is defined as any process related to the genesis of landforms.

Landforms are distinctive geometric configurations of the earth land surface (Strahler, 1969).

Pedogenesis is a term designating the collection of processes that transform parent material to soil (Veen, 1970). These processes operate in the pedosphere, i.e. the zone of interaction of the soil forming factors. It is often difficult to define the borderline between pedogenesis and weathering.

A river terrace is an old alluvial plain, left behind by a river after a period of vertical erosion, and showing a step-like feature in the landscape at some height above the recent floodplain (Zonneveld, 1957).

A terrace is a topographic form characterized by a flat and a scarp (Leopold et al., 1964).

Weathering is the disintegration and decomposition of rock, i.e. the destruction by physical and chemical processes (Geological nomenclature, 1959).

Micromorphological terminology followed the book of Brewer (1964), unless stated otherwise.

Textural classes used in this publication are those of the Soil Survey Manual (USDA, 1962) and the 7th Approximation (USDA, 1967).

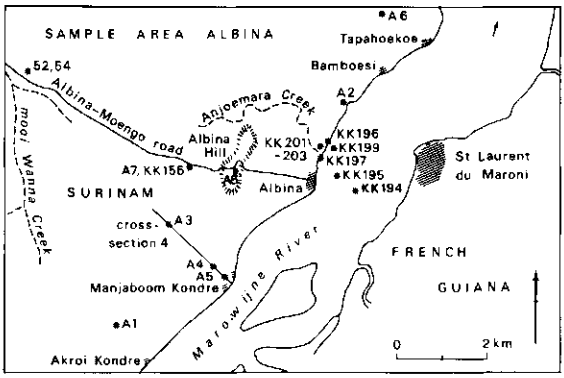


Fig. 2. Sketch-map of the sample area Albina and location of sampling sites.

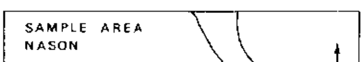


Fig. 3. Sketch-map of the sample area Nason and location of sampling sites.

Fig. 4. Sketch-map of the sample area Gransanti and location of sampling sites.

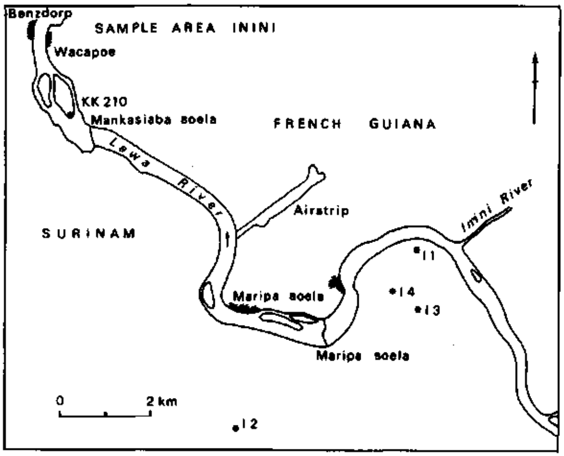


Fig. 5. Sketch-map of the sample area Inini and location of sampling sites.

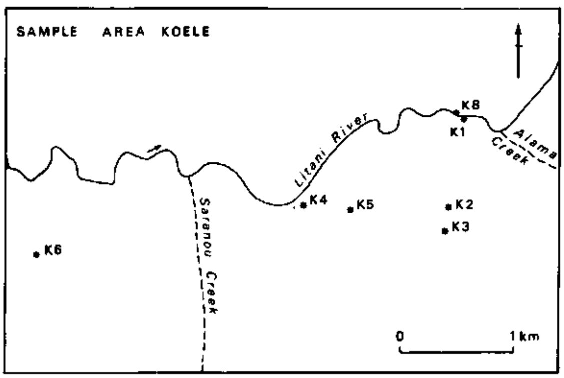


Fig. 6. Sketch-map of the sample area Koele and location of sampling sites.

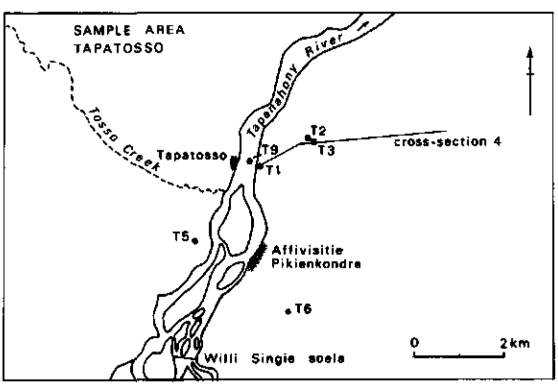


Fig. 7. Sketch-map of the sample area Tapatosso and location of sampling sites.

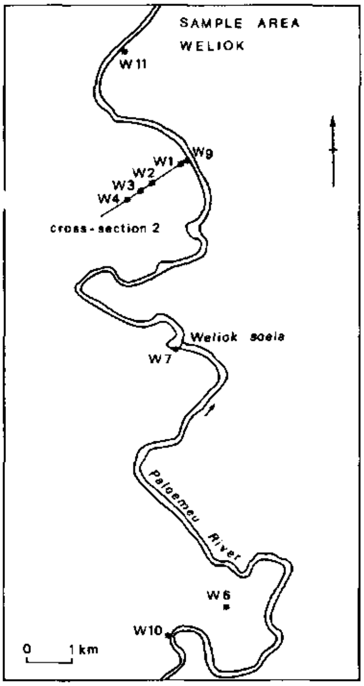


Fig. 8. Sketch-map of the sample area Weliok and location of sampling sites.

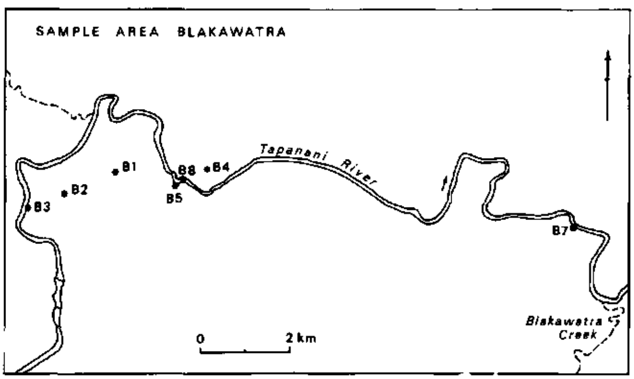


Fig. 9. Sketch-map of the sample area Blakawatra and location of sampling sites.

2 General description of eastern Surinam

2.1 The present climate

Many relevant data and many maps have been produced by the 'Meteorological Service' of Surinam. Some weather recording stations in eastern Surinam are mentioned in Table 1. Only the main characteristics are described below.

There is a marked periodicity in rainfall, as shown in Table 1. Four seasons can be distinguished: a long rainy season (April-July), a long dry season (August-November), a short rainy period (December-January) and a short dry period (February-March). In a southward direction the contrast between the short seasons becomes less distinct.

Table 1. Average precipitation values in eastern Surinam (mm).

	J	F	M	A	M	J	J	A	S	O	N	D	Tot.
Albina	211	177	235	280	370	279	212	137	75	61	109	230	2376
Hermina-dorp	214	104	142	97	274	261	223	132	95	82	137	202	1963
Stoelmans-eiland	210	113	152	173	328	303	220	155	75	46	87	192	2054
Benzdorp	245	220	222	295	344	259	186	141	70	53	76	195	2306
Oelemari	219	223	243	217	371	306	161	137	46	21	74	186	2204
Tapatosso	246	202	257	285	608	567	390	268	128	77	174	303	3505
Paloemeu	225	180	240	194	417	329	219	131	36	47	79	198	2295

Years of record: 29, 6, 6, 24, 6, 5, 6, respectively.

The temperature is high throughout the year with an annual mean ranging from 26.6 to 27.1 °C. The monthly averages vary by about 2.5 °C during the year.

The relative humidity of the air is generally high. The annual mean is about 80% for all stations. The winds are usually weak; hurricanes are unknown.

According to the classification of Köppen, eastern Surinam belongs to the regions of equatorial climates (van Wijk & de Vries, 1952). A monsoon climate (Am) is found in the interior of the country, except for Herminadorp and Tapatosso, where an equatorial rain forest climate (Af) occurs. The latter type is also characteristic for the major part of the coastal area, including Albina at the lower Marowijne River.

2.2 *The paleoclimate*

In this report the paleoclimate is of particular importance because of its relevance to the study of geogenesis and pedogenesis.

Formerly it was generally believed that glacials at higher latitudes were accompanied by pluvials at lower latitudes (Krook, 1969b). Thus van der Hammen & Gonzales (1960) explained that the Upper Pleistocene glaciations of the northern hemisphere corresponded with pluvials in the Columbian Andes. But according to Bigarella & de Andrade (1965) the Quaternary climate of eastern Brazil changed from humid tropical during the interglacial phases to arid or semi-arid during the glacial phases.

Van der Hammen (1961) remarked that the climatic changes of the Upper Pleistocene occurred simultaneously throughout the world. Changes in humidity were opposite or parallel, but temperature changes were parallel.

There are many indications that during the Last Glacial the climate in the Guianas was much drier than that of today. In a drill hole at Ogle Bridge, Guyana, van der Hammen (1963) found pollen of a poor savanna vegetation in deposits of Würm age. The same type of pollen was found by Wymstra (1969) in Würm sediments of the Alliance drill hole in northern Surinam.

According to Veen (1970) the gully pattern of dissection in the Old Coastal Plain of Surinam may be another indication for a drier climate during the Last Glacial. Savanna pollen were found at the base of a gully, indicating the presence of savannas in the Early Holocene on surfaces now covered by marsh-forest. Data from Roeleveld (1969) and Wymstra (1969) also suggested a larger extension of savannas in Surinam during the Last Glacial and the Early Holocene.

Nota (1958, 1967, 1971) mentioned the occurrence of very sandy deposits and reef-like bodies on the Guiana shelf. The so-called ST sands showed a grain-size distribution of braided rivers and were deposited at a lowered sea level in the Late Glacial. It was assumed that these sands accumulated at the same time as the reefs formed near the shelf break. These data point to a severe erosion of the 'hinterland', under conditions different from those of today. At present, the tropical rain-forest acts as a protective cover and mainly fine-textured sediments are deposited on the shelf (Nota, 1971). The fact that reefs could be formed may indicate that less clay was supplied by the Guiana current, because of less rainfall, less chemical weathering, or both (Krook, 1969b). Thus we may assume that at least a part of the rain forest had disappeared due to drier conditions and that its place was probably taken by savanna.

Damuth & Fairbridge (1970) established the presence of arkosic deep-sea sands in the Guiana basin. From a study of foraminifera these sands appeared to be of latest Wisconsin (Würm) age. The mineralogical composition pointed to a derivation from the Precambrian Shield. The authors explained that deposition took place during a semi-arid climate, which must have been widespread in northern South America during latest Wisconsin times. Mechanical weathering dominated and vast amounts of clastic detritus were removed to the sea.

The occurrence of argillic horizons in northern Surinam may be another indication for a drier climate in the Last Glacial. Because the present climate is not the most favourable one for lessivage, Veen et al. (1971) distinguished a phase of clay illuviation in some period of the Last Glacial. This epoch was related to drier conditions than the present ones.

The evidence provided by these data is still insufficient to determine the climatic evolution in the Guianas. There are strong indications for the occurrence of a drier climate in at least a part of the Last Glacial.

2.3 Hydrology

The drainage area of the Marowijne River comprises 65 500 km^2 of which 37 500 km^2 are on Surinam territory (Brouwer, 1966).

The river rises in the Toemoek Hoemak Mountains at about 400 km from the sea. The width is about 25 m near the Koele Koele Creek, some 200 m at Maripa Soela, 500 m at Gransanti and more than 2000 m in the estuary near Albina. Where the river shows a braided pattern, its width may exceed 5000 m.

Variations in the water level are determined by the tides, by seasonal variations in rainfall and by obstructions in the river valleys such as natural dykes and narrowings (Bakker, 1955, 1957). The influence of the tides is felt as far as Herminadorp at some 85 km from the sea. In the 'soela sector', where rapids and falls are numerous, differences in water level of 4-5 m are normal, but even values of 8 m have been recorded (Haug, 1966).

2.4 *Vegetation*

The following vegetation types were observed in the sample areas (Lindeman & Moolenaar, 1959):

Marsh or seasonal swamp forest Two storied forest on periodically flooded areas in the basins of the recent floodplain. The upper storey is not fully closed, showing an irregular canopy between 15 and 30 m with occasionally smaller trees. The lower storey between 5 and 15 m is in general very dense. The herb stratum is usually well-developed.

As a rule this type is rich in species. For details see Lindeman & Moolenaar (l.c.).

Savanna The Surinam savanna concept comprises all those vegetation types 'that periodically must withstand a more or less severe shortage of moisture' (Lindeman & Moolenaar, l.c.).

In eastern Surinam savanna was observed on alluvial fans, on laterite[1] crusts and on rocks with a thin soil cover. The savanna on alluvial fans corresponds with the 'Bosland' savanna type of Cohen & van der Eyk (1953).

Three subtypes could be distinguished:

Marshy savanna forest Two storied savanna forest. The upper storey is closed and fairly dense; trees reach up to 25-30 m. The lower storey usually consists of many slender trees with very narrow crowns. The characteristic trees of savanna forest are mainly restricted to the lower storey.

This type occurred locally on alluvial fans with a slope of more than 2%. It was of minor geographical importance.

Marshy savanna wood One storied savanna wood. It is more uniform and poorer in species than savanna forest. Trees range from 8 to 20 m in height, forming a very dense and regular wood of slender stems with small crowns.

This type was common on periodically flooded alluvial fans. The soil usually had an impermeable layer (ortstein) at about 1 m; the microrelief was hummocky. Slopes were less than 2%.

Mountain savanna forest A low, thin-stemmed forest with little stratification and a xeromorphic habit.

This type occurred on laterite crusts and on rocks with a thin soil cover.

1. In this chapter the term laterite is used in its geological sense, standing for sesquioxidic hardpans and crusts.

Rain forest In this study the term rain forest is used in the broad sense of Lindeman & Moolenaar, including all remaining primeval forests on well-drained soils. The forest is typically evergreen, though in the upper layers occasional trees may lose their leaves for short periods without a close relation to the seasons. As a rule it is very rich in species.

In optimal form 3-4 storeys can be distinguished. The uppermost storey consists of scattered emergents of 40-45 m, expanding their crowns above the fairly well-closed canopy of the second storey at 25-30 m. Underneath, there is a storey of slender trees, more or less separable from a layer of undergrowth treelets. The herb stratum is generally very open.

This forest type covers the main part of Surinam. In the sample areas it was found on levees, terraces, colluvium and in the hilly country.

Secondary forest In Surinam, secondary vegetation, resulting from shifting cultivation, is called 'Kapoewerie'. It is common in the inhabited parts of the river valleys. In its first stage it consists of a profuse seedling crop of species that require much light for germination. In some years it develops into a slender-stemmed forest, which gradually regenerates into rain forest and seldom into savanna.

2.5 *Landuse*

In the Marowijne area the bush-negro and Amerindian tribes have practised shifting cultivation. The period of landuse does not exceed two years and the fallow period may vary from some decades to less than ten years. The cultivated grounds are situated on well-drained soils in a narrow belt along the main rivers.

The bush-negro men clear and burn their plots, each about 1 ha in size, in the long dry season (October-November). In the short rainy season (December-January) the women plant several crops at the same time. Each family usually has several clearings, which often lie far apart.

The agricultural laws which oblige the bush-negro to stay within certain boundaries, the increasing population and the serious plague of leaf-cutting Atta ants have lead to a shortage of land in several areas (Geyskes, 1955). Measures to improve this situation and the problems involved were discussed by de Haan (1954) and Geyskes (1955).

The Amerindians are less numerous and lead a more nomadic life than the bush-negroes. Therefore, the limit of overcropping has not yet been reached.

2.6 *Prè-Quaternary geology*

2.6.1 Stratigraphy and lithology

Details and references on the stratigraphy and lithology of Surinam and French Guiana have been given by Brouwer (1961, 1964a, b, 1966) and by O'Herne (1969a, b, c). Simplified data on the Marowijne area are presented in Table 2 and in Fig. 10.

2.6.2 Landscapes

In his study on the landscapes of Surinam, O'Herne (1969d) defined a landscape according to van der Eyk (1957): 'A landscape is an area, which as a result of its specific geological origin, morphologically forms a unit, characterized by a special rock formation and a variation in soil conditions and vegetation typical of this area'. In the same work O'Herne stated: 'In a strongly weathered and densely forested country like Surinam, a landscape is characterized mainly by its relief and occasionally by its particular vegetation. Similar landscapes usually show similar rocks or rock associations'.

In this report only the following landscapes will be considered:

(1) The Brokolonko landscape

This landscape, which occurs in the sample area Nason (Fig.48), is characterized by deeply incised V-shaped valleys, sharp crests and numerous transverse valleys more or less perpendicular to the crests. Laterite crusts or boulder fields are common on tops and slopes. Lithologically the landscape is very uniform, which is not reflected in the relief. In the Nassau Mountains metamorphic basic lavas predominate (de Munck, 1954b).

Plateau-like tops may reach 460-680 m; the lowest areas have elevations of 50-75 m.

(2) The Tempati landscape

In the sample area Nason two main forms are distinguished (Fig. 48).

The Tempati I landscape consists of small rounded hills, lying at random. It is probably characteristic of the quartzite facies of the Armina series (Table 2).

The Tempati II landscape is a more common type, showing bean-shaped hills in complexes. It is probably typical of the schist facies of the Armina series.

Elevations are predominantly 25-100 m; exceptionally high tops 100-120 m; the lowest areas less than 25 m.

(3) The Tapanahony landscape

This landscape is restricted to the southern half of the country, where it occurs in the sample area Weliok (Fig. 49). It is composed of rounded or elongated, more or less cone-shaped hills and is strongly dissected. The diameter of the individual hills ranges from 300 to 1000 m. The landscape is typical of the granite facies of the Gran Rio massif (IJzerman, 1931). Elevations are usually 150-250 m; exceptionally high tops 250-300 m; the lowest areas 100-150 m.

(4) The Cover landscape

This landscape is found in the sample area Albina at a height of about 40 m above mean sea level (figs 13, 47). It is a dissected plain, consisting of coarse sand to loam. The occurrence of several savanna types is characteristic (Cohen & van der Eyk, 1953).

The landscape is typical of the sand facies of the Upper Coesewijne series (Table 2); in pedological literature it is known as the Zanderij landscape (Brinkman & Pons, 1968).

According to IJzerman (1931) the sands are of continental origin. Van der Eyk (1957) and Montagne (1964) assumed a deposition in a braided river environment. Bakker (1957) supposed that the Zanderij sands were deposited in estuaria and upon beaches. According to Boyé & Cruys (1959) the similar sands of French Guiana are weathered bedrock, reworked by pluvial washing out and creep: 'arène de délavage'.

2.6.3 Planation surfaces

The geomorphology of the Precambrian Shield is dominated by a series of step-like planation surfaces which can be followed over large distances (Choubert, 1957; King et al., 1964; Mc Connell, 1966; Zonneveld, 1969a). In general these surfaces are laterite-capped. Names, heights and probable ages of peneplains in the Guianas are shown in Table 3.

The existence and individuality of each of these planation surfaces can be established by various criteria. In the first place, they normally consist of vast peneplains which bevel different geological formations and rock types. Secondly, these relics are of fairly constant altitude, although they may display a slope of some promilles. Moreover, each peneplain is usually separated from the next younger one by a pronounced scarp. The profile with alternating flat and scarp is characteristic and the number of planations appears to be constant over large areas (Table 3).

The older peneplains are generally represented by flat-topped outliers

Table 2, Stratigraphy and lithology of the Marowijne area.

Rock units		Approximate age	Lithology
Surinam	French Guiana		
Demerara series Coropina series	Série de Demerara Série de Coswine	Holocene Pleistocene	Unconsolidated sands and clays
Coesewijne series Laterites Onverdacht series	Série détritique de base Latérites ?	Oligocene-Pliocene unconformities Upper Cretaceous-Lower Eocene	Unconsolidated sands (and clays) Ferric and aluminous laterites Partly consolidated sands and clays; marls, limestones
		unconformity	
Young dolerites	Dolérites	Permian-Triassic 210-230 m.y.	Augite-dolerite dykes
		unconformity	
Main suite of granites	Granite galibi Granite caraibe	Precambrian 1800-1900 m.y.	Granites, granodiorites, quartz-diorites
Armina series	Série de l'Orapu		Pelitic-psammitic metasediments (quartzites, graywackes, schists)
		unconformity	
Rosebel series	Série de Bonnidoro		Psammitic-psephitic metasediments (subgraywackes, conglomerates)
		unconformity	
Older granites?	Granite guyanais		Granites, granodiorites, diorites, migmatites)
		Post-Paramaka orogenesis	
Paramaka series	Série de Paramaka	older than 2600 m.y. ?	Metavolcanics (tuffs, lava's, agglomerates) Metasediments (graywackes, schists, phyllites, quartzites) Metabasites (amphibolites near granite contacts)

From O'Herne, 1969a,c.

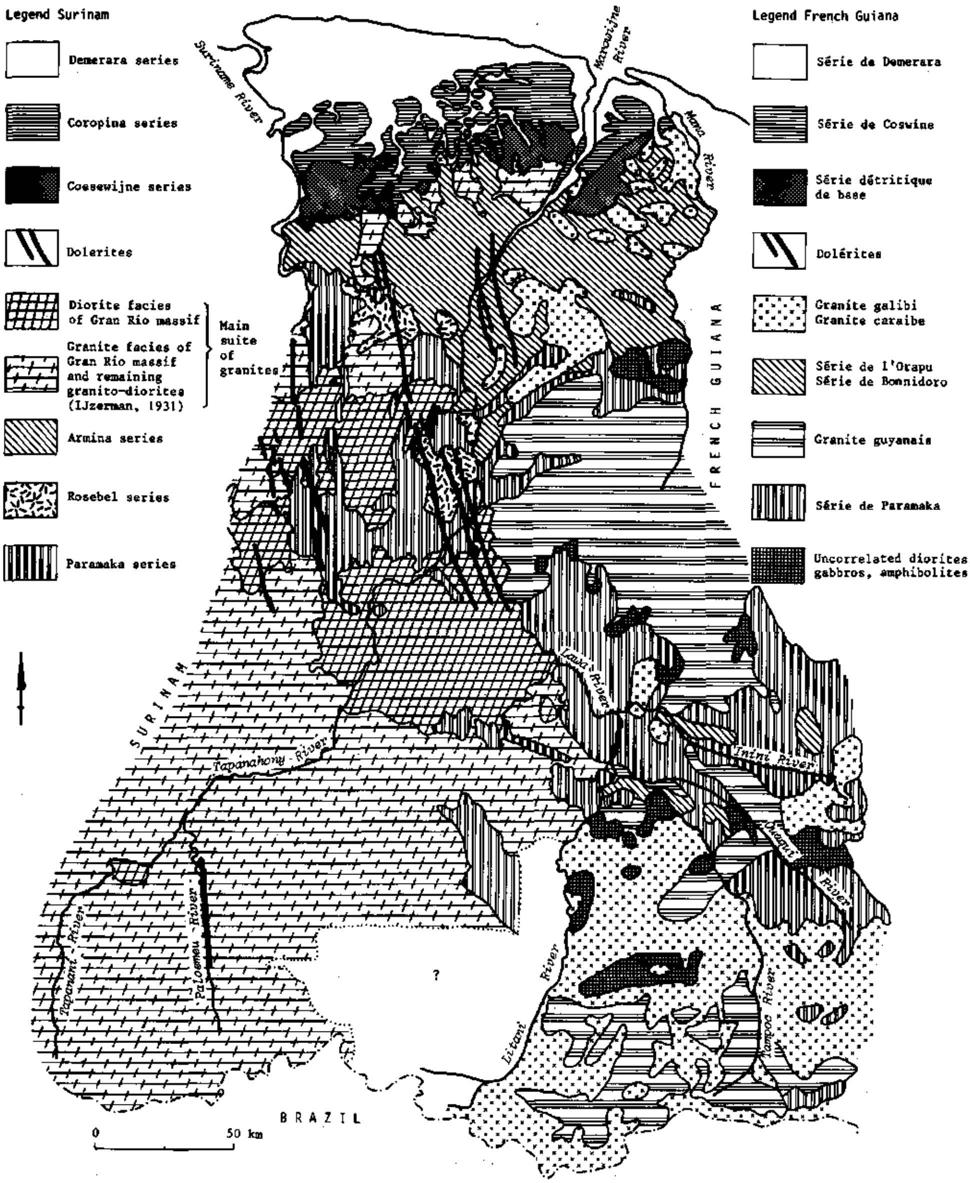


Fig. 10. Geological outline-map of the Marowijne area (from Choubert, 1966 and O'Herne, 1969).

Table 3. Data on peneplains in the Guianas.

Name of peneplain or cycle in			Altitude in m		Probable age
Guiana (G)	Surinam (S)	Fr. Guiana (F)			
no name	?	?	G : 1000 S?: 1000 F?: 600		?
Kopinang	Early Tertiary	Première pénéplaine	G : 600- 700 S : 450- 600 600- 700 F : 525- 550	 (Nassau Mts) (Lely Mts)	Late Cretaceous-Early Tertiary
Kaieteur	First Late Tertiary	Deuxième pénéplaine	G : 210- 300 400- 450 S : 300- 350 F : 300- 370	(Bartica Mts) (Pakaraima Mts)	Mid Tertiary
		Troisième pénéplaine	F : 240- 260		
Rupununi	Second Late Tertiary	Quatrième pénéplaine	G : 100- 150 S : 60- 200 F : 150- 170		End Tertiary
Mazaruni	Quaternary cycle of incision	Rajeunissement	G : 70 S : 30- 180		Quaternary

From Choubert (1957), King et al. (1964), Mc Connell (1966) and Zonneveld (1969a).

rising above the younger plains. The lowlands, sharply flanked by the mountains, do not form completely flat areas. They are generally characterized by a multiconvex relief with differences in height of some dozens of metres (Zonneveld, 1969a).

Some profiles perpendicular to the course of the rivers were constructed by Zonneveld, who used 1:200 000 and 1:100 000 maps with a contour interval of 50 m. These profiles clearly show that the planes which can be drawn through the hilltops (the hilltop envelopes) not only dip in downstream direction but also slope down to the main rivers.

Discussing the origin of the planation surfaces, Zonneveld (1969a) argued that they must have been formed one after the other, each younger one at a lower elevation, by a repetition of levelling processes. These processes were caused by intermittent epeirogenic movements (Choubert, 1957; Mc Connell, 1966; van der Hammen, 1969). The formation of the steps must have been controlled by the main lines of the river pattern, a relation with the courses of the main rivers being evident. Probably the process of parallel slope retreat played an important role (Zonneveld, l.c.).

As the planation surfaces approach the margin of the Precambrian Shield, they share in the seaward dip of a general coastal monocline, which causes them to plunge oceanwards. Consequently, the differences in height between the peneplains diminish progressively and eventually, in the basin of deposition, the surfaces pass into unconformities or depositional gaps (Mc Connell, 1966). The unconformities are surmounted by detrital deposits, corresponding to the renewed erosion of the successive cycle as a result of continental uplift, accompanied by a general subsidence of the coastal area (Fig. 11).

The age of the peneplains can be established by correlating depositional gaps with continental planation surfaces.

The Kopinang surface, which carries high-level bauxite, can be correlated with the epoch in which the high-grade bauxites in the coastal belt of the Guianas were formed. It is now generally accepted that there was only one period of bauxitization in the coastal area, occurring between the Lower Eocene and the Lower Oligocene. A corresponding hiatus occurs in the coastal sediments (van der Hammen & Wymstra, 1964).

The Kaieteur surface may be correlated with a hiatus which comprises at least a major part of the Miocene (van der Hammen, 1969).

The Rupununi surface is tentatively dated as Pliocene, on account of its correlation with the similar second Late Tertiary surface of Africa, India and Australia (King et al., 1964).

The youngest cycle recognized is a deep incision by the larger rivers during the Quaternary (King et al., Mc Connell, l.c.). The Mazaruni surface in the interior of Guyana would correspond with this complex cycle.

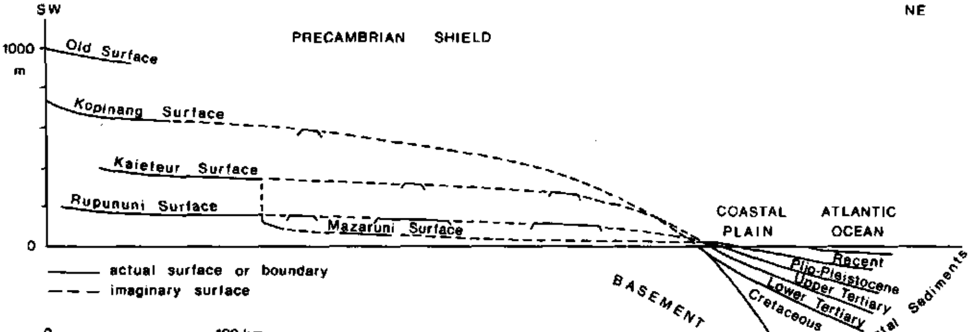


Fig. 11. Provisional diagram of planation surfaces in Guyana (from Mc Connell, 1966, slightly modified).

3 Quaternary geology

3.1 Geographical outline of the river valleys

A schematic unilateral cross-section of the valleys in eastern Surinam is given in Fig. 12. It forms the key to the following chapters. Some natural cross-sections are in figs 13-17.

The following geomorphological units, in a stratigraphic sequence, were observed in the sample areas:

Planation surfaces (E)

The study of levelled cross-sections has shown that at least three planation surfaces can be distinguished. These units bevel different rock types, and textures of the regolith range from clay to loamy coarse sand. Each level has about the same relative height[1] all over the river valleys. The surfaces considered are the following.

(1) The 30-m planation surface (E30) occurs at a relative height of about 30-35 m and is widespread along the river valleys. It corresponds to the second Late Tertiary surface of King et al. (1964) and to the Rupununi surface of Mc Connell (1966). For descriptions see 2.6.3.

Higher levels will not be considered here.

(2) The 15-m planation surface (E15) occurs at a relative height of 10-25 m and is found here and there in all sample areas upstream from the estuary (Fig. 17). As a rule it is strongly dissected and it slopes down to the river.

(3) The 5-m planation surface (E5) forms small, flat-topped hillocks at a relative height of 5-10 m, rising above the valley sediments (Fig. 16). The hillocks, which occur all over the valleys, are considered outliers of the present valley floor.

1. The relative height is the height above mean river level.

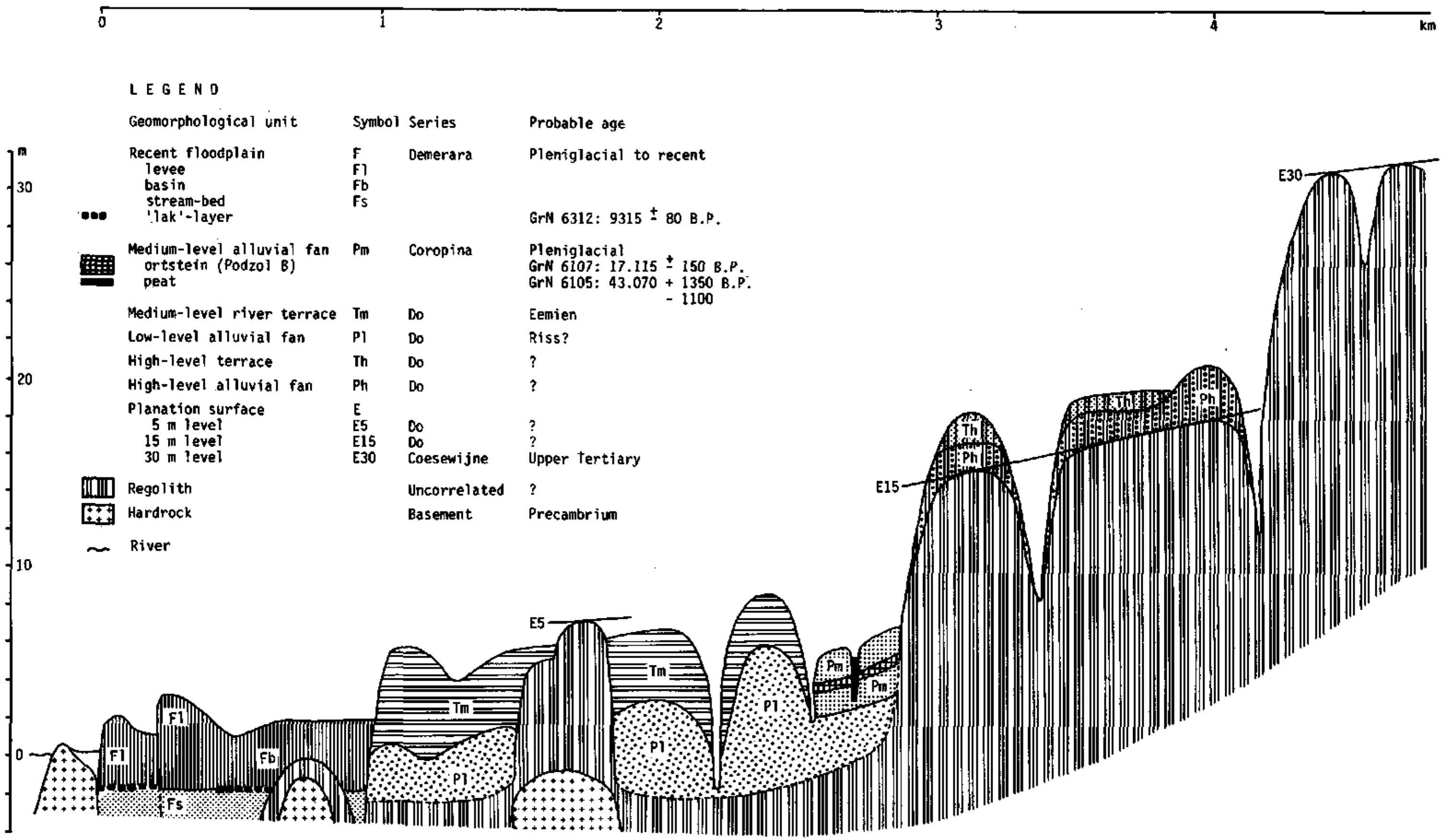


Fig. 12. Schematic unilateral cross-section of a river valley in eastern Surinam (upstream from the estuary).

The Cover or Zanderij landscape[1] (Z)

In this report the Zanderij landscape is only briefly mentioned (see 2.6.2). In the sample area Albina three features are of interest.

(1) The Zanderij hills consisting of bleached (Zb) and non-bleached sediments (Zn). The latter occur at the hill flanks (figs 13, 14).

(2) The Albina hill (Za) along the Moengo-Albina road (Fig. 13). Some similar hills are present in the environs at a height of about 40 m above mean sea level (Fig. 47).

The surface layer, down to 1.5 m, is mainly composed of stones consisting of sand indurated by iron compounds. The sediment layer is about 3.5 m thick; textures range from stony sandy clay loam to loamy coarse sand. In general there is an abrupt transition to weathered bedrock via a stone-line.

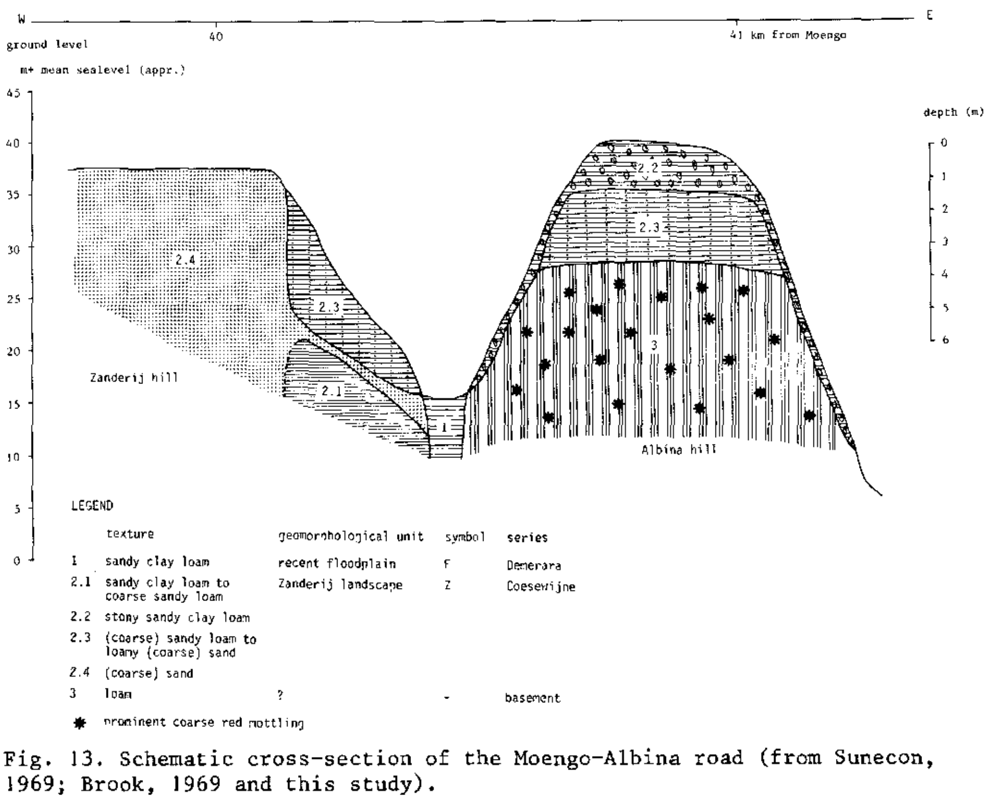


Fig. 13. Schematic cross-section of the Moengo-Albina road (from Sunecon, 1969; Brook, 1969 and this study).

1. Not in Fig. 12.

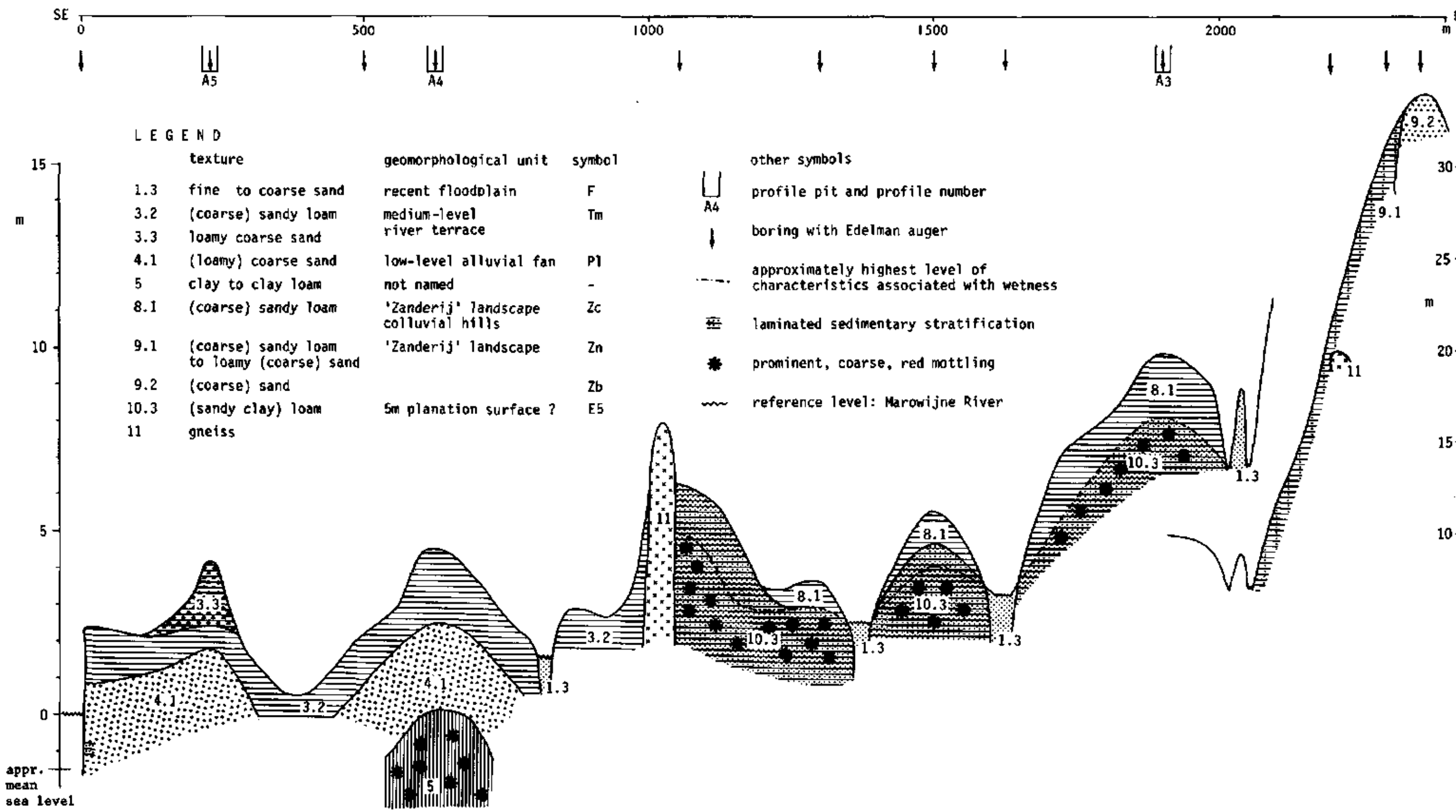


Fig. 14. Sample area Albina, cross-section 4.

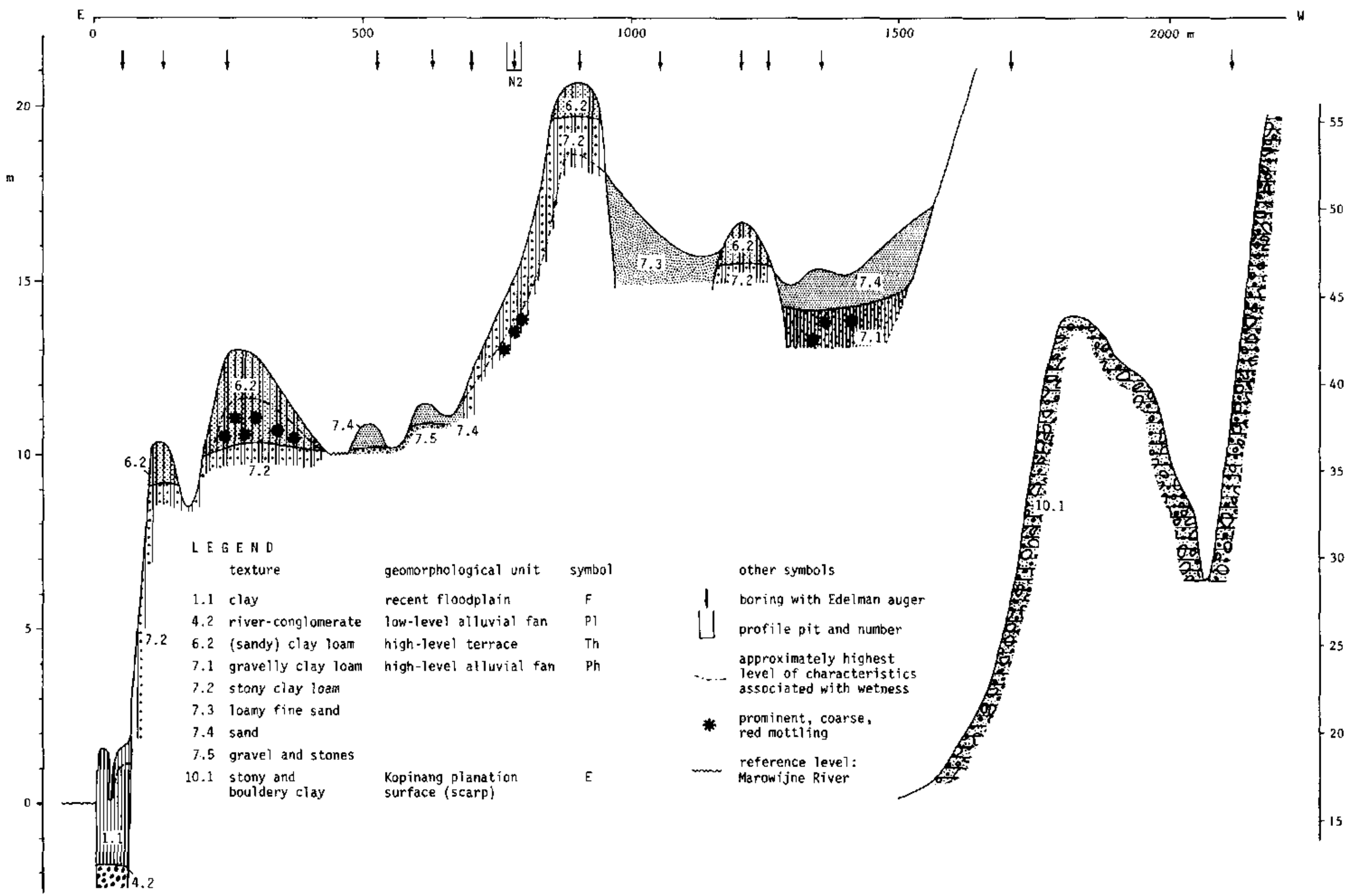


Fig. 15. Sample area Nason, cross-section 5.

Bakker (1955) supposed the Albina hill to be a terrace of the Marowijne River. It will be shown, however, that it belongs to the Zanderij landscape and that the sediments are closely related to the non-bleached Zanderij deposits (see 3.3.2).

(3) The colluvium (Zc) at the foot of the Zanderij hills near Albina (figs 14, 47) shows gentle slopes; its relative height ranges from 7 to 15 m. Textures vary from sandy clay loam to coarse sandy loam. Bedrock is often exposed or occurs at a slight depth (see also Brinkman, 1959).

The high-level alluvial fans (Ph)

In the river valleys remnants can be found of alluvial fans at a relative height of 10-30 m. They are rather well developed along the lower Marowijne River between the Gran Creek and Herminadorp (figs 15, 48); they may be as wide as 5 km. As a rule the fans are strongly dissected and valleys are sometimes deeper than 10 m. In a section perpendicular to the river the average slope ranges from 0.6 to 3.4%.

Rounded stones, consisting of quartz, sesquioxidic nodules, or both, are abundant; their diameter is up to 40 cm. The thickness of the sediment cover does not exceed 2 m.

Similar phenomena have been reported by other authors. De Munck (1954a) mentioned a 'terrace' containing a surface layer of coarse gravel and stones near Abenako along the lower Marowijne River. Bakker (1955) distinguished comparable 'terraces' at relative heights of 12-16 m near Nason, and at 22-25 m near Herminadorp; rounded stones abounded in both. Brinck (1956) reported rounded stones in 'terraces' along creeks near Benzdorp on the Lawa River. Brouwer (1961) mentioned a 'terrace' containing rounded stones along the crique Balaté, at a relative height of 10 m.

All these 'terraces' probably are alluvial fans of the same unit (see also 3.3.2). As the terrain is sloping, the surface may be found at different levels in vertical sections along the river. At Nason this phenomenon occurs over short distances. So there is no reason to distinguish separate levels.

The high-level terrace (Th)

The stony sediments of the high-level alluvial fans are often covered by sediments of clay to sandy clay loam texture (figs 15, 17). This cover is less than 4 m thick; it may be of colluvial or fluviatile origin. Laboratory data were too scarce to permit a definite interpretation of the environment of deposition.

The low-level alluvial fans (Pl)

In the Marowijne area the present valley bottom is filled, over a large area, with coalescent alluvial fans (figs 14, 17). They are often exposed along the rivers, from the estuary up to the headwaters; as a rule they are covered by other sediments. The fans are less than 2.5 km wide when measured perpendicular to the river, and their surface may reach a relative height of 13 m. The topography is very irregular because of strong dissection; nevertheless the height shows a tendency to increase in the direction of the hilly country. The average slope is between 0.2 and 1.9 %.

Literature data strongly suggest a lateral supply of the sediments (see 3.3.2). The thickness of the sediment cover is mostly less than 3 m and textures range from sandy clay loam to gravelly coarse sand. Iron pans are often conspicuous at lithologic discontinuities.

The base of the fans usually shows an abrupt transition to weathered bedrock (de Munck, 1954c; Bakker, 1955; Brinck, 1956). In the sample area Albina, however, the Pl deposits are underlain by sediments of clay loam texture (Fig. 14). In this area, at a depth of about 8 m, soft, laminated and reduced marine clay was found by Brinkman (1959).

The low-level alluvial fans include the river conglomerates which are exposed in the Marowijne and lower Tapanahony River (IJzerman, 1931; de Munck, 1954b; Brinck, 1956; Beekman, 1961; O'Herne, 1961; Bakker, 1968). These conglomerates consist of rounded stones cemented by sesquioxides (Fig. 15).

The medium-level river terrace (Tm)

The medium-level river terrace is widespread in the valleys of eastern Surinam, from the estuary up to the headwaters (figs 47-49). Its width is less than 2.5 km; its relative height ranges from 4 to 14 m (figs 14, 17). Usually the height shows a tendency to increase with increasing distance from the river. Often the topography is irregular due to strong dissection. Levees and basins were seldom recognized and old riverbeds were not observed.

The thickness of the sediment cover is mostly less than 6 m; it rests upon alluvial fans and rarely upon regolith (Fig. 16). Textures range from clay to loamy coarse sand.

The occurrence of a terrace at a relative height of about 6 m in the Marowijne area was also mentioned by de Munck (1954), Bakker (1955), Brinck (1956), Choubert (1957) and Brouwer (1961).

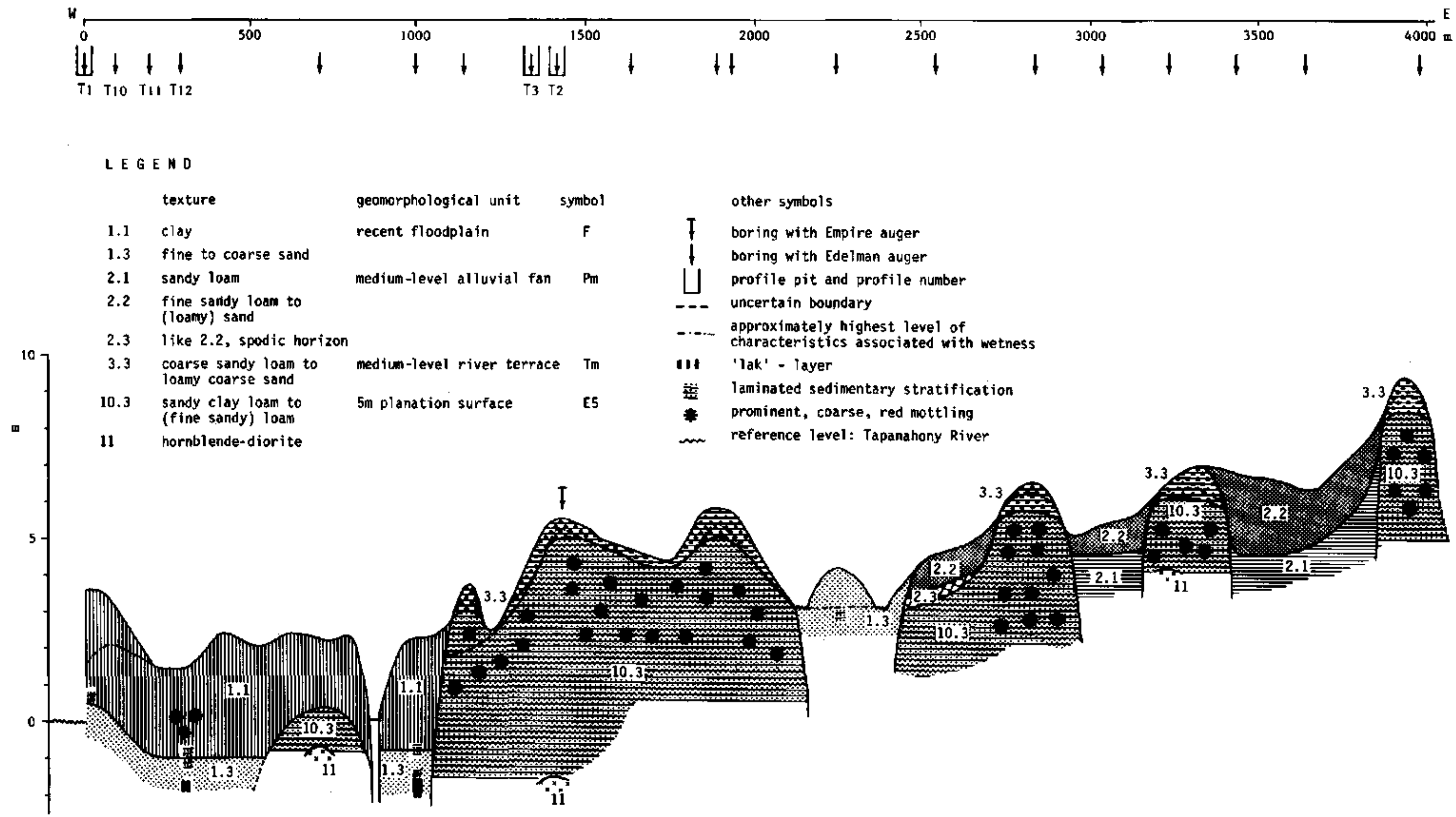


Fig. 16. Sample area Tapatosso, cross-section 4.

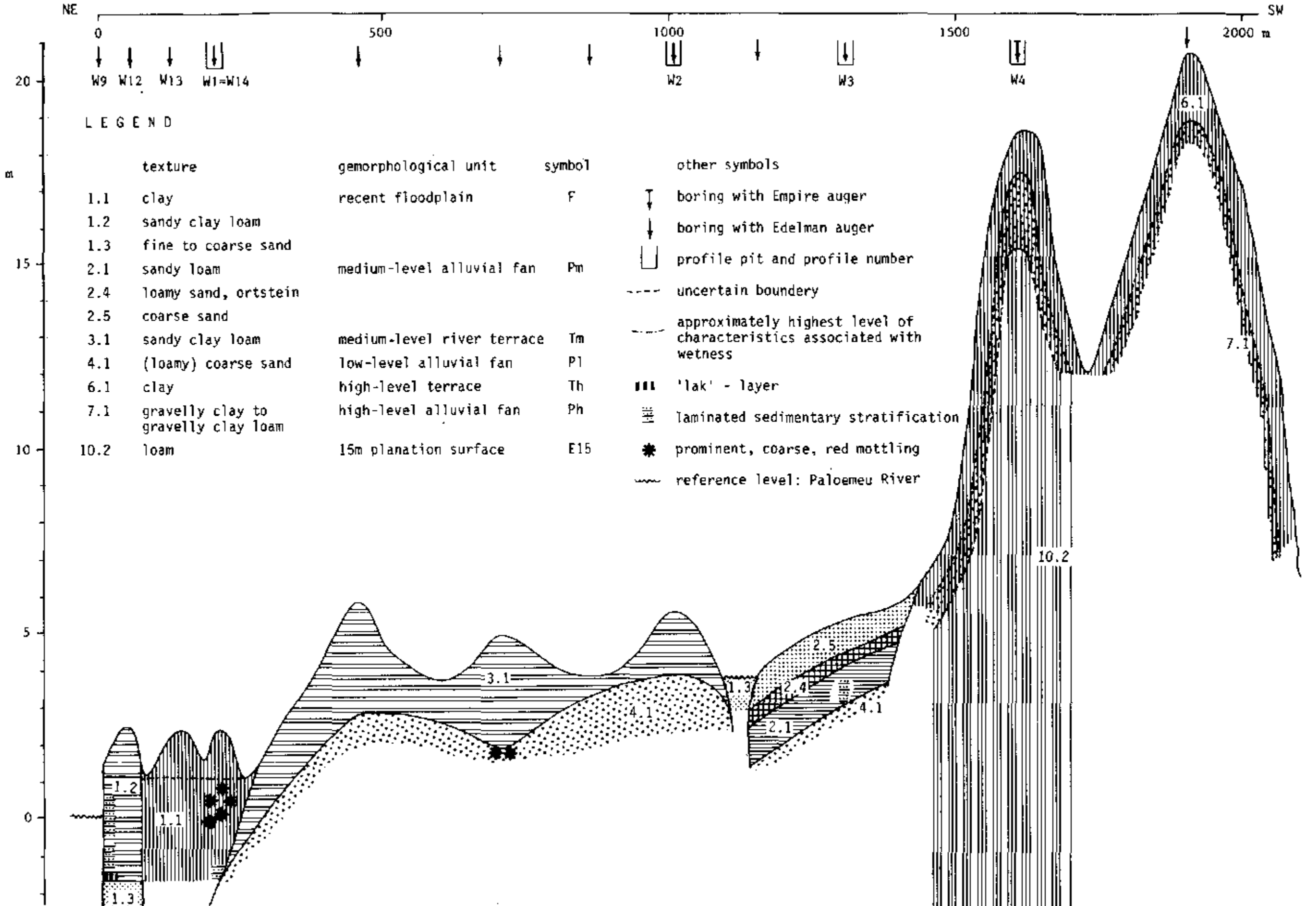


Fig. 17. Sample area Weliok, cross-section 2.

The medium-level alluvial fans (Pm)

In most sample areas outside the estuary, alluvial fans can be found at the footslopes of the hilly country (figs 16, 17, 49). These fans form depressions in the Tm river terrace; they occupy areas of less than 2 km^2. In the sample area Tapatosso an intricate pattern of coalescent fans is present, surrounding isolated hillocks of the 5 m planation surface (Fig. 16).

The relative height varies from 2 to 14 m; slopes are mostly less than 2%. As a rule the fans are strongly dissected and remnants of old gullies are often filled with peat.

Textures range from sandy clay loam to sand. The thickness of the sediment cover may exceed 3 m. The occurrence of an ortstein (Podzol B) at a depth of about 1 m is characteristic (Fig. 17). Locally the fans are underlain by weathered bedrock.

Similar phenomena have been reported from northern Surinam by Cohen & van der Eyk (1953) and van der Eyk (1957): At the footslopes of schist-hills of the Armina series, sandy sediments showed ortsteins at shallow depth.

The recent floodplain (F)

The recent floodplain occurs all over the river valleys. Its relative height is 1-5 m; its width is always less than 1.5 km and mostly less than 1 km (figs 47-49).

Two levels can be distinguished: a 1-2 m level and a 2-5 m level (Bakker, 1955; de Boer, 1966). Besides the stream-bed (Fs) both levels show levees (Fl) and basins (Fb). In the sample area Koele, levees are only weakly develloped.

Textures range from clay to sand, but in recent times hardly any sand has been deposited outside the stream-bed.

The base of the sediments mostly consists of sand. In the basins an old peaty surface ('lak'-layer) is often present at a depth of about 2 m below mean river level (figs 16, 17). The deposits rest upon bedrock or upon alluvial fans; their thickness ranges from some cm to over 6 m.

The recent floodplain corresponds to the '2-4 m terrace' of Choubert (1957) and Brouwer (1961).

The geographical distribution of some geomorphological units in the sample areas Albina, Nason and Weliok is shown in figs 47-49. These sample areas are considered to be representative of the whole valley system as the geomorphological structure of the other strips is similar to that of Fig. 49.

In other words the geomorphology of the river valleys upstream from Nason was found to be uniform.

The width of the valleys, defined as the shortest distance between the scarps of the lowest Tertiary planation surface on opposite sides of the valley, is small as compared with that of many other valley systems. At the Koele Koele Creek the width is about 1.5 km, at Maripa Soela 5 km, at Gransanti 3 km and at Albina in the estuary 6.5 km. It varies greatly over short distances; where falls and rapids are numerous, the valley may even be as narrow as 200 m.

In addition, a typical characteristic of the valleys in eastern Surinam is the absence of converging or diverging surfaces in downstream or upstream direction all over the valleys. This phenomenon was also mentioned by Bakker (1957): in the Marowijne valley, downstream from the Gran Creek, floodplain and terrace surfaces were found at the same relative height in a step-like pattern.

3.2 *Mineralogy*

Mineralogical analyses were carried out to study the regional distribution of the sediments, to establish their provenance and to determine stratigraphic relationships. The light as well as the heavy fraction were studied.

In doing so, the principles of the 'Dutch school' have been applied (see Edelman, 1933; Doeglas, 1940, 1952).

3.2.1 Description of minerals

General descriptions of minerals are in the textbooks of Kerr (1959), Milner (1962) and Heinrich (1965). Only some special characteristics of minerals from eastern Surinam will be given below.

Opaque heavy minerals

The opaque fraction usually consists of ilmenite and some leucoxene. In recent sands goethite, hematite and limonite often occur as well. Hydro-ilmenite, a weathering product of ilmenite, was observed in the Tertiary sands of the Coesewijne series. It shows the diffraction patterns of goethite and rutile (Krook, pers. commun.).

Zircon

Zircon occurs in two varieties; the metamict variety (malacon) is usually more abundant. The characteristics of the varieties were compared by Krook (1965a):

Sample EW 1722, creek sediment near Tapanahony River, sh.66 CBL

	Zircon	Malacon
Colour	colourless or pink	brown to purple-brown
Birefringence	strong	medium (too low for zircon)
Fluorescence in UV light	strong (yellow)	none
Radioactivity	33 counts/3 min	66 counts/3 min
Inclusions	few	many small inclusions
Cracks	some	many cracks in all directions
Elements (X-ray spectrography)	mainly Zr, traces of U, Th, Hf, Pb, Fe, Ti	mainly Zr, some U, Th, Pb, traces of Y, Hf, Fe, Ti

Monazite

As a rule, in eastern Surinam, monazite occurs together with zircon and malacon; mostly its percentage does not exceed 3% of the transparent heavy fraction. Under a common microscope the distinction between zircon and monazite is difficult; under a quartz lamp without UV filter, however, monazite can be recognized by its typical emerald green colour (Krook, 1969c). In this study monazite, zircon and malacon were counted together as zircon.

Alterites

Alterites are weathering products of various minerals; they are characterized by aggegrate polarization.

Unknown mineral

In nearly all samples examined an unknown mineral was present with the following characteristics (Krook, pers. commun.):

Shape	well-rounded, usually < 70 μm
Colour	dark brown
Cleavage	none
Refraction index	high
Other optical characteristics	mostly isotropic, sometimes slightly anisotropic and uniaxial positive
Diffraction pattern	like Anatase
Elements (X-ray spectrography)	Ti

Although the diffraction pattern points to anatase, its optical characteristics are completely different. It is remarkable that Krook, who studied many samples from all over Surinam, never observed it before. It was, however, reported from Turkey (Miss Bakker, pers. commun.). As a rule, iron was not removed from Krook's samples, but from the eastern Surinam and Turkish ones it was. Therefore, the titaniferous mineral may be of secondary origin and may have resulted from iron removal procedures. Another possibility is that Krook counted the mineral in the opaque fraction because of a coating of iron oxides.

Light minerals

In the light fraction quartz usually prevails. The feldspars have not been subdivided. Only the more stable forms were found: mostly K-feldspar and sometimes albite. The same was reported from northern Surinam by IJzerman (1931) and Krook (1969a). The feldspars were often strongly weathered. Muscovite is generally present in small amounts.

3.2.2 Heavy mineral associations

A mineral association is the combination of minerals by which a soil or sediment is characterized (van Andel, 1950).

Mineralogical data from the Marowijne area are given in Appendix II and in Fig. 19. From these data it is concluded that at least eight heavy mineral associations can be distinguished in eastern Surinam (Table 4):

(1) The EZ association (Epidote-Zircon association)

The EZ association may be classified as a zircon deposit with varying amounts of epidote and green hornblende. Unstable minerals, such as apatite, augite and hypersthene, may occur in these sands.

The EZ sands are widely distributed over the southern part of Surinam and occur in the sample areas Koele, Loe, Weliok and Tapatosso. Similar sands are present in the upper Tapanahony area (Krook, 1965a, b). The EZ association is also found in the upper Marowijne (Fig. 19).

(2) The Z association (Zircon association)

In its pure form the Z association almost completely consists of zircon (Table 4: sample K5-4). It must be regarded as an impoverished mineral assemblage derived from the EZ association by weathering away of epidote, hornblende and other unstable minerals (see 3.2.5).

Like the EZ sands the Z sands occupy large areas in the southern part of Surinam.

(3) The EZM association (Epidote-Zircon-Metamorphic group association)

This mineral suite is characterized by relatively high contents of epidote, green hornblende and minerals of the metamorphic group (garnet, staurolite, kyanite and andalusite). Zircon is usually present in somewhat smaller amounts.

The EZM association is found in the Lawa River downstream from Anapaike (Fig. 19).

(4) The ZM association (Zircon-Metamorphic group association)

This mineral assemblage has been formed from the EZM association by weathering (3.2.5). Garnet, epidote and hornblende are absent or have decreased significantly.

It occurs in the sample areas Blakawatra, Inini, Gransanti and Nason.

(5) The EZS association (Epidote-Zircon-Staurolite association)

The EZS sands differ from the EZM sands by a higher content of staurolite and a lower content of the other metamorphic minerals (Table 4, Appendix II). The percentages of the diagnostic minerals may vary a lot from place to place.

The EZS association is found in the lower Marowijne from the Gran Creek down to Albina (Fig. 19).

(6) The ZS association (Zircon-Staurolite association)

The ZS association is an impoverished mineral assemblage derived from the EZS association (3.2.5). It shows high percentages of zircon and staurolite in varying proportions; it occurs in the sample area Albina.

(7) The S association (Staurolite association)

The S association contains 50-90 % staurolite, some other metamorphic minerals, and some tourmaline, zircon, epidote and hornblende. Mineralogically these sands correspond with the S association as distinguished by Krook (1969a) in the beach ridges of eastern Surinam.

The S association is found in the northern part of the Marowijne estuary (Fig. 19). In the Marowijne River S sands occur here and there between sands

Table 4. Characteristic heavy mineral assemblages in sands from eastern Surinam (50-420 μm).

Sample nr	Depth (cm)	Geomorphological unit	Heavy mineral association	% Opaque	Tourmaline	Zircon	Rutile	Anatase	Garnet	Staurolite	Kyanite	Andalusite	Sillimanite	Corundum	Epidote	Gr. Hornblende	Alterites	Other minerals	Distribution of transparent heavy minerals[1]
N3-3[2]	45-170	E	TZ	99	47	16	2	tr	-	13	-	tr	-	-	19	tr	-	3	96- 4-0
Mar 9	0	Fs	S	87	7	tr	-	-	1	89	-	1	-	-	1	1	-	-	.
A1-3	140-230	Za	ZS	81	5	60	2	-	-	25	1	5	tr	-	-	-	1	tr	47-47-6
A4-5	240-310	Pl	EZS	63	3	52	2	-	-	23	1	4	1	-	12	1	-	1	.
N2-2	90-115	Ph	ZM	81	13	72	1	tr	-	6	tr	3	tr	tr	3	-	-	tr	68-30-2
KK213	0	Fs	EZM	81	2	7	-	-	tr	10	1	11	-	-	33	34	-	2	.
K5-4	100-130	E	Z	73	-	98	1	tr	-	-	-	-	-	-	-	-	tr	-	72-28-0
T1-4	90-160	Fl	EZ	66	1	78	1	tr	tr	1	tr	-	-	tr	13	2	-	2	87-13-0

1. For an explanation see Section 3.2.4
2. For sampling sites see figs 1-9 and Fig. 19

tr = trace

. = non-determined

of the EZS association (Fig. 19: Mar 3, 9, 10, 24); the origin will be explained in 3.2.6.

(8) The TZ association (Tourmaline-Zircon association)

This mineral suite is characterized by a high percentage of tourmaline, accompanied by a significant amount of zircon. Metamorphic minerals may play an important role as well. It includes the Tourmaline-Zircon association as distinguished by Kiel (1955).

TZ sands are found in the sample areas Inini and Nason.

The mineralogical variations in the heavy fraction are reflected in the composition of the light fraction. As a rule high percentages of garnet, epidote and hornblende are accompanied by significant amounts of feldspars. This phenomenon can be observed in the EZ, the EZM and the EZS associations. In the impoverished mineral assemblages, feldspars are absent or occur in small amounts. Then they often have a strongly weathered appearance.

Before considering the significance of the mineral assemblages as to their origin, it is essential to examine whether they represent true associations or not. Therefore, the influence of chance, grain size and weathering on the mineral frequencies will be considered first.

3.2.3 Chance variations

Chance variations are variations in the mineralogical composition caused by sampling errors, operator's errors and counting errors (van der Plas & Tobi, 1965).

In this study sampling errors will be neglected. Countings were made in two laboratories: the Geological and Mining Service of Surinam and the Geological Institute of the Wageningen University. The first applied the field-counting method, the other the line-counting method (Appendix I). With the study of minerals that were not fractionated with respect to grain size, the field-counting method may give somewhat higher percentages of the fine-grained minerals (Krook, 1969a).

To evaluate the effect of chance variations some samples were counted in both laboratories. The differences were small and did not influence the general trends observed in the preceding section.

3.2.4 Granular variations

Granular variations are variations in the mineralogical composition caused by differences in grain size. These fluctuations result from the preference of some minerals for certain grain-size fractions. Zircon, for example, often occurs in small grains and the frequencies of this mineral are therefore generally higher in fine-grained sediments than in coarse ones. The reverse may hold true for staurolite.

According to Doeglas (1952), a fractionated analysis is the ideal tool to study the influence of grain size on mineral frequencies. For practical reasons this analysis is restricted to some representative samples (van Andel, 1950; Nota, 1958).

To get a quick impression, however, of the influence of granular variations, the average grain diameter of the heavy fraction is often determined before a fractionated analysis is carried out. This is of little value when the heavy minerals are badly sorted, as the median does not give any information on the standard deviation. In this study, therefore, another method is introduced. With microscopic means the distribution of the transparent heavy minerals over the 50-105, 105-210 and 210-420 μm size grades was determined in many samples, and the percentages were plotted in a triangle diagram (Fig. 18).

With the heavy minerals, the grain-size distributions of the EZS and ZS sands clearly differ from those of the other mineral assemblages, but no differences can be shown between the latter. This does not point to a sorting relationship between the EZ, Z, ZM and TZ associations. The distinctive zone

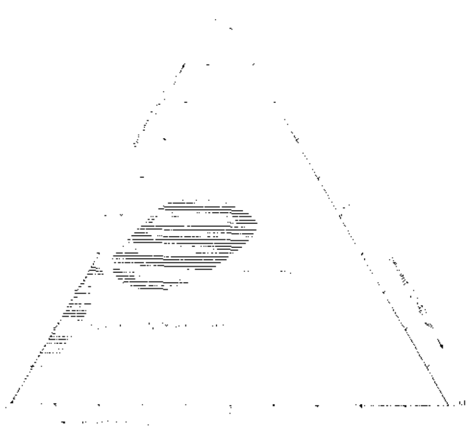


Fig. 18. Distribution of transparent heavy minerals.

diagram of the EZS and ZS samples, however, might be due to sorting.

Therefore, some selected samples of the EZ, Z, ZM, TZ, EZS and ZS associations were subjected to a fractionated analysis. From these samples, sieve fractions of the 50-105, 105-210 and 210-420 µm size grades were studied. Because of the lack of material no sieve fractions could be made of the EZM and the S sands.

As can be seen from Table 5, the relation between size-grade and frequency for zircon, epidote and the metamorphic minerals differs widely in each of the mineral assemblages.

In the Z association, zircon does not show any preference for a particular grade. In the other associations, zircon has a clear maximum in the finest grade, while there is a rapid decrease in quantity with an increase in size. This tendency is less pronounced in the ZM association.

In the EZ association, epidote is concentrated in the 105-210 µm size grade. No such preference can be observed in the EZS association. In the other associations, epidote is absent or of minor importance, with the exception of the TZ association. The TZ sands are well-sorted, while their mineralogical composition differs from that of all other sands.

In the EZS and ZS associations, the percentage of staurolite and of the other metamorphic minerals has a strong tendency to increase with increasing size-grade. In the ZM association, the metamorphic group is of minor importance in all size grades. In the EZ and Z associations, metamorphic minerals are not present at all.

Hence, variations in the weight percentages of the size fractions usually coincide with variations in the frequencies of the diagnostic minerals. Within the mineral associations under consideration, however, the trends of these variations differ.

The petrographic variations can also be evaluated by comparing the percentages of the various mineral species within each grade. From Table 5 it is concluded that, after a sorting of the parent material, each mineral association will retain its own character. The differences between the mineral associations can not be explained by a variation in grain-size composition. For then similar fractions would have an identical mineralogical composition.

3.2.5 Weathering

To study the weathering of minerals, the relation between the mineralogical composition of the samples and their stratigraphic position was considered.

Table 5. Mineralogical fraction analyses.

Sample nr	Heavy mineral asso-ciation	Size grade (µm)	% heavy fraction per grade	% Feldspars	Heavy minerals														
					% Opaque	Tourmaline	Zircon	Rutile	Anatase	Staurolite	Kyanite	Andalusite	Sillimanite	Corundum	Epidote	Gr. Hornblende	Alterites	Other minerals
N3-3	TZ	50-105	18.2	tr	99	47	16	2	tr	13	-	tr	-	-	19	tr	-	3
		105-210	21.8	-	100	tr	tr	tr	-	tr	-	tr	-	-	-	-	-	tr
		210-420	25.1	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-
A1-3	ZS	50-105	10.8	-	96	10	72	tr	tr	13	-	4	-	tr	-	-	-	tr
		105-210	4.8	-	90	7	45	1	2	38	-	5	1	-	-	-	-	1
		210-420	1.3	-	93	10	6	-	tr	70	-	13	-	tr	-	tr	-	tr
A4-5	EZS	50-105	3.4	58	89	4	63	-	1	8	1	3	1	-	14	1	tr	4
		105-210	1.6	14	85	6	15	-	-	52	-	4	1	-	17	4	-	1
		210-420	0.8	4	85	6	tr	-	-	77	tr	6	1	-	5	2	-	2
N2-2	ZM	50-105	0.6	-	75	7	83	3	-	3	-	1	-	tr	2	-	-	tr
		105-210	1.2	tr	97	10	71	3	tr	9	-	5	-	-	1	-	-	1
		210-420	0.9	-	99	-	tr	tr	-	tr	-	tr	-	-	tr	tr	-	tr
G3-3	ZM	50-105	0.3	-	74	1	94	1	-	2	-	2	-	-	-	-	-	-
		105-210	0.3	-	81	3	79	1	-	8	-	7	1	tr	-	tr	-	-
		210-420	0.1	-	95	-	tr	tr	-	tr	tr	tr	-	-	-	-	-	-
K5-4	Z	50-105	1.7	tr	72	-	97	-	-	-	-	-	-	-	tr	-	tr	2
		105-210	1.5	-	84	-	99	-	-	-	-	-	-	-	-	-	-	1
		210-420	0.8	-	98	-	99	-	-	-	-	-	-	-	-	-	-	1
K1-4	EZ	50-105	.	33	67	-	69	1	-	-	-	-	-	-	20	tr	tr	10
		105-210	.	26	88	-	14	tr	tr	-	-	-	-	-	57	4	-	25
		210-420	.	5	tr	-	-	-	-	-	-	-	-	-	tr	tr	-	-

Garnet was seldom found outside the stream-bed of recent rivers: it mainly occurred in the sands of the EZM, the EZS and the S associations. The same applied to hornblende, epidote and feldspar. Hornblende was nearly absent in the Z, ZM and ZS associations, while epidote and feldspar only occurred in low amounts in these assemblages. Z, ZM and ZS sands were mainly observed outside the recent floodplain.

Similar phenomena have been reported from northern Surinam (Krook, 1968b). Garnet-bearing sands were found almost exclusively in beach ridges of Subatlantic age. In the older ridges, belonging to the same mineral association, only traces of strongly weathered garnet were present. It was found, however, at a greater depth.

In the Calcutta and Alliance deep-drillings and in the Zanderij-Onverdacht area, hornblende and epidote were abundant in sediments of Holocene age. In Pleistocene soil profiles, there was no garnet, hornblende and epidote, but these minerals did occur at a greater depth of the same formation. K-feldspar was absent as well but appeared at a smaller depth (Krook, 1969a; IJzerman, 1931).

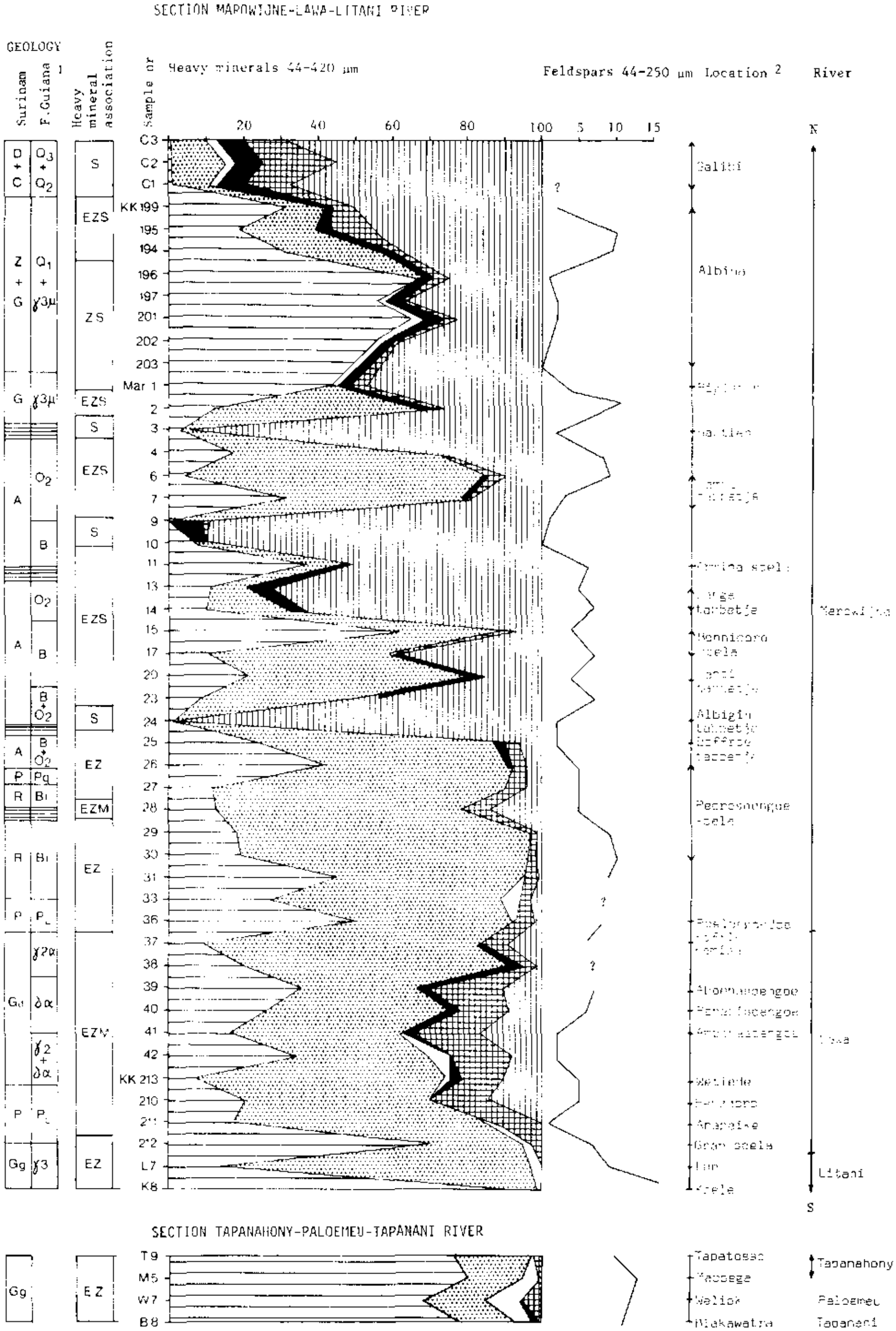
Summarizing it can be stated that there is weathering of minerals. Results were already observed in sands of Subatlantic age, as shown by the disappearance of garnet. Another example was given by Krook (1969a): In a soil profile of Subboreal age, hornblende was absent in the A2 horizon, while epidote and K-feldspar had decreased significantly compared with the underlying layers.

As explained before, the mineralogical differences between the heavy mineral associations can not be ascribed to chance variations or sorting. Therefore, the Z, ZM and ZS associations are impoverished mineral assemblages, derived from the EZ, EZM and EZS associations, respectively. Under oxidizing conditions, garnet, hornblende, epidote and K-feldspar are gradually corroded in this sequence.

3.2.6 Origin of the sand fraction

The relation between the mineralogical composition of river sands in eastern Surinam and the stratigraphy of the Precambrian Shield is indicated in Fig. 19. The position of the samples on the vertical axis represents a sequence from the headwaters down to the Marowijne estuary. From right to left the sampling site, the mineral association to which the sample belongs, and the stratigraphy of the adjacent bedrock can be read in separate coluns.

From Fig. 19 a close relation appears between the mineralogical composition



1. Symbols refer to the geological maps of Brouwer (1961-1966).
2. See Fig. 1.

Fig. 19. Mineralogical composition of river and beach sands in eastern Surinam and relation to bedrock (from Kiel, 1955; Krook, 1969 and this study).

Formation / Series				Lithology
Surinam		French Guiana		
D	Demerara series	Q3	Série de Demerara	unconsolidated sands and clays
C	Coropina series	Q2	Série de Coswine	
Z	Coesewijne series (Zanderij formation)	Q1	Série détritique de base	unconsolidated sands
G	Main suite of granites (undifferentiated)	$\gamma 3$	Granite caraibe	
		$\gamma 3\mu$		orthogneiss
A	Armina series	O	Série de l'Orapu	
		O2		schists
				staurolite-schists
R	Rosebel series	B	Série de Bonnidoro	
		B		schists and quartzites
		Bi		schists, graywackes, conglomerates
G	Main suite of granites	$\gamma 2$	Granite guyanais	
Gg	granite facies	$\gamma 2$		granites
Gd	diorite facies	$\gamma 2\alpha$		migmatites
		$\delta\alpha$		diorites
P	Paramaka series	P	Série de Paramaka	
		Pq		metasediments and metabasites
		P_L		metavolcanics

Zircon, malacon and monazite

Staurolite

Epidote and green hornblende

Other metamorphic minerals (garnet included)

Tourmaline

Other minerals (mainly rutile)

of the river sands and the nature of the adjacent bedrock. So upstream from the estuary, little sand has been transported in recent times.

The EZ sands in southern Surinam are of granitic origin and are related to the Gran Rio massif of IJzerman (1931). In his study on the mineralogical composition of creek and river sands in the Tapanahony area, Krook (1965a, b) came to the same conclusion.

At the transition from the Gran Rio massif to the Paramaka series, the EZM association arises. The metamorphic minerals must have been derived from the Paramaka rocks, which show a varying degree of metamorphism (van Eijk, 1961; Brouwer, 1966).

No significant change in the mineralogical composition can be observed at the transition from the Paramaka series to the diorite facies of the Gran Rio massif. The number of samples in this area, however, is restricted and metamorphic rocks occur in the environs of the samples (Brouwer, 1964b, 1966).

The sedimentary Paramaka formation and the Rosebel series along the upper Marowijne supply hardly any metamorphic minerals to the river sands. This fact is in accordance with the lithologic descriptions of O'Herne (1961) and de Munck (1953). The EZ association is found in this area.

A pronounced change in the mineralogical composition of the river sands occurs close to the transition from the Rosebel series to the Armina series: the S and the EZS associations originate. The S association is regarded as the erosion product of staurolite-schists which occur in the contact-metamorphic zones of the Armina series and the main suite of granites. The location of these schists is clearly indicated on the geological maps of de Munck (1954) and Brouwer (1961-1966). S sands are found in the direct environs of these schists.

The varying percentages of metamorphic minerals and zircon in the sands of the EZS association reflect the occurrence of more or less metamorphic rocks in the neighbourhood of the individual samples (see IJzerman, 1931; de Munck and Brouwer, l.c.). Sorting effects may play a role as well.

The EZS sands in the lower Marowijne River probably resulted from a mixing of different mineral assemblages by tidal currents. Dost (1959) reported a transport of sandbars and mud in the lower Marowijne. In the stream-bed, sandbars are displaced in a downstream direction, whereas the sand moves upstream along the banks. It is assumed that both the Armina series and the gneisses near Albina contributed material to the recent sands. The garnet in these sands has probably been derived from the Armina series, as the older sediments in this region are devoid of this mineral (Appendix II).

The composition of the beach sands near Albina (Fig. 19: KK196-203) differs from that of the stream-bed (KK194, 195, 199). The ZS sands of the beaches, however, are identical to those of the overlying Tm river terrace. Therefore, the beach sands are reworked terrace sands. Bakker (1957) arrived at the same conclusion on sedimentological grounds.

Summarizing it is concluded that the EZ sands have been supplied by rocks of granitic origin, by the sedimentary Paramaka formation and by the Rosebel series.

The EZM sands can be related to the basic and volcanic Paramaka formation and to its migmatites.

The EZS sands have been derived from various rocks of the Armina series.

The S sands are erosion products of staurolite-schists of the Armina series.

The Z, ZM and ZS sands, being impoverished mineral assemblages, must have the same source area as their respective primary associations.

The TZ association was observed in regolith from undifferentiated Paramaka and Armina rocks.

As for the origin of the individual minerals the following can be said. Metamorphic minerals have been derived from metamorphic rocks of the Paramaka series, the Armina series and their migmatites. Staurolite has mainly been supplied by staurolite-schists which are restricted to contact-metamorphic zones, surrounding the main suite of granites. High contents of tourmaline seem indicative of near schists. Rutile, zircon, malacon, epidote and hornblende are not characteristic of any rock type as they may have been derived from many rocks.

3.3 Sedimentology

Mechanical analyses were carried out to describe the characteristic grain-size distributions in eastern Surinam, to study such geogenetic problems as mixing and sorting and to establish the relationship between the size-frequency distribution and the environment of deposition.

In a definite sedimentary environment, the size-frequency distribution may vary considerably. It has been shown, however, that many environments can be recognized by the predominance of certain grain-size distributions (Doeglas, 1946, 1950).

The distinction is based upon differences in symmetry and deviations from it. These phenomena are clearly visible on probability paper with an arithmetical size-scale. On this paper, cumulative symmetrical size-frequency distributions give straight lines and deviations from symmetry appear as curved or kinked lines.

In this chapter, the results of the mechanical analyses are illustrated as cumulative curves on arithmetical probability paper. The interpretation is based upon the position and shape of the curves, giving information on the source of a sediment, on the nature of the transported material, on the way of differentiation and on mixing (Doeglas, 1946, 1950).

In the following sections, a selection from 175 detailed grain-size analyses of the Marowijne area will be given.

Before considering the significance of the grain-size distribution for the study of geogenesis, however, it is essential to evaluate the influence of pedogenesis.

3.3.1 The influence of pedogenesis on size-frequency distribution

Pedogenesis may change the grain-size distribution of soils, especially in humid tropical regions. Neglection of this fact may lead to wrong interpretations of geogenesis.

The effect of mixing was described by Doeglas (1946). It will be shown that many soil materials in eastern Surinam are of a mixed character (see 4.2).

The influence of clay migration is illustrated in Fig. 20. The curves A, B and C represent cumulative grain-size distributions of the types that are frequent in eastern Surinam. A and C are natural examples, B is a hypothetical distribution. When 9% clay is removed from the A distribution, a curve like Doeglas' R type[1] results. This type is commonly found in the A horizons of Podzols, while a type like the A distribution may occur in the subsoil of the same profile (Fig. 27). This points to a removal of fine particles from the A horizon, either by clay migration or by clay destruction.

The shape of the B and C curves hardly changes when even 10% clay is removed or added. The position of the curves, however, does change. Eluviation and illuviation of clay result in almost parallel upward and downward displacement, respectively. These phenomena often occur in soil profiles from eastern Surinam, pointing to clay migration in uniform materials (Fig. 29).

Fig. 21 shows the influence of ferrallization in regolith on a hornblende-

1. R fractions result from the deposition of the coarse part of a transported material, while the remaining suspension is called a T fraction (Doeglas, 1946).

diorite. Weathering of sand and silt and newformation of clay result in a progressive flattening of the curves, and ultimately a nearly straight distribution above 2 μm results (Curve T2-3). This picture of ferrallization can frequently be recognized in eastern Surinam (figs 28, 29).

To evaluate the influence of pedogenesis, mostly data from different soil horizons of the same profile will be given (figs 21-30).

3.3.2 Size-frequency distributions

In this section, the mechanical characteristics of the sediments in eastern Surinam will be dealt with in a stratigraphic sequence (see 3.1).

For a proper reconstruction of geogenesis, however, the nature of regolith on various rock types must be considered first.

(1) Regolith

Grain-size distributions of regolith on rocks of the main suite of granites are given in figs 21 and 22.

Rotten-rock samples of granitic origin are characterized by flat and straight curves down to 50 μm and a strong curvature to the left in the silt fraction (curves T2-7, T2-9).

Flat, nearly straight curves down to 2 μm are typical of A and B2 horizons of soils on granitic rocks (curves T2-3, T2-5). Similar data on granite soils in northern Surinam were given by Bakker & Müller (1957).

Soils on schists of the Armina and Paramaka series have straight, very flat curves at the base of the diagram, showing a strong curvature to the left in the silt fraction (Fig. 22B). Similar curves of schist soils in northern Surinam were presented by van der Eyk (1957).

To characterize the silt and clay fractions of soils on different rock types, the q and q' values were calculated according to Bakker & Müller (1957). The q value is defined as $\% <2\mu m \,/\, \% <16\mu m$ and the q' value as $\% <2\mu m \,/\, \% <50\mu m$. When the clay percentages are low, small errors in the determination of the clay content may cause large deviations of the q and q' values. Therefore, these values were only calculated for samples exceeding 10% clay.

The available information on q and q' values of regolith is given in Fig. 23. It will be shown that these criteria are useful in the study of the relationship between regolith and sediments.

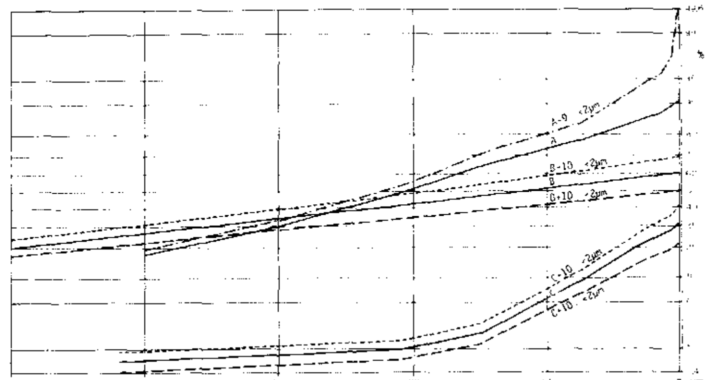


Fig. 20. The influence of clay migration on size-frequency distribution.

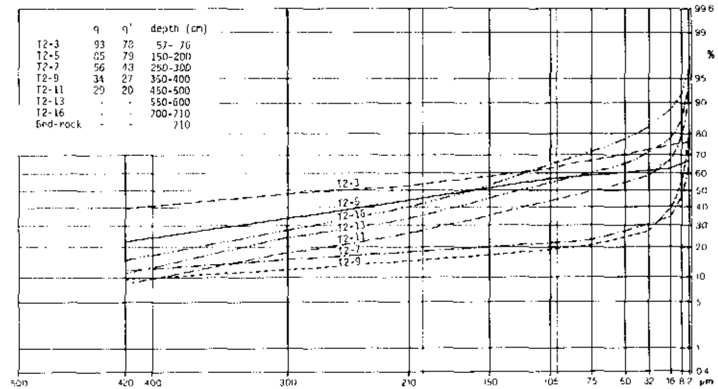


Fig. 21. Grain-size distributions of regolith on a hornblende-diorite. The influence of ferrallization.

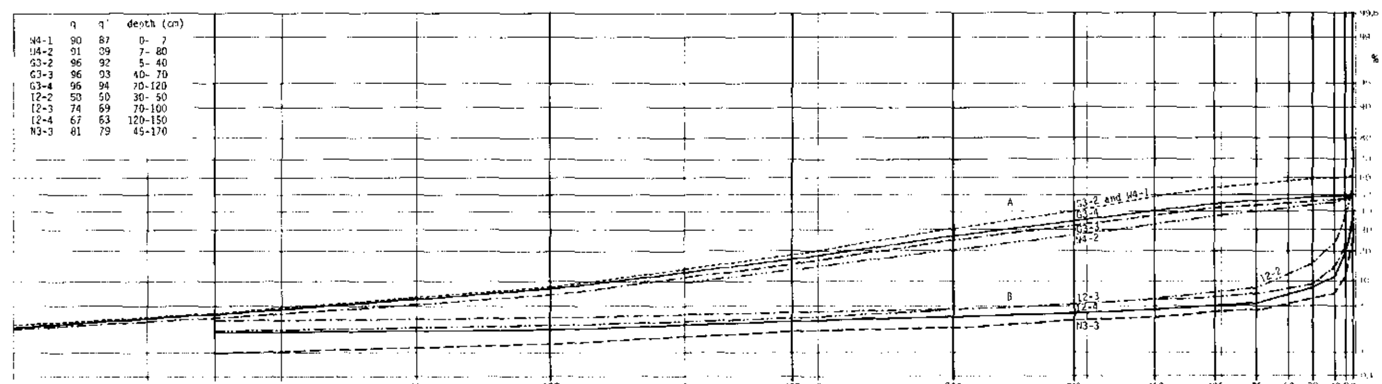


Fig. 22. Grain-size distributions of regolith. W4: soil on alkali-granite. G3: soil on quartz-diorite. I2: soil on Paramaka schist. N3: soil on Armina schist.

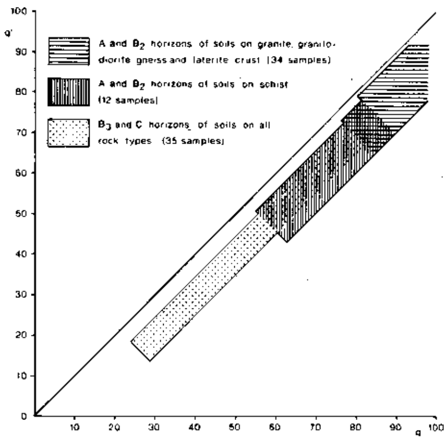


Fig. 23. Zone diagram showing q and q' values of soils on various rock types (for samples exceeding 10% clay).

(2) Sediments of the Zanderij hills (Z)

A zone diagram of Zanderij sediments is given in Fig. 24. The bleached Zanderij sediments (Zb) are white and are typical of strongly leached A horizons; they contain less than 1% clay. The non-bleached Zanderij deposits (Zn) are predominantly brown to reddish-yellow and contain 5-20% clay. These soil-associations are closely related as the sand fractions are similar.

The curvature to the left in the curves of the bleached sediments is due to a removal of fine particles as a result of podzolization (3.3.1). There is no reason to assume a discharge of fine components in a surf environment as stated by Bakker (1957).

The poorly sorted sediments of Fig. 24 must have been deposited under rapidly changing conditions of sedimentation. According to van der Eyk (1957), originally an alternation of sand and clay layers was present which were mixed by the soil fauna. But recent theories suggest that the Zanderij material at least partly has been formed from weathering of boulders in situ (Pons, pers. commun.). Therefore, the origin of the fine tails of the distributions could also be explained by a newformation of clay in situ. As data are too scarce, no definite interpretation can be given.

The heavy mineral composition of the Zanderij samples (Appendix II) points to a derivation from both granitic and metamorphic rocks. The metamorphic minerals must have been supplied by schists of the Armina series (3.2.6); the high zircon percentages probably reflect the influence of nearby gneisses (Fig. 10).

Hence, the sediments were probably deposited in a braided river environment.

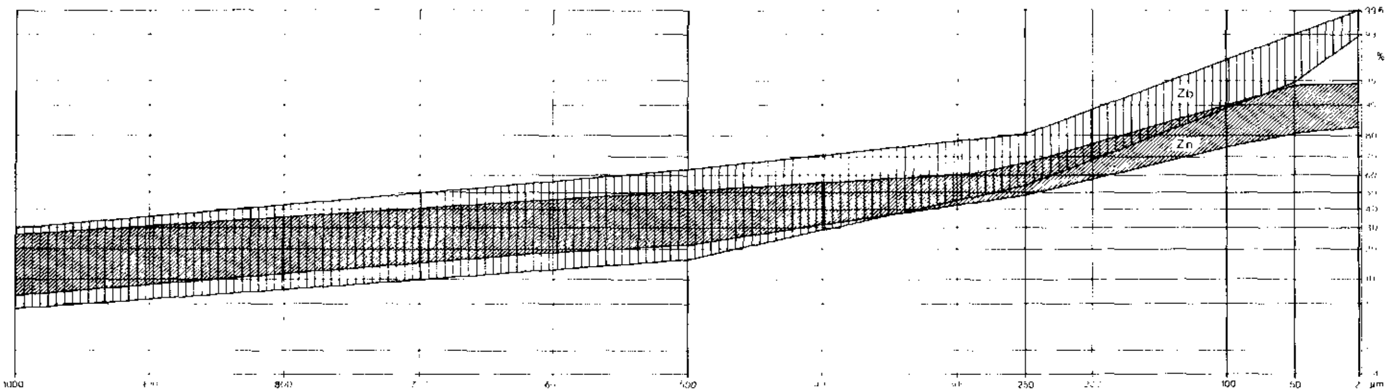


Fig. 24. Zone diagram of bleached (Zb) and non-bleached (Zn) Zanderij sediments near Albina. Zb: 8 samples. Zn: 14 samples.

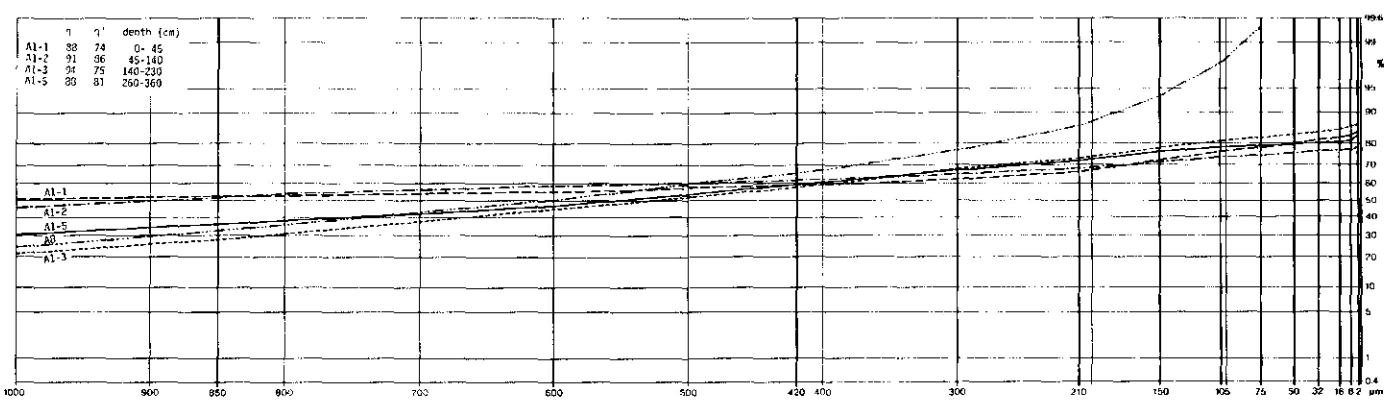


Fig. 25. Grain-size distributions of Albina hill (Za) sediments.

(3) Sediments of the Albina hills (Za)

The curves of the Albina hill sediments are identical to those of the non-bleached Zanderij deposits (Fig. 25).

The surface layers are slightly less sorted than the Zn sediments. This is due to the presence of nodules consisting of cemented sand. Removing iron from these nodules results in materials which are similar to those of the substrata that do not contain nodules (curves A1-3, A1-5). Curve A8, for example, represents the sand fraction of a nodule containing 42% iron compounds.

The mineralogical composition of the Albina hill sands can not be distinguished from that of the Zanderij sands. All show a ZS association (Appendix II).

From these data it is concluded that the Albina hill sediments belong to the Zanderij formation or Coesewijne series (Table 2).

(4) Sediments of the high-level alluvial fans (Ph)

The high-level alluvial fans consist of very coarse deposits as illustrated in Fig. 26 (note the different size-scale!). These sediments must have been deposited by very turbulent streams which were subjected to a sudden decrease in stream velocity.

The heavy mineral composition of the sands points to a lateral supply. In the samples N2 and N4, a significant amount of tourmaline and metamorphic minerals is present (Appendix II). These minerals must have originated from Armina schists which hardly occur upstream from the profiles. This interpretation is supported by the relatively low q and q' values (see Fig. 23).

Micromorphological evidence of a lateral supply follows from the omnisepic plasmic fabric of profile N2. This fabric seems to be restricted to rotten rock (4.5.5). In the present case it is related to the weathering of schist in situ (van der Plas, pers. commun.). Therefore, the fine tails of the cumulative curves are at least partly due to weathering and newformation in situ.

With a view to the physiography (3.1) and the nature of the Ph deposits it is clear that alluvial fans are involved.

(5) Sediments of the low-level alluvial fans (Pl)

Size-frequency distributions of Pl deposits are given in Fig. 28. The poorly sorted nature of these sediments must be due to strong fluctuations in the stream velocity.

The nearly horizontal part in the sand fraction and the slight curvature to the right at 75-150 µm point to an admixture of fine components to the

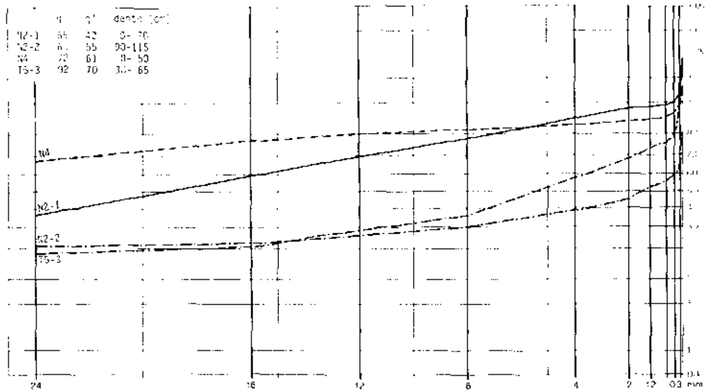


Fig. 26. Grain-size distributions of the high-level alluvial fans (Ph).

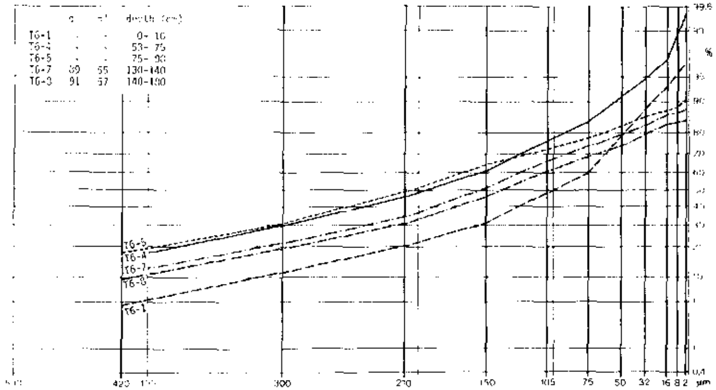


Fig. 27. Grain-size distributions of the medium-level alluvial fans (Pm).

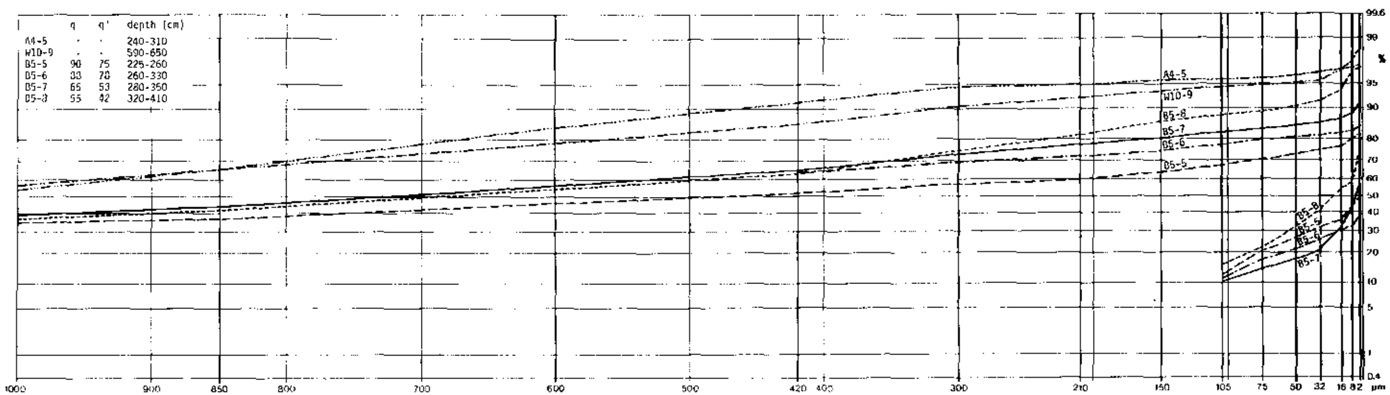


Fig. 28. Grain-size distributions of the low-level alluvial fans (Pl).

bottom material (Doeglas, 1946).

The origin of the fine tails in profile B5 needs some further consideration. When the size grades <150 μm are plotted separately on a 100% base, the strong curvature in the silt fraction is conspicuous. These curves resemble those of rotten rock (Fig. 21: curves T2-7, T2-9). Furthermore, the q and q' values of the Pl deposits quickly decrease with depth. This tendency is typical of weathered rock. The relatively low q and q' values can not be explained by a schistose origin, as schists neither occur upstream nor laterally from the profile. Therefore, it is reasonable to assume that the fine fractions of these sediments resulted mainly from newformation in situ.

The Pl deposits in eastern Surinam were also studied by Brinck (1956), Bakker (1968) and Krook (1969b). Their data strongly suggest a lateral supply of the sediments, which must have been derived, for a large part, from quartz veins.

In the sample area Albina, the Pl deposits can not be related to the adjoining Zanderij sediments as their mineralogical composition is different (Appendix II).

Summarizing it is concluded that alluvial fans are involved, which have been reworked in the estuary.

(6) Sediments of the medium-level river terrace (Tm)

Fig. 29 presents a selection from 46 grain-size distributions of the medium-level river terrace. Two types of sediments can be distinguished:

Type 1 (Profile W10) shows a grain-size distribution of river suspensions (Doeglas, 1946, 1950). The entire suspension must have been deposited in nearly stagnant water, the deposits being fine-textured basin sediments of a meandering river.

The grain-size distributions of Type 2 (Profile B5) are interpreted as coarse-textured basin sediments. Deposition must have taken place under fluctuating stream-velocities.

In Fig. 29 the influence of clay-migration can be recognized as explained in 3.3.1. Moreover, in both sediment types, a flattening of the curves is apparent in the fine-silt fractions of A and B horizons, whereas it is absent in the substratum and in basin sediments of the recent floodplain (Fig. 30). This phenomenon is probably due to a breakdown of silt as a result of ferrallization.

The origin of the coarse tails in the Tm curves needs some further consideration. The Tm deposits are usually underlain by coarse Pl sands which often

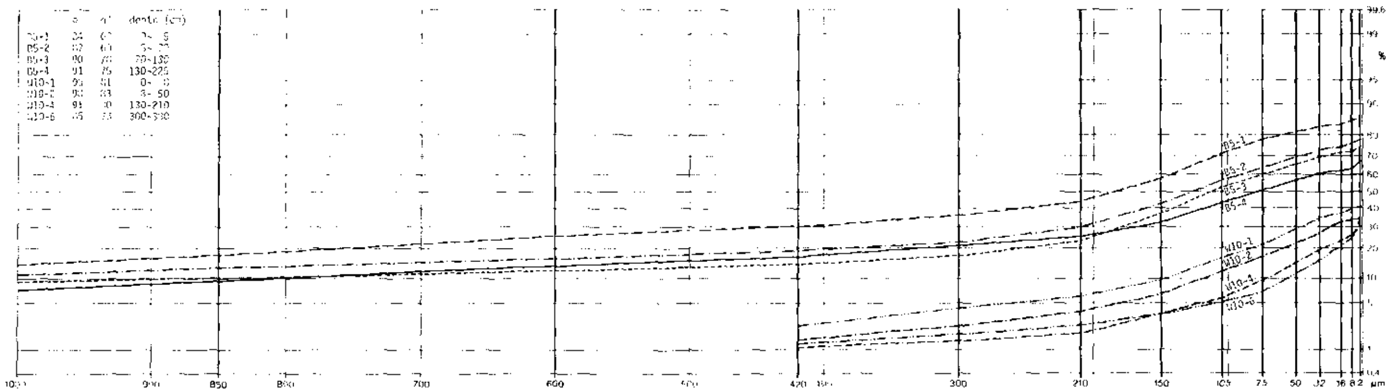


Fig. 29. Grain-size distributions of the medium-level river terrace (Tm).

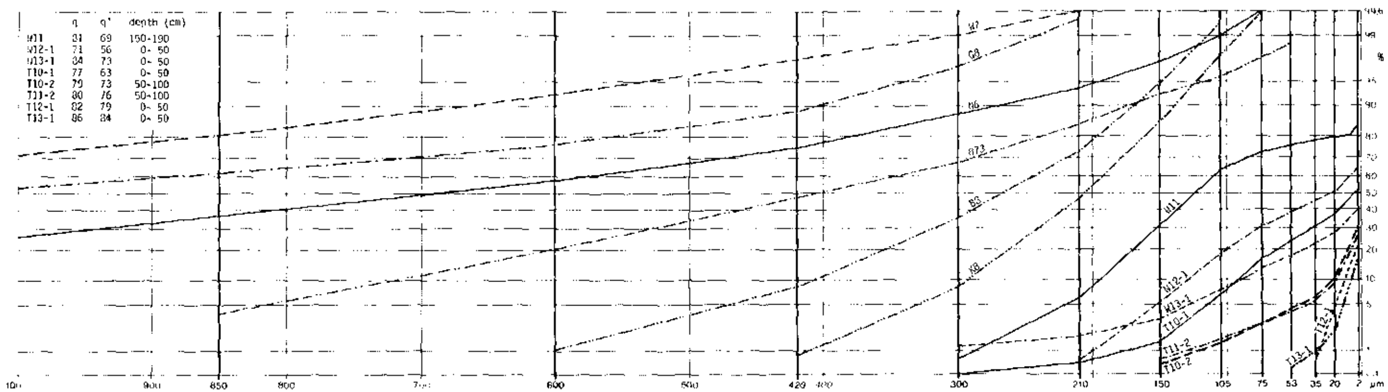


Fig. 30. Grain-size distributions of the recent floodplain (F).

show a different mineralogical composition in stratigraphic profiles: Pl sands commonly have more weatherable minerals in the 50-420 μm size range (Appendix II).

When zone diagrams (not presented) are drawn of sands from granitic regolith and of Tm and Pl sands in the Gran Rio massif, it appears that the distribution of the Tm sands largely coincides with that of the regolith, whereas the Pl sands are much coarser. Therefore, the sands of the medium-level river terrace have mainly been derived from regolith. Reworking of Pl sands may have occurred here and there.

Sediment-type 2 of Fig. 29 was often found at the inner sides of the river valleys at the transition to the hilly country. For this reason, the relation between regolith and Tm deposits was studied in several cross-sections all over the valleys. The fluviatile character of the Tm sediments always stood out clearly against the residual character of the regolith, as illustrated in figs 22 and 29. Hence, colluviation did not play an important role in the formation of the medium-level river terrace.

The absence of levees and old river-beds in the Tm river terrace points to a deposition under backswamp conditions. Only in the sample area Albina levees are weakly developed (Fig. 47). It is probable that the river valleys were drowned on a large scale during wet periods in which discharge was greatly hindered by damming effects.

(7) Sediments of the medium-level alluvial fans (Pm)

Fig. 27 gives a selection from 21 grain-size distributions of the medium-level alluvial fans. The curves correspond to those of coarse suspensions (T6-5, T6-7, T6-8). Many fractions must have been deposited simultaneously because of a sharp decrease in stream velocity.

In the A horizon (curves T6-1 and T6-4) a removal of fine particles is apparent due to podzolization (see also 4.6.2).

With a view to the physiography (3.1) and the nature of the sediments it is concluded that the material was brought down from the nearby hills. There can be no doubt that alluvial fans are involved.

Similar sediments were found at the footslopes of schist-hills in northern Surinam by van der Eyk (1957: Fig. 13).

(8) Sediments of the recent floodplain (F)

As shown by Fig. 30, size-frequency distributions of recent sediments in eastern Surinam may vary considerably. The curves W7-K8 are typical stream-bed sediments. They reflect the strongly fluctuating stream-velocities which exist in rivers and creeks. Because of a continuous current and erosion of the bottom material the fine fractions have been washed out. The curves N6-K8 represent the predominant type of sandbars; W7 and G8 are extreme examples that can be found in rapids.

According to Bakker (1957), hardly any coarse gravel is produced under a humid tropical climate because of disintegration of coarse particles by intensive weathering. Therefore, recent stream-bed sediments in eastern Surinam usually consist of sand with or without fine gravel, and they clearly stand out against the older deposits of the low-level alluvial fans. As a rule, the latter are much coarser and contain less weatherable minerals (Appendix II).

In levees of the recent floodplain, T fractions predominate with a slight admixture of coarse material (curves W11-W13-1). This kind of sediment can be found all over the world outside the stream-bed of meandering rivers (Doeglas, 1946, 1950). Sandy deposits like W11 are scarce in eastern Surinam. In levees, mostly types of curve T10-1 or finer deposits are found. This fact is probably due to the influence of a dense vegetation which strongly retards stream velocities outside the stream-bed.

The curves T10-2 - T13-1 are basin sediments which must have been deposited in nearly stagnant water.

In the Gran Rio massif, q and q' values of recent sediments are usually lower than those of the older Tm deposits. As both materials are of granitic origin, these differences reflect the state of weathering of the recent sediments. In contrast to the Tm deposits, the recent sediments may still contain significant amounts of weatherable minerals (Appendix II).

Outside the Gran Rio massif it is not possible to distinguish recent soils from older ones on the base of q and q' values, as the influence of the origin interferes with the effects of weathering, clay migration and sorting.

3.4 Geomorphology

3.4.1 Development of the drainage pattern

According to Bakker (1955), four sectors can be distinguished in the valleys of eastern Surinam:

(1) The sector of the headwaters

(2) The 'soela' sector in which rapids are numerous

(3) The estuary sector

(4) A transition zone between the soela and estuary sector

The sector of the headwaters is relatively short. In the Litani River it extends to Krobai Soela (Fig. 1). It is characterized by a trunk channel and tributary streams with numerous small meanders. Rapids are absent. According to Haug (1966) the watersheds may be very indistinct.

The soela sector includes the bulk of the valleys and extends from Armina Soela to Krobai Soela. Many rapids and some cascades occur in this zone. A morphographic description of these soelas was given by Zonneveld (1952).

The soelas may be complex, the flow consisting of converging and diverging runoff in sheets, multiple channels, rapids and falls. In other parts of the valley, simple soelas can be found which originate from a single rock barrier.

In the estuary sector there is a trunk channel and tributary streams but no rapids and falls.

According to Bakker & Müller (1957), the classic Davisian picture of valley formation going from a youth stage to a senile stage does not apply to the Marowijne valley. The authors mentioned a 'Dauerjugendstadium' (permanent youth stage) because of 'the absence of an equilibrium profile during a significant part of the Quaternary'. In a later publication (1965) Bakker stated: 'In the humid tropics differential deep weathering in floodplains dominates to such a degree that a graded profile as a result of vertical erosion or a normal curve can never exist'.

Moreover, Bakker & Müller explained that the soelas are not ephemeral forms that will be cleared away by erosion. Their permanence would have resulted from the strong tendency of the rivers to form a braided pattern. Consequently the river channels would be quickly abandoned and old gullies would be covered with sediments before the erosion terminant is reached. Vertical erosion at one place would be an ephemeral phenomenon, quickly giving way to sedimentation. This theory would be supported by the studies of Bleys (1953) who described some buried soelas in the Suriname River.

Garner (1967) supposed that the remarkable multichannelled drainage-patterns in Venezuela and in many other parts of South America were connected with a change in climate from dry to humid conditions. Perennial streams which originated during this transition would have been forced to spread across extensive areas of coarse gravels, which had been deposited during the former dry period. These rivers would not yet have had the opportunity to degrade their beds and would only find their way in unconcentrated and unorganized channel systems.

This pattern, however, would be unstable and only represent a transitional stage to a trunk channel. Garner's view was supported by Krook (1969b).

In the Marowijne area, the valleys were also filled up with sands and gravels on a large scale. These deposits, however, are not restricted to the soela sector but they occur in the headwaters and in the estuary as well. If Garner's opinion is correct, it is difficult to explain why these fans (P1) are well-preserved in parts of the valleys with a trunk channel without indications of alternate, abandoned channels.

According to Haug (1966), tectonic movements may have influenced the drainage pattern as well. In the Tapanahony-Paloemeu region, tilting resulted in some stream captures and in a rejuvenation of some valley parts. Downstream from Maboega Soela, for instance, the Tapanahony River shows a strong change in habitus. There is a knickpoint from the north to the east and many cascades appear. The terrace pattern, however, can be traced to the north in the direction of the Jai Creek. These phenomena can only be explained by a stream capture during the Pleistocene. The Paloemeu River once followed the course of the Jai Creek and was captured by the Tapanahony River. Zonneveld (1969a) arrived at the same conclusion.

Summarizing it is concluded that differential weathering probably is the main factor responsible for the origin of the soelas. Single or complex soelas are formed where the rivers pass resistant rock-barriers (Zonneveld, 1969b).

It seems incorrect, however, to assume that the soelas will not be cleared away. This would imply that the river has stayed at the same level and that terraces can not have been formed. This is not in accordance with the facts (Fig. 12). Erosion must have been active in the river valleys since Tertiary times (Mc Connell, 1966). The occurrence of significant amounts of weatherable minerals in the sand fraction of recent sediments (Fig. 19) reveals that fresh rock is still being eroded. Soelas must have been cleared away, but new ones must have been formed at lower levels. Buried soelas may be found here and there.

3.4.2 Development of landforms

Development of landforms in river valleys has been explained in terms of changes in sea level, tectonic movements and alternations in the climate (Cotton, 1940; Bakker, 1948; Quinn, 1957; Leopold et al., 1964; Fairbridge, 1968). The relevance of these factors to geogenesis in eastern Surinam will now be discussed.

(1) Influence of changes in sea level

A river terrace formed by a sinking or rising sea level converges with the recent stream-bed in downstream and upstream direction, respectively, if mature valleys are involved (Escher, 1958). No such tendency was observed in eastern Surinam. All terraces lie at about the same relative height all over the river valleys.

If a lowering of the sea level initiated downcutting, the cutting would have had to extend to the headwaters to account for the terracing. It is difficult to see why the excavation would have been of the same order all over the valleys. A subsequent rise in sea level would merely have caused cutting beyond the limit of inundation. Filling would not have extended beyond this limit (Quinn, 1957). Therefore, it seems improbable that the series of paired terraces in eastern Surinam can be explained by eustatic changes in sea level.

The author did not find remnants of interglacial marine sediments in the valleys of eastern Surinam. Probably, the influence of sea level fluctuations was restricted to a deep incision of the estuary. In the lower course of the Saramacca River, Krook (1969b) found an iron pan at a depth of more than 20 m. This pan must have been formed during a low stage of the sea level when the surface was exposed. Formation may have occurred during the Last Glacial. Van der Hammen (1963) remarked that during the Würm glacial the lower Demerara River at Mackenzie, Guyana, was eroded 120 feet below the present river level. The other rivers of the Guianas must have been deepened as well during this regression. Many rivers, however, had a large supply of sand which accumulated on the deep river bottoms when the sea level rose during the Holocene (Krook, 1969b).

(2) Influence of tectonic movements

According to van Boeckel (1969), the earth crust of eastern Surinam predominantly shows negative gravity values and has at least a tendency to rise. A slight uplift of the Coastal Plain in this area was suggested by Brinkman & Pons (1968). Nota (1967, 1971) established a fair agreement of submarine terrace patterns all over the Surinam shelf. Hence, vertical deformations since the Last Interglacial did not exceed some metres.

The occurrence of very coarse sediments in eastern Surinam can not be attributed to tectonic movements. According to Bakker (1957), the intensive chemical weathering in the humid tropics does not favour the preservation of coarse gravel and stones. In these regions, the sediments of steep and flat peripheries can hardly be distinguished, and coarse deposits are not indicative of

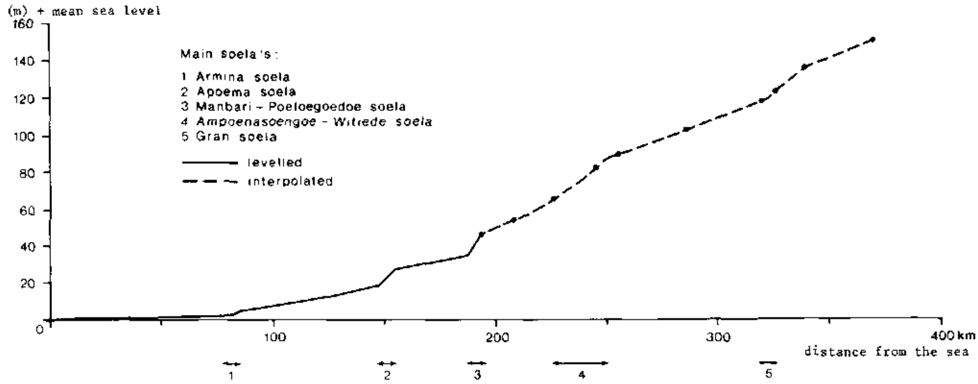


Fig. 31. Thalweg of the Marowijne, Lawa and Litani River (from BWKW, 1969 and CBL, 1962-1969).

a steep relief as resulting from tectonic movements.

The absence of converging or diverging terrace surfaces and the very flat thalweg (Fig. 31) in eastern Surinam once more suggest that tectonics only played a subordinate role in landscape development during Quaternary times. Intermittent positive epeirogenesis would have to be involved to account for the widespread terracing. Alluviation would have required depression as well (Quinn, 1957).

The effect of tectonic movements in eastern Surinam was probably restricted to local block faulting and tilting, with a rejuvenation of some valley parts (Haug, 1966).

(3) Influence of changes in climate

To study the effect of climate on geogenesis in eastern Surinam, the occurrence of fine-textured sediments on top of coarse-textured, gravelly material must be considered.

Recent F sediments, which are related to the present humid tropical weathering regime, do not contain coarse gravel and stones. In levees and basins, mostly clay to clay loam is found and coarse sands are restricted to the stream-bed (3.3.2). Obviously, the present rivers do not supply coarse gravel and stones. Bakker (1957) and Krook (1968a, 1969b) came to the same conclusion.

Hence, the coarse-textured alluvial fans (3.3.2) must have originated under conditions different from those of today. These units may contain significant amounts of coarse gravel and stones, reflecting subdued chemical weathering. It is remarkable that the Pl deposits often contain a higher content of weatherable minerals than the overlying fine-textured Tm sediments which are younger (Table 5, Appendix II). This may be another indication of a drier climate during formation of the fans.

Palynological analysis of a peat section in a Pm alluvial fan in the sample area Loë, revealed the existence of two relatively dry periods during Pleniglacial times (Wymstra, pers. commun.; see also 3.5). In contrast to the present marshy savanna wood, the area was then covered by a dry savanna forest and an open savanna vegetation, similar to that of the present Rupununi savanna in Guyana (Wymstra & van der Hammen, 1966).

Therefore, it seems reasonable to assume that the fine-textured deposits (Th, Tm, F) reflect humid tropical conditions, whereas the coarse-textured sediments (Ph, Pl, Pm) originated in a relatively dry climate.

The conditions in an interpluvial and pluvial cycle in eastern Surinam can now be reconstructed as follows (see also 2.2).

In an interpluvial phase, an open savanna vegetation covered large areas (van der Hammen, 1969) and mechanical weathering dominated. During torrential rains, coarse-textured material was eroded from the unprotected valley walls and alluvial fans were formed (3.3.2). Clastic detritus clogged valley floors, preventing entrenchment. River regimes were braided. Lateral corrasion of valley sides progressed and slopes retreated, giving rise to the formation of a broad floodplain. These processes were the more active in a subsequent early-pluvial phase when precipitation was increasing and valley slopes were not yet fully wooded (Buringh, 1960).

The transition to a plenipluvial phase produced more adequate vegetation cover in the drainage basins and chemical weathering produced a mantle of regolith. Only fine-textured material was eroded from the hill slopes. Retreat of valley walls nearly stopped because the surfaces were protected by vegetation. Meandering river systems were formed and entrenchment ensued within the limits of the old floodplain. During high floods, fine-textured material was deposited on top of the former alluvial fans (3.3.2).

In the beginning of the next interpluvial phase there was still a closed vegetation cover. With decreasing humidity a new cycle started at a lower level.

Literature data suggest a coinciding of interpluvials in Surinam with glacials in temperate regions (Zonneveld, 1968). This view is supported by the occurrence of Pl deposits below the present mean sea level (Fig. 14) and by the previously discussed palynological studies of the Pleniglacial Pm sediments.

The subordinate role of changes in sea level and tectonic movements in the development of landforms in eastern Surinam once more points to climatic alternations as the only general cause of terracing. This is consistent with the fair agreement of terrace patterns in separate valleys, which can only be explained by changes in climate (Cotton, 1940).

3.5 *Stratigraphy*

Absolute age data for eastern Surinam are scarce: Only four ^{14}C estimations are available. A relative age sequence, however, can be established and the absolute ages can be confined within certain limits.

In this section, the stratigraphy will be discussed from young to old (see Fig. 12).

The recent floodplain (F)

As explained before, an old peaty surface (lak-layer) is widely distributed in the recent floodplain at a depth varying between 280 and 410 cm. Pieces of this layer in the sample areas Weliok and Loë were dated as 300 ±65 (GrN 6106) and as 9315 ±80 years BP (GrN 6312). The lower value is doubtful, as deposition of three metres sediment in about 300 years seems unlikely under the present conditions.

Similar peaty layers at the base of fluviatile (and estuarine) deposits were found elsewhere in the Guianas (van der Hammen, 1963; Brinkman & Pons, 1968; Roeleveld, 1969; Veen, 1970). These layers, representing a break in depositional conditions, were dated between 10 000 and 6000 years BP.

The lak-layer in eastern Surinam, at the transition from coarse to fine-textured sediments, equally represents a break in depositional regime. This layer is tentatively correlated with the peaty layers in the coastal area.

Summarizing these data there can be no doubt that the recent floodplain is of Holocene age. The underlying sandy stream-bed sediments were deposited in the Early Holocene and possibly in the Last Glacial.

The medium-level alluvial fans (Pm)

In the Pm alluvial fans, remnants of old gullies often occur. A ^{14}C estimation of peat at the base of a gully in the sample area Loë revealed an age of 43 000 years (GrN 6105: 43 070 +1350/-1100 BP). Furthermore, a podzol B in the sample area Weliok was dated as 17 115 ±150 BP (GrN 6107). These data illustrate the Pleniglacial age of the Pm deposits.

The medium-level river terrace (Tm)

The Tm sediments must be older than the Pm deposits as the latter occupy uncovered depressions within the Tm terrace (Fig. 12). Therefore, the Tm sediments are probably of Early Glacial or Eemien age.

The river-terrace deposits in the sample area Albina are situated at about the same elevation as the Old Coastal Plain. Brinkman & Pons (1968) considered these units to be of the same age, which was indicated as Eemien by Veen (1970). This opinion seems correct as many pedological features in the Old Coastal Plain and the Tm river terrace are similar (4.4, 4.8).

Bakker (1968) also correlated his (Tm) 'humous swamp clays' in the Marowijne valley with fine-textured sediments in the Old Coastal Plain. The latter would have been deposited in the Holocene, during a transgression of the sea over the Old Sea Clay Plain. This opinion, however, is based on a wrong interpretation of pedogenesis. As explained by Veen (1970, p.92), Bakker's gray brown and brown clay is not a Holocene deposit, but is the well-drained topsoil of the Coropina sediments.

The low-level alluvial fans (Pl)

The Pl sediments were probably deposited in an interpluvial phase when the sea level was lower than the present one (3.4.2). As these materials immediately underlie the Tm sediments, they may be of Riss age.

Other geomorphological units

The estimation of the age of the older sediments and of the E5 and E15 planation surfaces can only be speculative. These ages lie somewhere between the Riss glacial and the age of the E30 or Rupununi surface which is supposed to be End Tertiary (2.6.3).

A stratigraphic table for eastern Surinam is given in Fig. 12.

3.6 *Summary of the polycyclic landform development in eastern Surinam*

In conclusion, the succession of depositional and erosional events in eastern Surinam will be deduced from the morphological and petrological material dealt with before. For a good understanding of this synthesis see Fig. 12.

The first cycle(s) of geogenesis

After the formation of the End-Tertiary Rupununi or E30 planation surface, a new erosional surface was formed, bordering the river valleys. This 15-m planation surface (E15) shows a very irregular relief in a direction parallel to the river. This does not point to river erosion. Probably a denudation surface is involved which was formed in a relatively dry period by slope recession at some height above the river (Zonneveld, pers. commun.). During or at the end of the pedimentation, this erosional surface was covered by very coarse-textured Ph sediments and piedmont alluvial plains or bajadas originated. The nature of the Ph deposits (3.3.2) suggests that mechanical weathering was dominant. Vegetation must have been scarce and hardrock must have occurred at a shallow depth.

After a transition to humid conditions, a forest cover developed and a regolith mantle was formed by chemical weathering. Fine-textured colluvial or fluviatile sediments were deposited on top of the former bajadas. Meandering rivers progressively deepened their valleys until such times as rejuvenation ceased by a return to a drier climate (3.4.2).

No exact age is known of this cycle; it may even be polycyclic.

The second cycle of geogenesis

During an interpluvial period, an open savanna vegetation developed and a new erosional surface was formed by slope retreat and lateral planation in a braided-river regime. The present valley bottom was carved out but resistant hardrock barriers were left as the 5-m planation surface (E5). Mechanical weathering produced large quantities of coarse-textured Pl material that was deposited in the form of alluvial fans, possibly during the Riss glacial. Bajadas originated.

An increase of precipitation, probably during the Riss-Würm interglacial, gave rise to intensive chemical weathering under rain forest. Meandering rivers deposited fine-textured Tm sediments on top of the sandy Pl surface during high floods under backswamp conditions (3.3.2). Locally Pl sands were reworked. Outliers of the 5-m planation surface were seldom covered and stood upright as rock-defended terraces. Dissection was strong and depressions were formed in the Tm surface at the foot of escarpments. During a lowering of the sea level the estuary was deeply incised (3.4.2).

The third cycle of geogenesis

After a return to drier conditions, probably during the Pleniglacial, the rain forest changed into an open savanna vegetation (2.2). Alluvial fans (Pm) were formed at the footslopes of valley walls.

In the river-beds deposition of sand proceeded during the Late Glacial and the Early Holocene when river regimes were braided. These sands now occur below mean river level. The estuary was filled up and large amounts of coarse sediments were transported to the present shelf area (Nota, 1971).

A temporary standstill of fluviatile sedimentation occurred in the Early Holocene and peat originated (3.5). Depositional conditions gradually changed. Fine-textured levees and basins developed, reflecting the present humid tropical weathering regime. Erosion proceeded in the river-beds until recent times (3.4.1). Transport of sand mainly occurred in the estuary (3.2.6).

4 Pedogenesis

In the study of pedogenesis, frequent use was made of a graphical method, the reference diagram, which will be discussed first.

4.1 The reference diagram

The reference diagram was introduced by Doeglas to study geogenesis of sediments (Doeglas, 1955, 1960). This diagram can also be used to interprete pedogenetic relationships in soils (Doeglas, 1962).

In this report it will be shown that the diagram is an aid in the study of such pedogenetic processes as bioturbation and clay migration. Lithologic discontinuities and sedimentary stratification are also obvious from the diagram. Soil profile descriptions, therefore, can be improved.

The reference diagram can also supplement petrochemical studies of soils. It is not always possible to deduce from chemical data whether differences in soil materials result from pedogenesis or not. Thus, with a combined interpretation of chemical and grain-size data, there is a better chance of determining whether materials are related or not.

A description of the reference diagram and some interpretations are given below.

The sides of the diagram show an arithmetical scale from 0 to 100 %. The way of plotting a size-frequency distribution is indicated in Fig. 32. Symbols of grades are given in Fig. 32a. The percentages larger than given sizes are plotted from left to right on a horizontal line.

The given distribution D (Fig. 32c), plotted in this way, is now drawn into the diagram according to the percentage larger than a certain reference size. This percentage is indicated on the right vertical of the diagram. Thus the symbol of the reference size falls upon the diagonal.

In Fig. 33, the reference size is 50 μm and the cumulative data of sample D have been plotted at a height of 40% larger than 50 μm.

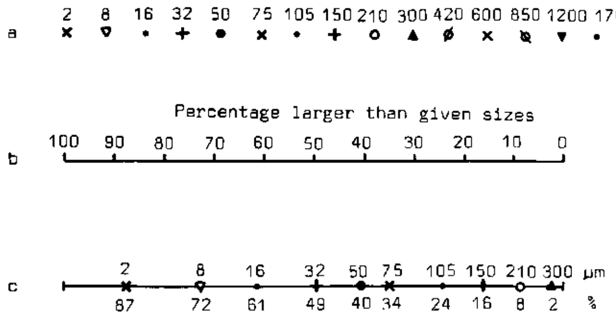


Fig. 32. (a): indicators for grain size in μm. (b): horizontal scale of reference diagram. (c): way of plotting cumulative percentages of given sample D on horizontal axis of reference diagram. (upper scale: sizes in μm; lower scale: percentages larger than given sizes).

In this way all grades of a size-frequency distribution can be shown and many grain-size distributions can be plotted in a single diagram.

A line connecting the cumulative percentages of the same size in different samples is called a grade line. The grade lines of the sizes smaller and larger than the reference size fall inside the left and the right triangle of the diagram, respectively.

The interpretation of the genetic relationships between the samples is based on a well-known geometric principle which is illustrated in Fig. 33. In this figure, a:b:c:d:e = a':b':c':d':e' and m:n:o:p:q = m':n':o':p':q'. In other words, constant weight ratios of the size grades in different samples appear as a convergence of grade lines to one or more definite points.

To test the method described, the mechanical data of 27 soil profiles from eastern Surinam were graphically worked out. The following interpretations are of interest:

Lithologic discontinuities and sedimentary stratification

In the reference diagram, lithologic discontinuities and sedimentary stratification give rise to chaotic grade lines when the samples of different layers do not show constant weight ratios of the size grades.

A similar picture arises when the grain-size determinations of related samples are unreliable or when all three grades (sand, silt and clay) have been subjected to weathering and newformation.

Bioturbation (biological homogenization)

Bioturbation in laminated materials results in mixed components. If a material M smaller than the reference size, and a material N larger than the refer-

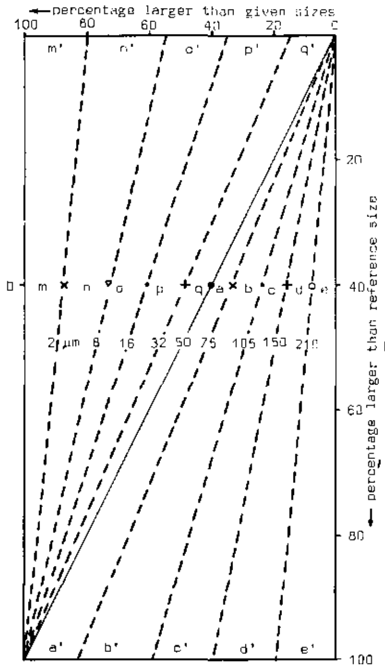


Fig. 33. Sand-clay intermingling in various proportions, due to lamination. Symbols of grades below reference size are on straight lines converging in left bottom corner. Those above reference size are on straight lines converging in right top corner. Ratios of sand grades (a-e) and those of silt & clay (m-q) remain constant. Reference size: 50 µm.

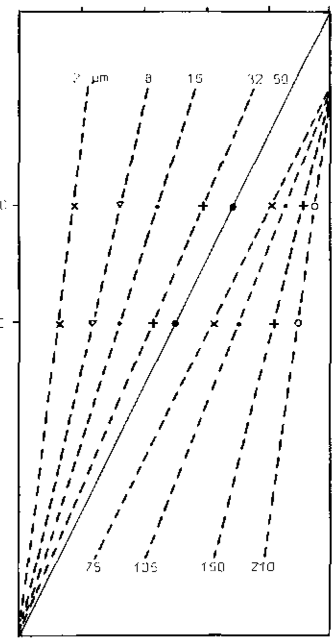


Fig. 34. Intermingling of two components, showing overlap in 50-75 µm size grade. Symbols of grades below reference size are on straight lines converging in left bottom corner. Grade lines of 50 and 75 µm are more or less parallel. Symbols of grades > 75 µm converge on right vertical.

Reference size: 50 µm.

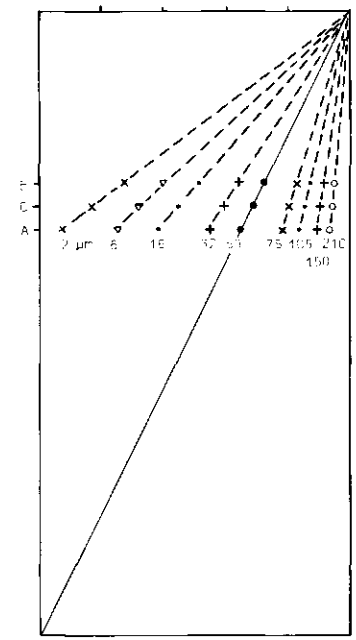


Fig. 35. Clay migration without other changes in size composition. Grade lines converge in right top corner. Sample A lost 10% clay, sample B gained 10% clay in relation to sample C.

Reference size: 50 µm.

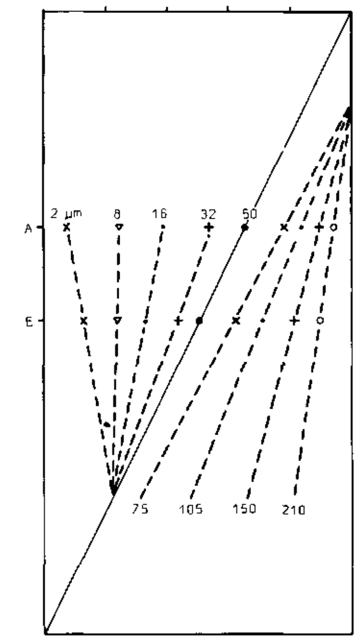


Fig. 36. Clay migration and intermingling of two components, showing overlap in 50-75 µm size grade (compare Fig. 34). Left conversion point shifts along diagonal or its extension, right conversion point moves along right vertical or its continuation.

Reference size: 50 µm.

ence size are mixed in various proportions, the weight ratios of the size grades of the individual components do not change. Consequently, in the reference diagram, mixtures containing x% M and (100-x)% N show two bundles of grade lines converging to the left bottom corner and the right top corner, respectively (Fig. 33).

If the coarsest grades of the fine component and the finest grades of the coarse component overlap, the percentages of these grades apparently increase with increasing content of one component. At the same time, however, the content of the other component decreases and consequently the percentages of the overlapping size-fractions are more or less constant throughout the series. Therefore, in the zone of overlap, grade lines are roughly parallel. If the reference size is equal to the minimum size of the coarse component, the grade lines converge to the left bottom corner and the right vertical of the diagram, respectively (Fig. 34). This results from the fact that the weight ratios of the size fractions are constant with increasing or decreasing content of the individual components.

Clay migration

When clay particles migrate in homogeneous material, the weight ratios of the size grades larger than clay size do not change. The ratio percentage of clay to percentage of other size grades, however, is variable. The grade lines then converge to the right top corner of the diagram (Fig. 35). In Fig. 35, sample A lost 10% clay and sample B gained 10% clay in relation to sample C.

Clay migration in mixed materials is illustrated in Fig. 36. In a mixture of components, showing an overlap (Fig. 34), addition or substraction of clay particles will displace the conversion points. The left conversion point will shift along the diagonal or its continuation, and the right conversion point will move along the right vertical or its extension.

Similar phenomena may result when clay is destroyed or newly formed without changes in size of the sand and silt minerals.

When the grade lines of several samples from a single profile are drawn, the picture often seems chaotic. To gain insight into the genetic relationships of soil materials, pairs of samples should be studied. Nevertheless, the picture may still be very complicated.

If the conversion point of the grades below or above the reference size lies in the diagram but not on any side nor on the diagonal with its continuations, all grades (sand, silt and clay) have changed. Then the constant weight ratios of some grades may still point to related samples.

It will be clear that the determination of many grain-size fractions favours a reliable interpretation of pedogenesis. In general the number of grades as indicated in the Soil Survey Manual (USDA, 1962) is insufficient for these purposes.

4.2 Bioturbation[1]

Bioturbation is the mixing of soil components by animals. This process is very active in the well-drained soils of eastern Surinam, as shown by a frequent occurrence of biogenic structures and gradual to diffuse horizon boundaries.

The mixed character of the soil material can often be seen in the reference diagram. Pictures like those of Fig. 36 are common in the well-drained soils outside the recent floodplain (Fig. 38).

The biological processes, however, can best be studied by micromorphological analysis. Here, the attention will be focused on well-drained loamy and clayey soils. The predominant humus form in these soils is the zoogenic, mechanically inseparable, mixture of organic matter and mineral particles, defined as homogeneous mull (Jongerius & Schelling, 1960). Moder formation is also found, as evident from the conversion of withered roots to organic fecal pellets. This moder, however, is soon worked up further by the mull formers.

The soils under discussion are essentially built up of excrements, but no information is available on mull-forming organisms. In the A1 horizon of some loamy soils, the excrements have partly disintegrated, forming debris-cutans around skeleton grains (Jongerius, pers. commun.). In all soils the individual excretions usually coalesce to form aggregates, which may reach a diameter of some hundreds of micrometres. With depth, aggregates increasingly fuse together and ultimately the soil becomes apedal. Bal (1970) referred to these processes of disintegration and welding as ageing. Thus a coherent, porous soil mass has formed which is intersected by ramifying cavities, lined by welded spheroids. These mamillated interconnected vughs and the related spongy microstructure (Kubiena, 1938) may extend to a depth of more than 2 metres.

When shifting cultivation is practised on these soils, a decay of the humus form and the microstructure may result (4.7.1).

1. Faunapedoturbation in the terminology of Jongerius (1970).

4.3 Appauvrissement

'Appauvrissement' is a removal of clay from the A horizon without a correlative accumulation in the B (CPCS, 1967). It will be shown that this process occurs widely in the Marowijne area.

In this region, nearly all soils show an increase in clay content from surface to subsoil. The same was mentioned by Brugiere & Marius (1966) and Marius & Misset (1968), who studied some soils in French Guiana.

To trace the origin of differences in soil texture, the mechanical data of 27 soil profiles were plotted in the reference diagram (4.1). Thus the study of the vertical clay distribution could be restricted to profiles of a uniform parent material, excluding primary differences in clay content. In some profiles the homogeneity of the parent material could be checked by means of detailed chemical data of the soil and the clay fraction (4.5). Furthermore, hundred thin sections of A, B and C horizons were analysed (Appendix III, IV)[1].

It appeared that the differences in clay content were mainly due to clay migration, as illustrated in figs 37 and 38. Fig. 37 depicts changes in clay content without other changes in size composition (compare Fig. 35). This picture was observed in regolith and in heavy-textured basin sediments of the Tm river terrace. Fig. 38 shows the effect of clay migration in mixed material. The existence of more or less parallel grade lines points to a mixture of components with an overlap (compare figs 34, 36). The shifting of the left conversion point along the diagonal is indicative of clay migration together with variations in the contents of the individual components. The variations are due to lamination and subsequent bioturbation. Pictures like Fig. 38 were often observed in sediments outside the recent floodplain.

These interpretations are consistent with the trend in the chemical data. With depth, there is generally a sharp decrease in the SiO_2/Al_2O_3 quotient of the soil material. This can be explained by either clay migration or clay destruction with the subsequent leaching of aluminumoxide (Slager & van Schuylenborgh, 1970). The constant chemical composition of the clay fraction then points to clay migration (4.5: profiles W4, B5; Appendix IV: W10, A4).

Thin-section analysis did not show more than traces of clay skins in well-drained virgin soils. Hence, the differences in clay content can not be ascribed to clay illuviation, so the accumulation of clay in the B horizons

1. Stencilled copies of Appendix IV are available from the Laboratory of Soil Science, P.O.B. 37, Wageningen, the Netherlands.

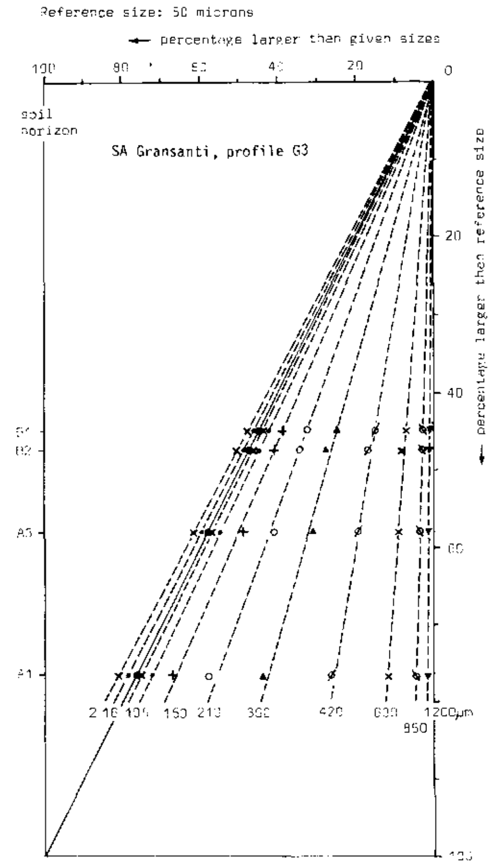


Fig. 37. Clay migration in a soil profile on quartz-diorite.

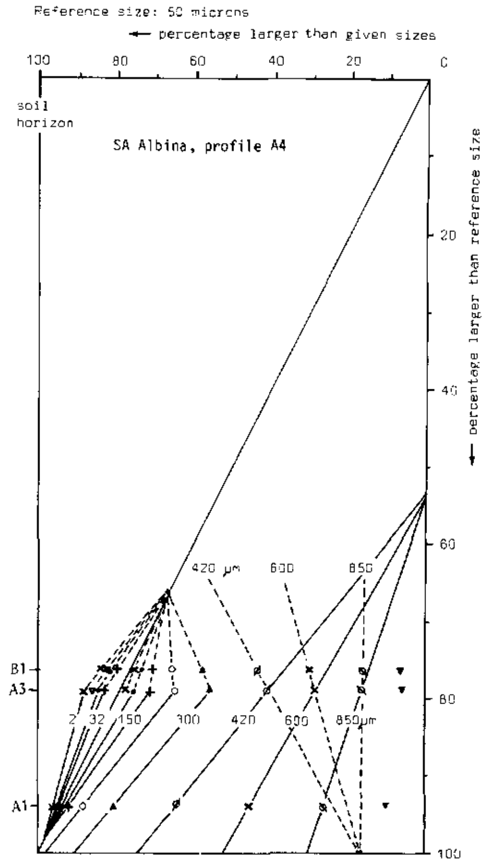


Fig. 38. Clay migration and bioturbation in a soil profile of the Tm river terrace.

is largely a relative one.

The distinction between an absolute and relative accumulation of clay in eastern Surinam can not be made by comparing the mechanical data of the B and C horizons. In the C horizon weathering and neosynthesis are still active (see 4.5). Therefore, a decrease in clay content from the B to the C horizon is no proof of illuviation, as it may be due to differential weathering (Brewer, 1968; Oertel, 1968).

Summarizing it can be stated that superficial erosion has contributed to the coarser texture of the A horizons. Surface wash, however, that deprives the soil of its finer constituents could normally only affect the immediate surface. It must act together with an agent constantly supplying fresh material to the surface to create a clay-impoverished A horizon. Hence, in the profiles under consideration, the effect of surface wash has been combined with the effect of bioturbation. This hypothesis is supported by the mixed character of the soil material as evident from the reference diagram (Fig. 38) and the micromorphological phenomena (4.2). The particle-size differentiation in some soils of western Nigeria was explained in a similar way by Fölster & Ladeinde (1967).

It was discussed before that the well-drained soils of eastern Surinam are characterized by a high faunal activity. As bioturbation has not compensated the effect of heterogenization, appauvrissement must have been active until recent times.

4.4 *Lessivage*

'Lessivage' is the process of migration and deposition of unaltered clay-sized particles in the soil profile (CPCS, 1967; van den Broek & van der Marel, 1968).

For the study of lessivage in eastern Surinam, thin-section analysis proved to be essential. Field determinations of clay skins were unreliable and mechanical data did not show the existence of pedogenetic clay peaks.

As the identification of clay-illuviation phenomena in thin sections may be uncertain, the criteria applied in this study will shortly be reviewed.

(Ferri)-argillans are plasma concentrations, showing a modification of the texture and fabric at natural surfaces, due to a concentration of clay minerals (Brewer, 1964). In eastern Surinam, these oriented clay bodies have sharp boundaries and are often layered. They generally have a waxy appearance in plain light and show a continuous orientation pattern under crossed polarizers. Derived papules are not associated with any natural surface and commonly have rounded forms.

These phenomena have to be distinguished from plasma separations due to stress. Stress cutans in eastern Surinam have a striated orientation and are not recognizable in plain light. They partly occur at the edge of the thin sections as a result of mechanical pressures during sampling.

Equant to prolate domains with a varying degree of orientation and recognizable cleavage or twin patterns (phantom structures) have been attributed to newformation in weathered minerals (Bisdom, 1967).

It appeared that clay skins were nearly absent in well-drained virgin soils. So the present humid climate of Surinam (2.1) is not the most favourable one for clay illuviation.

Similar phenomena were reported from northern Surinam: in the Holocene soils of the Young Coastal Plain no clay skins were found and in well-drained Pleistocene ridge soils only a few ferri-argillans were seen (Slager & van Schuylenborgh, 1970; Veen, 1970; Veen et al., 1971). These illuviation cutans only occurred in the periphery zones of relicted ferric nodules, where they escaped biological reworking.

In the Marowijne area, ferri-argillans were also present around relicted nodules in the B2 horizon of a well-drained Pleistocene virgin soil (Profile N3). Here, a clustered distribution of sand and silt grains illustrated the absence of a complete homogenization. Clay skins, however, were not observed in virgin soils of the recent floodplain. These data suggest that the clay-illuviation phenomena are fossile.

Other evidence of lessivage in eastern Surinam came from a study of plinthite in some soils of the Tm river terrace and the E5 planation surface (Appendix III, IV: profiles A6, T2, T3). In the B horizons of these soils, gradual transitions occurred from phantom structures to accumulations of fine material, due to transport over short distances. Argillic horizons, however, were only found in an imperfectly drained position (profiles T2, T3). In these horizons, the cutans have hardly been reworked to papules, which is consistent with a low faunal activity as expressed by a low porosity and the absence of biogenic structures. Hence, the illuviation cutans must have been preserved by hydromorphic conditions.

A correlation with the Old Coastal Plain of Surinam is once more evident. In this area, argillic horizons were found in well to poorly drained silty clay soils. In the well-drained soils, most of the oriented clay bodies were disrupted (Veen, 1970).

Summarizing it is concluded that there was at least one cycle of clay illuviation in eastern Surinam. This process is generally related to a climate in which the soils become thoroughly or partially dried at some season (USDA, 1967). As the present humid tropical climate seems unfavourable for clay illuviation, the lessivage may have occurred in some period of the Last Glacial, when the climate was drier than that of today (see 2.2). This view is confirmed by a ^{14}C estimation of a B2h horizon overlying a former textural B (GrN 6107: 17 115 ±150 BP). Veen et al. (1971) equally suggested a cycle of clay illuviation in the Old Coastal Plain during some drier period of the Last Glacial. As the Old Coastal Plain is probably the extension of the Tm river terrace (3.5), lessivage is likely to have happened simultaneously in both units. In the course of time the illuviation cutans have progressively been reworked. This process, however, was hampered by hydromorphic conditions.

Most curiously, a second, younger cycle of clay illuviation has to be distinguished. Thin-section analysis revealed that in the cultivated soils ferri-argillans invariably occurred. The illuviation phenomena appeared already in the A horizon and their quantity varied from traces to some 7% by volume. The maximum amount of illuviated clay did not coincide with the maximum amount of total clay, and clay peaks were not observed.

The abundance of mamillated interconnected vughs and the related granular or spongy microstructure in these soils point to a high faunal activity (4.2). Therefore, the lessivage, as expressed by the illuviation phenomena in situ, must be a recent process.

As mentioned before, lessivage was hardly observed in non-cultivated soils under rain forest. So the clay illuviation process has been induced by shifting cultivation.

The cutans under discussion are no agri-cutans. They are often layered, but organic matter is not detectable by micromorphological means (Jongerius, pers. commun.). In extreme cases, pores may be completely filled up with translocated clay (Profile K4).

In southern Surinam, many cultivated grounds were abandoned (Haug, 1966). Hardly any clay skins, however, were found in soils that were cultivated in the past. Therefore, the cutans have probably been reworked after a regeneration of the rain forest.

Obviously, anthropogenic clay illuviation in eastern Surinam is not a time-consuming process. The results are discernable within a period of some decades and possibly after some years. The translocated clay is Al-saturated, as evident from the chemical data (Appendix III, IV). In soils this clay is normally flocculated and immobile. Peptization can only be explained by a strong lowering of the electrolyte content in the soil solution, resulting in a large increase of the double-layer thickness. In eastern Surinam this may be related to the effect of heavy rains beating upon a dry soil after a clearing of the rain forest.

4.5 Ferrallization and plinthization

Ferrallization is a complex process, composed of hydratation, hydrolysis and oxidation of primary minerals, followed by leaching of the liberated bases and silica. Neosynthesis of goethite, kaolinite or gibbsite is characteristic.

Plinthization is the formation of plinthite as defined in the 7th Approximation (USDA, 1967).

To study these processes a new method was applied. This method included the recalculation of the chemical data into the normative mineralogical composition, as indicated by van der Plas & van Schuylenborgh (1970). For this purpose, three soil profiles were selected, which were thought to be representative of some geomorphological units in the sample areas Weliok, Blakawatra and Tapatosso.

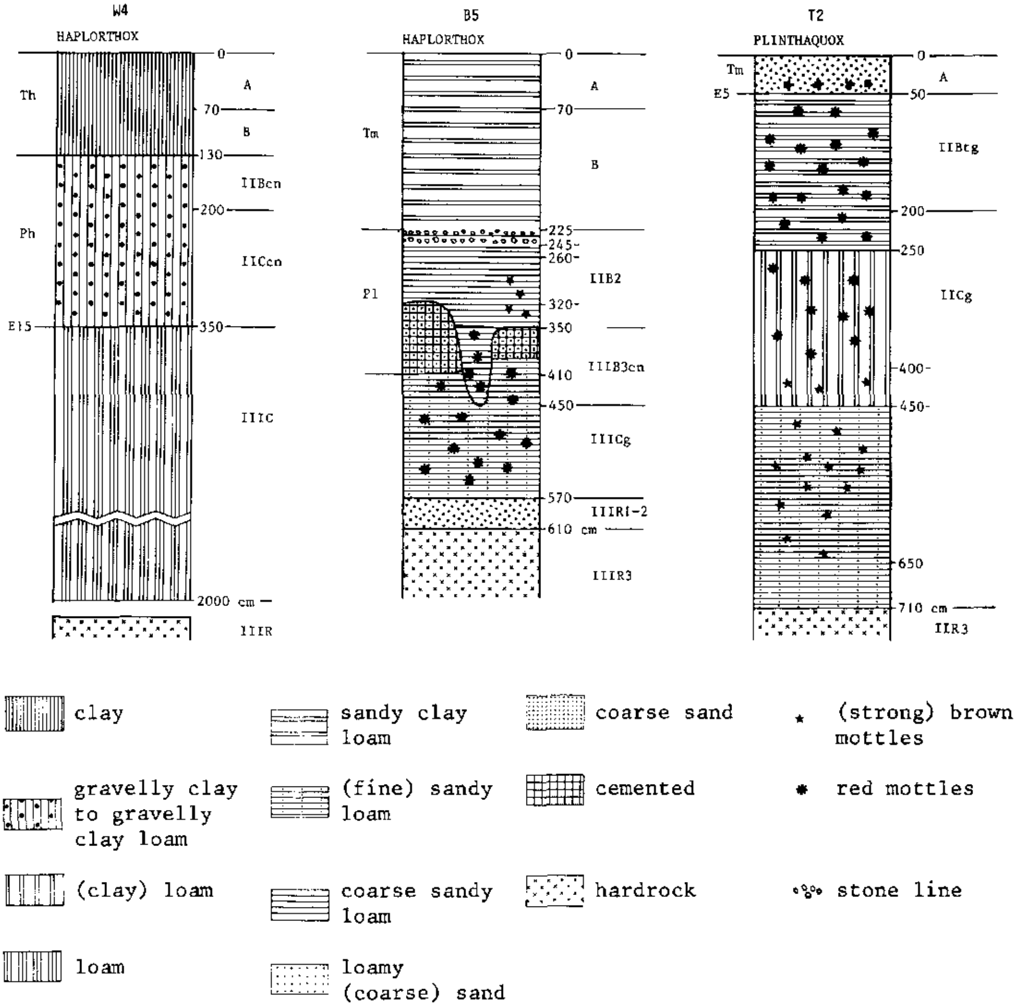


Fig. 39. Sketches of selected ferrallitic soils.

4.5.1 The ferrallitic weathering of an alkali-granite I (Profile W4)

Profile W4 can be divided into three major sections. Section I is composed of colluvial sediments of the Th terrace, resting upon sediments of a Ph alluvial fan (Section II). This fan is mainly built up of hard sesquioxidic nodules which may be indicated as petroplinthite (Sys, 1968) or 'pea iron'

(Buringh, pers. commun.). Section III is composed of regolith, derived from an alkali-granite.

A diagram of the profile is given in Fig. 39; analytical and mineralogical[1] data are presented in tables 6-10; a profile description and micromorphological characteristics can be found in Appendix III.

The profile studied does not form a complete weathering sequence: There is a hiatus between the deepest layer sampled and the parent rock. In accordance with results of Haug (1966), the mineralogical composition of the rock was found to be nearly constant over a distance of several kilometers.

The regolith

In the regolith of section III, ferrallization has been active. Silica has partially been removed, while alkalis and earth-alkalis have almost completely disappeared. There is a concentration of iron, alumina and titanium, relative to the parent rock. This corresponds to a decrease of the silica/sesquioxide quotients of the soil (Table 7). The variations in the chemical composition, however, are partly due to primary differences in the parent material.

The normative mineralogical data (tables 8-10) show that alkali-feldspars and ferro-magnesian minerals have almost been completely weathered. K-feldspar has been transformed into muscovite (illite) and eventually into kaolinite and gibbsite. Na-feldspar was even more unstable than K-feldspar. Because of the decomposition of the primary minerals, the soil was residually enriched in silica.

Iron compounds have been indicated as goethite (Table 9), but probably a mixture of goethite and some hematite is present. This accounts for the shortage of water in the normative mineralogical composition. In the clay fraction, hematite seems to be the dominant iron compound, as evident from X-ray analysis and the data on crystal water (Table 8).

The advanced stage of weathering, even at a depth of 19 metres below the soil surface, is remarkable. The association of kaolinite and gibbsite in the

1. For practical reasons percentages of minerals were expressed in equivalent percentages. The equivalent percentage is defined as
(weight percentage/equivalent weight) x ΣEqw/100
where the equivalent weight is the formula weight divided by the number of cations per molecule (Burri, 1964), and ΣEqw is the sum of the equivalent weights of all minerals considered. Except when the amount of iron minerals or carbonates is rather high, the final result of a norm calculation has not to be recalculated in terms of weight percentages, because differences are too small (van der Plas & van Schuylenborgh, 1970).

Table 6. Profile W4. Analytical data on the fine earth.

Horizon Depth (m)	Texture				Org. C %	CEC mEq/100g clay	pH (1:2.5)		Free iron % Fe_2O_3	Free alumina % Al_2O_3
	gravel >2mm	sand 2mm-50μm	silt 50-2μm	clay <2μm			H_2O	$CaCl_2$ 0.01M		
A1'	0.6	58.1	5.4	36.5	2.4	4.7	4.5	3.9	4.8	2.6
A2'	1.6	43.3	6.1	50.6	1.1	3.3	5.1	4.2	5.6	3.1
B2h'	12.2	40.9	4.2	54.9	0.9	3.3	5.1	4.2	6.5	4.0
B2	9.2	35.5	7.0	57.5	0.4	4.0	5.2	4.3	6.7	3.9
IIB2cn	54.1	29.3	12.9	57.8	0.3	3.3	5.7	4.6	6.9	3.5
IIB3cn	27.6	41.4	21.6	37.0	0.3	4.7	5.2	4.7	16.2	3.8
2 - 2½	8.8	45.6	19.6	34.8	0.1	4.0	5.4	4.5	11.3	2.4
4 - 4½	0.4	45.3	28.9	25.8	0.1	4.0	5.2	4.4	6.8	1.3
7½- 8	0.1	40.7	39.9	19.4	0.1	2.7	5.3	4.3	6.8	3.8
9½-10	1.9	47.9	35.1	17.0	0.1	2.7	5.4	4.5	4.7	1.0
15 -15½	0.3	48.0	38.1	13.9	tr	2.7	5.1	4.1	3.8	0.5
19 -19½	1.2	46.0	38.0	16.0	tr	3.3	5.2	4.3	5.1	1.2

clay fraction points to conditions of moderate to strong leaching, which is probably due to the flow of groundwater (4.5.4).

The occurrence of hematite in the clay separates may be another indication of a drier climate in the past. For a theoretical explanation see 4.5.4.

The alluvial fan sediments

The sesquioxidic nodules in Section II are pedorelicts in the sense of Brewer (1964). Their granulometric and chemical composition, which strongly differ from that of the surrounding s-matrix, the sharp boundaries and the rounded shapes do not point to a formation in situ. This material must have originated in an older, probably Tertiary, weathering cycle at a higher topographic level.

X-ray data and the normative mineralogical composition (not given) prove that the nodules mainly consist of kaolinite and goethite (50 and 40%, respectively). These data explain the relatively low SiO_2/Al_2O_3 and SiO_2/R_2O_3 quotients of the soil material. The high content of free iron is probably related to a high content of broken nodules, due to augering.

The composition of the clay fraction hardly differs from that of the upper and lower section of the profile (Table 8).

The terrace deposits

The colluvial deposits of section I are also composed of strongly weathered material.

Table 7. Profile W4. Chemical composition of clay separates, soil and parent rock (weight percentages) and the molar relation silica/sesquioxide.

Horizon Depth (m)	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5	H_2O	SiO_2/Al_2O_3	SiO_2/R_2O_3	SiO_2/Fe_2O_3	Al_2O_3/Fe_2O_3
Clay separates																
A1'	35.0	35.6	12.9	0.2	tr	-	-	0.1	tr	1.4	0.2	15.3	1.7	1.3	7.2	4.3
A2'	35.0	36.0	12.9	0.2	tr	-	-	0.1	tr	1.4	0.1	15.2	1.6	1.3	7.2	4.4
B2h'	34.7	36.1	13.3	0.2	tr	-	-	0.1	tr	1.4	0.1	15.3	1.6	1.3	6.9	4.3
B2	34.8	36.3	13.4	0.2	tr	-	-	0.1	tr	1.4	0.1	15.3	1.6	1.3	6.9	4.2
IIB2cn	34.8	35.7	12.5	0.2	tr	-	-	0.1	tr	1.3	0.1	15.3	1.6	1.3	7.4	4.5
IIB3cn	34.2	34.8	14.8	0.2	tr	-	-	0.1	tr	1.3	0.2	15.0	1.7	1.3	6.2	3.7
2 - 2½	35.4	35.3	14.2	0.1	tr	-	-	tr	tr	1.4	0.2	14.6	1.7	1.3	6.6	3.9
4 - 4½	35.6	33.3	15.1	0.2	tr	-	-	0.1	0.1	1.8	0.3	14.5	1.8	1.4	6.2	3.4
7½ - 8	32.8	31.2	19.5	0.1	tr	tr	-	0.1	0.2	1.8	0.6	13.8	1.8	1.3	4.5	2.5
9½ -10	36.2	35.7	12.1	0.1	tr	tr	-	0.1	0.2	1.2	0.4	14.6	1.7	1.4	7.9	4.6
15 -15½	36.5	32.7	15.2	0.2	tr	tr	-	0.1	0.4	1.3	0.9	13.6	1.9	1.5	6.4	3.4
19 -19½	39.5	33.4	11.9	0.1	0.1	tr	-	0.1	0.5	1.1	0.5	13.0	2.0	1.6	8.8	4.4
Soil and parent rock																
A1'	69.1	12.8	5.6	0.4	tr	-	-	-	-	1.0	tr	10.2	9.1	7.1	33	3.6
A2'	60.8	18.7	7.3	0.2	tr	-	-	-	-	1.4	tr	10.3	5.5	4.4	22	4.0
B2h'	55.8	18.9	11.4	0.2	tr	-	tr	-	-	1.2	tr	10.2	5.0	3.6	13	2.6
B2	52.4	22.5	11.4	0.1	tr	-	tr	-	-	1.3	tr	10.7	3.9	3.0	12	3.1
IIB2cn	36.3	21.8	27.6	0.3	tr	-	0.1	-	tr	1.1	tr	10.8	2.8	1.6	3.5	1.2
IIB3cn	38.7	22.0	27.0	0.2	tr	-	0.1	-	tr	0.9	tr	10.8	3.0	1.7	3.8	1.3
2 - 2½	46.4	23.5	17.5	0.2	tr	-	tr	-	-	0.9	tr	10.5	3.4	2.3	7.1	2.1
4 - 4½	58.3	24.1	8.2	0.2	tr	-	-	0.1	-	1.0	0.1	9.6	4.1	3.4	19	4.6
7½ - 8	59.9	23.6	7.5	0.2	tr	-	-	0.1	0.1	0.7	0.1	9.0	4.3	3.6	21	4.9
9½ -10	51.6	29.0	5.4	0.3	tr	-	-	tr	0.1	0.7	0.1	12.7	3.0	2.7	25	8.4
15 -15½	63.6	23.1	5.1	0.2	tr	-	-	tr	0.1	0.5	0.1	8.3	4.7	4.1	33	7.1
19 -19½	62.5	22.0	6.1	0.2	0.1	-	-	tr	0.5	0.7	0.1	8.3	4.8	4.1	27	5.7
R	71.2	17.1	2.0	0.1	tr	1.6	0.7	2.6	5.8	0.4	tr	0.8	7.1	6.5	91	13

Table 8. Profile W4. Goethite normative clay composition (equivalent percentages).

Horizon Depth (m)	Strengite	Rutile Anatase	Illite	Smectite	Kaolinite	Gibbsite	Hematite[1]	Excess water
A1'	0.4	1.2	0.9	0.5	78.1	8.2	10.7	1.0
A2'	0.4	1.2	0.5	0.5	78.1	8.6	10.7	-0.2
B2h'	0.3	1.2	0.5	0.5	77.5	8.9	11.1	-0.2
B2	0.3	1.1	0.5	0.3	77.4	9.3	11.1	-0.8
IIB2cn	0.3	1.1	0.9	0.3	78.2	8.7	10.5	0.8
IIB3cn	0.4	1.1	0.9	0.3	76.6	8.2	12.5	0.0
2 - 2½	0.4	1.1	0.9	0.3	78.0	7.5	11.8	-1.5
4 - 4½	0.5	1.6	0.9	0.5	79.5	4.4	12.6	2.2
7½- 8	1.2	1.5	2.8	0.3	72.8	5.1	16.3	0.7
9½-10	0.6	1.0	2.3	0.2	79.2	6.8	9.9	-0.2
15 -15½	1.8	1.1	4.7	0.3	77.2	2.9	12.0	1.4
19 -19½	0.9	0.9	5.7	0.3	82.4	0.3	9.5	0.9

1. Hematite variant.

Table 9. Profile W4. Normative mineralogical soil composition (equivalent percentages).

Horizon Depth (m)	Str	Ru	Ms	Mm Chl	Kaol	Gibb	Go	Q	W+
A1'	0.1	0.8	0.3	0.6	28.5	3.0	4.7	62.0	-0.4
A2'	0.2	1.2	0.3	0.4	40.7	4.3	6.1	46.8	-1.3
B2h'	0.1	1.0	0.2	0.5	44.7	4.3	10.1	39.1	-2.6
B2	0.2	1.0	0.3	0.3	50.1	4.9	10.0	33.2	-2.3
IIB2cn	0.1	1.0	0.2	1.3	55.5	2.3	26.0	13.6	-3.6
IIB3cn	0.1	0.7	0.2	0.6	54.7	2.7	24.3	16.7	-4.7
2 - 2½	0.1	0.8	0.3	0.6	57.2	2.4	15.1	23.5	-2.7
4 - 4½	0.1	0.8	0.2	0.2	58.6	1.1	6.7	32.3	-2.1
7½- 8	0.2	0.5	0.5	0.6	56.7	1.0	6.1	34.4	-3.0
9½-10	0.1	0.6	1.4	0.7	71.3	1.2	4.4	20.3	5.0
15 -15½	0.3	0.5	0.7	0.5	55.6	0.4	4.0	38.0	-2.4
19 -19½	0.1	0.6	4.4	0.5	50.9	tr	4.8	38.7	0.0

Str= Strengite. Ru= Rutile and Anatase. Ms= Muscovite and Illite. Mm= Montmorillonite. Chl= Chlorite. Kaol= Kaolinite. Gibb= Gibbsite. Go= Goethite. Q= Silica. W+= Excess water.

Table 10. Profile W4. Normative mineralogical composition of parent rock (equivalent percentages).

	Ca-phosphate	Rutile Anatase	Microcline	Albite	Epidote	Hornblende	Andalusite	Hematite	Silica
R	0.2	0.3	34.2	23.3	2.6	3.8	7.8	1.4	26.4

The sharp decrease in the silica/sesquioxide quotients of the soil with depth, together with the constant composition of the clay fraction point to a process of appauvrissement (4.3). This is consistent with the absence of clay skins in the thin sections (Appendix III).

4.5.2 The ferrallitic weathering of an alkali-granite II (Profile B5)

Profile B5 is composed of three major sections. The upper section (I) consists of fluviatile deposits of the Tm river terrace, resting upon sediments of a P1 alluvial fan (II). The lower section (III) is built up of regolith, derived from an alkali-granite.

A sketch of the profile is given in Fig. 39; analytical and mineralogical data are presented in tables 11-15; a profile description and micromorphological characteristics can be found in Appendix III. The mechanical properties of the fluviatile sediments were discussed in 3.3.2.

The regolith

Section III shows the typical characteristics of ferrallization. Alkali-feldspars and hornblende have progressively been transformed into muscovite (illite), chlorite, smectite and kaolinite and eventually into kaolinite and gibbsite (tables 13-15). As a result of the decomposition of the primary minerals, silica was enriched residually.

Table 11. Profile B5. Analytical data on the fine earth.

Horizon	Texture				Org. C %	CEC mEq/100g clay	pH (1:2.5)		Free iron % Fe_2O_3
	gravel >2mm	sand 2mm-50μm	silt 50-2μm	clay <2μm			H_2O	$CaCl_2$ 0.01M	
A1	2.5	84.1	1.7	14.2	3.4	2.7	4.7	3.8	0.7
A3	2.9	73.5	2.6	23.9	1.1	4.0	3.8	3.8	1.1
B1	3.9	70.5	2.7	26.8	0.5	3.3	4.4	4.0	1.1
B2	1.6	63.1	2.8	34.1	0.3	2.7	4.5	4.1	1.4
IIB22	11.2	75.5	2.6	21.9	0.1	2.7	4.7	4.1	1.8
IIB23	10.4	77.8	4.9	17.3	0.3	2.0	4.2	4.0	1.2
IIB24g	14.0	87.5	2.3	10.2	0.1	1.3	4.9	4.2	0.2
IIB25ir	7.6	94.0	2.0	4.0	0.1	3.3	4.9	4.6	2.9
IIIB3cn	64.8	78.5	5.3	16.2	0.1	2.0	4.8	4.2	1.0
IIICg	3.3	74.8	7.0	18.2	0.1	2.0	5.1	4.1	0.3
pedotubule	8.0	74.9	5.3	19.8	0.3	2.0	4.6	4.1	0.5
IIIR1	-	92.7	4.5	2.8	0.2	7.3	5.0	4.5	6.3
IIIR2	-	95.5	3.5	1.0	tr	•	5.5	5.1	2.7

Table 12. Profile B5. Chemical composition of clay separates, fine earth and parent rock (weight percentages) and the molar relation silica/sesquioxide.

Horizon	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5	H_2O	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
Clay separates																
A1	39.2	36.8	5.7	0.2	tr	-	-	0.1	0.3	1.3	0.2	15.6	1.8	1.6	18	10
A3	39.2	38.6	6.2	0.1	tr	-	-	0.1	0.3	1.3	0.2	15.4	1.7	1.6	17	9.7
B1	39.0	38.4	6.1	0.2	tr	-	-	0.1	0.3	1.3	0.2	15.4	1.7	1.6	17	9.9
B2	38.2	37.7	6.1	0.1	tr	-	-	0.1	0.2	1.3	0.1	15.6	1.7	1.6	17	9.7
IIB22	39.4	38.7	6.4	0.2	tr	-	-	0.1	0.2	1.4	0.2	15.1	1.7	1.6	16	9.5
IIB23	38.2	37.6	6.1	0.2	tr	-	-	0.1	0.2	1.4	0.2	15.6	1.7	1.6	17	9.7
IIB24g	40.9	40.1	2.5	0.1	tr	-	-	tr	0.1	1.3	0.4	16.2	1.7	1.7	42	25
IIB25ir	37.1	33.8	12.2	0.4	0.1	-	-	0.1	1.3	1.2	2.2	21.7	1.9	1.5	8.1	4.4
IIIB3cn	36.1	41.3	3.0	0.3	-	-	-	0.1	0.2	1.8	0.2	17.5	1.5	1.4	33	22
IIICg	28.7	46.0	1.3	0.1	-	-	-	tr	0.1	1.7	0.2	21.0	1.1	1.0	60	56
pedotubule	32.8	43.7	2.1	0.2	-	-	-	tr	0.2	1.6	0.3	19.1	1.3	1.2	42	33
IIIR1	19.7	34.7	18.8	0.5	0.1	tr	0.2	0.1	1.5	3.1	0.6	21.7	1.0	0.7	2.8	2.9
Fine earth and parent rock																
A1	82.5	6.8	1.2	0.2	tr	-	-	tr	0.4	0.5	tr	8.5	20	18	196	9.6
A3	77.9	11.3	2.2	0.2	tr	-	-	tr	0.6	0.8	tr	6.6	12	10	93	7.9
B1	77.5	11.9	2.4	0.1	tr	-	-	tr	0.5	0.9	tr	5.8	11	9.8	86	7.8
B2	75.9	14.1	2.6	0.1	tr	-	-	tr	0.2	0.9	tr	6.3	9.2	8.2	79	8.6
IIB22	83.0	10.2	1.6	0.2	tr	-	-	tr	0.1	0.6	tr	4.5	14	13	138	10
IIB23	84.3	9.3	1.1	0.3	tr	-	-	tr	0.1	0.5	tr	4.4	15	14	201	13
IIB24g	88.1	7.3	0.6	tr	tr	-	-	tr	tr	0.3	tr	3.0	20	19	367	18
IIB25ir	90.0	4.8	3.8	0.1	tr	-	-	tr	tr	0.2	tr	2.5	32	21	62	2.0
IIIB3cn	74.0	15.5	1.4	0.1	tr	-	-	tr	tr	0.5	tr	7.0	8.1	7.7	137	17
IIICg	54.7	29.2	1.1	tr	tr	-	-	tr	0.1	0.7	0.1	13.1	3.2	3.1	130	41
pedotubule	55.7	27.9	1.2	0.1	tr	-	-	tr	0.2	0.7	0.2	13.4	3.4	3.3	116	34
IIIR1	46.4	27.1	8.6	0.2	tr	-	0.5	0.5	0.3	0.8	0.2	14.7	2.9	2.4	14	4.9
IIIR2	57.3	20.8	5.5	0.5	tr	0.3	2.4	0.3	2.0	0.7	0.2	9.5	4.7	4.0	28	6.0
IIIR3	70.6	16.6	2.1	0.1	tr	0.6	0.6	2.3	6.6	0.4	0.2	1.1	7.2	6.7	90	12

Table 13. Profile B5. Goethite normative clay composition (equivalent percentages).

Horizon	Strengite	Rutile Anatase	Illite	Smectite	Kaolinite	Gibbsite	Goethite	Excess water
A1	0.4	1.1	3.8	0.5	84.2	5.4	4.6	3.4
A3	0.4	1.1	3.8	0.3	82.0	7.5	4.9	- 1.2
B1	0.4	1.1	3.8	0.5	81.9	7.5	4.8	- 0.8
B2	0.1	1.0	2.9	0.5	82.9	7.5	5.1	0.4
IIB22	0.4	1.1	2.9	0.5	82.7	7.3	5.1	- 2.9
IIB23	0.4	1.1	2.9	0.5	82.7	7.5	4.9	0.6
IIB24g	0.7	1.0	1.4	0.3	87.6	7.3	1.7	2.4
IIB25ir	4.1	1.0	13.4	0.8	69.1	3.5	8.1	30.7
IIIB3cn	0.4	1.5	2.9	0.6	77.5	14.8	2.3	1.7
IIICg	0.4	1.5	0.9	0.2	66.2	29.9	0.9	3.0
pedotubule	0.5	1.4	1.9	0.5	72.9	21.3	1.5	2.2
IIIR1	1.2	2.9	18.3	2.3	30.7	27.7	16.9	13.7

The molar quotients SiO_2/Fe_2O_3 and Al_2O_3/Fe_2O_3 indicate a higher mobility of iron than of alumina and silica. This is consistent with the data on free iron, which point to a significant release of iron in the R horizon (Table 11). In the C horizon, iron was redistributed due to alternate reduction and oxidation. For a theoretical explanation see 4.5.4.

The IIIB3cn horizon is intermediate in composition between the regolith and the alluvial fan sediments. This may indicate reworking during sedimentation or mixing during sampling.

The alluvial fan sediments

The variations in the composition of the Pl deposits in Section II are partly due to primary differences in the parent material. A study of the detailed mechanical data by means of the reference diagram did not show a simple geogenetic relationship between the individual samples. As appears from Fig. 28, however, the conditions of sedimentation must have been very similar. The variations in the chemical data equally point to small differences in related materials.

The mineralogical data (tables 13, 14) indicate an advanced stage of weathering. As explained before, the clay fraction has probably been formed by newformation in situ (3.3.2). This is consistent with the frequent occurrence of phantom structures in the iron pan at the base of the fan. These relics of K-feldspars have been preserved by free grain ferrans (Appendix III) and have obviously been transformed into illite (Table 13).

Table 14. Profile B5. Normative mineralogical composition of fine earth (equivalent percentages).

	Strengite	Rutile Anatase	Muscovite Illite[1]	Microcline[1]	Albite	Smectite Chlorite	Kaolinite[1]	Gibbsite	Goethite	Silica[1]	Excess water[1]
A1	0.1	0.4	4.1	-	-	0.5	12.5	0.8	1.0	80.6	0.8
A3	0.1	0.6	5.7	-	-	0.3	20.4	1.8	1.8	69.3	1.8
B1	0.1	0.7	5.0	-	-	0.3	22.3	2.0	1.9	67.7	1.3
B2	tr	0.7	1.9	-	-	0.4	30.2	2.6	2.1	62.1	0.3
IIB22	0.1	0.5	1.0	-	-	0.4	21.7	1.6	1.2	73.5	0.8
IIB23	0.1	0.4	1.2	-	-	0.8	19.8	1.3	0.9	75.5	10.0
IIB24g	0.1	0.2	0.1	-	0.3	tr	16.5	0.7	0.4	81.7	- 0.7
IIB25ir	0.2	0.1	0.5	-	-	0.2	10.8	0.1	2.8	85.3	0.7
IIIB3cn	0.1	0.4	0.5	-	-	0.3	34.3	2.4	1.1	60.9	2.9
IIICg	0.2	0.6	1.1-0.2	0- 0.7	-	tr	64.7-65.2	5.4	0.8	27.2-26.9	7.2- 6.8
pedotubule	0.3	0.6	1.7-0.4	0- 0.9	-	0.3	62.8-63.6	4.2	0.9	29.2-28.8	8.9- 8.7
IIIR1	0.4	0.7	5.3-0.5	0- 3.4	5.6	2.6	62.0-64.7	0.8	7.2	15.4-14.1	16.7- 16.0
IIIR2	0.6	0.6	18.7-0	0-13.4	3.2	10.7	26.4-37.0	-	4.4	35.4-30.1	11.2- 8.6

1. Standard Epinorm and Microcline variant of the Epinorm, respectively.

Table 15. Profile B5. Normative mineralogical composition of parent rock (equivalent percentages).

	Ca-phosphate	Rutile Anatase	Microcline	Albite	Hornblende	Andalusite	Hematite	Silica
IIIR3	0.4	0.3	39.3	21.3	3.0	9.0	1.5	25.2

The river terrace deposits

The Tm sediments in the upper section of the profile are also composed of strongly weathered material.

The trend in the iron and aluminum oxide contents of the clay separates indicate a translocation of sesquioxides relative to silica. A similar tendency is recognizable in the free iron contents of the fine earth. So podzolization has started. This process is common in the loamy-textured soils of eastern Surinam and the more remarkable in cultivated soils.

The trend in the silica/sesquioxide quotients of the fine earth is due to the combined effect of podzolization and appauvrissement, as explained before.

4.5.3 The ferrallitic weathering of a hornblende-diorite (Profile T2)

Profile T2 consists of regolith, derived from a hornblende-diorite. It forms part of the E5 planation surface and is covered by fluviatile deposits of the Tm terrace. The latter will not be considered.

In this profile, weathering has occurred under hydromorphic conditions and plinthite was formed.

A diagram of the profile is given in Fig. 39; analytical and mineralogical data are presented in tables 16-20; a profile description and micromorphological characteristics can be found in Appendix III. Mechanical properties were discussed in 3.3.1.

Ferrallization

The mineralogical variations in the regolith are partly due to primary differences in the parent material. A break in the silica/sesquioxide quotients, for instance, points to a lithologic discontinuity at a depth of about 2 m. The fluctuations in the hornblende content in the lower part of the profile can be explained in a similar way.

As can be seen from tables 16-20, the parent rock has been subjected to ferrallization. Silica has partially been removed and bases have been released, as evident from the relatively high pH values in the lower part of the profile. Iron, alumina and titanium have been enriched slightly (Table 17).

The normative mineralogical data show that alkali-feldspars, epidote and hornblende have progressively been transformed into chlorite, smectite, muscovite and kaolinite. With additional microscopic analysis of the sand fraction and X-ray analysis of the clay separates three zones could be distinguished:

(1) a zone of maximum chlorite content at a depth of more than 5 m.
(2) a zone of maximum smectite content at a depth of 4 to 5 m, corresponding with a maximum in the CEC values (Table 16).
(3) a zone of maximum kaolinite content, extending from the surface to a depth of about 4 m.

Thus chlorite, smectite and muscovite have almost completely been transformed into kaolinite, while silica was enriched residually. The constant composition of the clay fraction in the solum proves that, under the given çonditions, kaolinite is a stable phase.

Plinthization and gleying

The morphological characteristics (Appendix III) indicate that iron is very mobile in this profile.

As evident from the greenish-yellow colours, the zone of permanent reduction extends from a depth of 6.5 m downwards. The mottling pattern points to a progressive redistribution of iron from the bottom to the surface, due to alternate reduction and oxidation. As a result of dehydration the colour of the mottles changed from strong brown to red. For a theoretical discussion see 4.5.4.

Thin-section analysis of the IIB2tg horizon showed the existence of two types

Table 16. Profile T2. Analytical data on the fine earth.

Horizon Depth (cm)	Texture				Org. C %	CEC mEq/100g clay	pH (1:2.5)		Free iron % Fe_2O_3
	gravel >2mm	sand 2mm-50μm	silt 50-2μm	clay <2μm			H_2O	$CaCl_2$ 0.01M	
A11	-	80.6	12.0	7.4	0.4	•	4.6	4.0	0.3
A12g	2.1	84.0	8.4	7.6	0.4	•	4.8	4.0	0.5
IIB1tg	1.6	70.8	5.7	23.5	0.2	•	4.5	3.9	1.7
80-150	2.7	70.8	5.6	23.6	0.2	2.0	4.8	4.1	2.4
150-200	0.9	60.3	8.3	31.4	0.2	2.7	4.8	4.0	2.6
200-250	2.2	57.1	15.9	27.0	0.3	6.7	4.8	3.9	5.5
250-300	0.9	23.6	39.8	36.6	0.1	7.3	4.6	3.8	7.0
300-350	0.1	28.2	45.6	26.2	0.2	6.0	4.8	3.9	4.9
350-400	-	22.3	57.1	20.6	0.1	5.3	5.2	4.1	4.6
400-450	-	36.6	46.0	17.4	0.1	18.7	5.3	4.4	11.0
450-500	-	52.4	37.8	9.8	0.1	19.3	5.6	4.9	7.5
500-550	-	56.6	34.1	9.3	0.1	13.3	6.1	5.3	4.4
550-600	-	67.3	25.9	6.8	0.1	12.7	6.2	5.5	2.8
600-650	-	65.6	26.9	7.5	0.1	14.7	6.7	6.0	2.4
650-700	-	71.6	24.0	4.4	0.1	9.3	6.7	6.2	2.3
700-710	-	75.0	21.7	3.3	0.1	8.0	7.0	6.8	0.8

ges) and the molar relation silica/sesquioxide.

Horizon Depth (cm)	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5	H_2O	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
Clay separates																
A11	44.7	33.6	4.5	0.3	-	-	tr	tr	0.1	1.2	0.1	14.6	2.2	2.1	27	12
A12g	43.3	33.6	5.8	0.3	-	-	tr	0.1	tr	1.2	0.7	14.4	2.2	2.0	20	9.2
IIB1tg	41.9	34.1	7.0	0.4	-	-	-	0.1	0.1	1.1	0.1	15.1	2.1	1.8	16	7.6
80-150	41.7	34.4	7.2	0.1	-	-	tr	tr	0.1	1.1	0.2	14.9	2.1	1.8	15	7.5
150-200	41.1	33.6	8.3	-	-	-	0.1	tr	0.1	1.1	0.2	15.3	2.1	1.8	13	6.3
200-250	42.2	33.1	8.3	tr	-	-	tr	tr	tr	1.2	0.1	14.7	2.2	1.9	14	6.2
250-300	43.3	33.7	7.3	tr	-	-	tr	tr	tr	1.0	0.3	14.2	2.2	1.9	16	7.2
300-350	41.9	33.3	7.2	0.1	-	-	0.1	tr	tr	1.1	0.1	15.0	2.1	1.9	16	7.3
350-400	40.4	32.3	9.6	0.1	-	-	0.1	tr	0.1	1.2	0.1	15.9	2.1	1.8	11	5.3
400-450	40.1	27.9	13.8	0.6	tr	tr	0.1	0.1	0.1	2.0	0.1	13.6	2.4	1.9	7.8	3.2
450-500	41.7	26.1	15.0	0.9	0.1	tr	0.3	0.1	0.1	1.9	0.2	12.4	2.7	2.0	7.5	2.7
500-550	42.3	27.5	12.6	0.6	tr	0.2	0.1	0.2	0.1	1.4	0.2	13.1	2.6	2.0	8.9	3.4
550-600	41.9	26.3	13.5	0.8	tr	0.4	0.9	0.3	0.2	1.7	0.3	12.5	2.7	2.0	8.2	3.0
600-650	40.9	23.2	17.3	0.8	0.1	1.0	1.6	0.7	0.3	1.6	0.7	11.9	3.0	2.0	6.3	2.1
650-700	42.0	24.4	13.0	0.9	0.1	1.3	1.5	1.2	1.9	1.2	0.4	12.1	2.9	2.2	8.6	2.9
700-710	45.6	21.5	11.9	0.8	0.1	2.0	2.2	2.4	2.6	1.0	0.4	9.5	3.6	2.6	10	2.8
Fine earth and parent rock																
A11	96.0	2.3	1.0	0.1	-	-	-	0.1	tr	0.4	tr	1.8	69	55	266	3.8
A12g	93.0	3.3	1.2	0.1	-	-	-	0.2	tr	0.5	tr	2.0	48	39	193	4.0
IIB1tg	84.9	9.2	2.7	0.1	-	-	-	0.2	tr	0.5	tr	4.3	16	13	83	5.3
80-150	83.1	9.8	2.9	-	-	-	tr	tr	tr	0.4	tr	4.3	14	12	77	5.3
150-200	79.0	11.5	3.8	tr	-	-	tr	tr	tr	0.5	tr	5.2	12	9.6	55	4.7
200-250	55.5	23.8	10.2	0.1	tr	-	0.1	tr	tr	1.0	tr	10.3	4.0	3.1	14	3.6
250-300	69.6	16.3	6.9	0.2	tr	-	0.1	tr	tr	0.8	tr	7.1	7.2	5.7	27	3.7
300-350	55.2	23.1	9.9	0.2	tr	tr	0.2	tr	tr	1.1	tr	10.9	4.0	3.2	15	3.7
350-400	46.6	26.0	12.0	0.1	-	0.1	0.2	0.1	0.1	1.4	tr	11.6	3.0	2.4	10	3.4
400-450	44.7	22.0	16.9	0.3	0.1	0.8	0.9	0.5	0.1	2.1	tr	10.4	3.4	2.3	7.0	2.0
450-500	46.9	18.3	13.8	0.9	0.1	3.3	2.7	1.3	0.2	1.9	0.1	7.2	4.3	2.9	9.1	2.1
500-550	51.1	20.7	9.1	1.0	0.1	4.5	3.6	2.6	0.2	1.3	0.1	5.6	4.2	3.3	15	3.6
550-600	50.3	18.0	8.7	2.1	0.1	6.2	4.8	2.6	0.3	1.4	0.1	4.1	4.7	3.6	15	3.3
600-650	50.1	16.7	7.8	3.7	0.1	7.4	5.7	3.0	0.3	1.5	0.2	2.8	5.1	3.9	17	3.3
650-700	55.4	18.0	7.9	1.2	0.1	6.8	2.9	4.2	0.3	1.2	0.3	2.1	5.2	4.1	19	3.6
700-710	64.2	17.8	5.1	0.3	tr	5.1	1.5	4.6	0.3	0.7	0.3	1.0	6.1	5.2	33	5.5
IIR3	51.6	14.3	8.1	5.2	0.2	9.5	5.6	2.6	0.4	1.4	0.1	0.9	6.1	4.5	17	2.7

Table 18. Profile T2. Goethite normative clay composition (equivalent percentages).

Horizon Depth (cm)	Ca-phosphate Strengite	Rutile Anatase	Illite	Albite	Horn-blende	Smectite[1]	Chlo-rite[1]	Kaolinite[1]	Gibb-site[1]	Goe-thite	Silica[1]	Excess water[1]
A11	0.1	1.0	1.4	-	-	3.0	-	86.5	-	3.7	4.3	6.8
A12g	1.3	1.0	1.5	-	-	3.0	-	86.7	-	4.2	2.3	5.4
IIB1tg	0.1	0.9	1.9	-	-	4.1	-	87.1	-	5.9	-	6.3
80-150	0.4	0.9	1.4	-	-	1.0	-	89.7	-	5.9	0.7	4.6
150-200	0.4	1.0	1.4	-	-	1.5	-	88.1	-	6.9	0.7	6.3
200-250	0.1	1.0	1.0	-	-	-	-	87.4	-	7.0	3.5	4.4
250-300	0.5	0.8	0.5	-	-	2.0	-	87.2	-	5.9	3.1	2.7
300-350	0.1	1.0	0.5	-	-	2.5	-	88.2	-	6.1	1.6	6.0
350-400	0.1	1.0	1.4	-	-	2.5	-	85.2	-	8.3	1.5	9.2
400-450	0.1	1.7	1.9	-	-	8.2	-	71.5	-	12.1	4.5	3.2
450-500	0.4	1.7	1.9	-	-	18.0	-	60.6	-	12.8	4.6	1.2
500-550	0.4	1.2	1.9	1.0	-	8.7	-	69.1	-	10.9	6.8	2.3
550-600	0.7	1.4	1.9	3.5	0.8	25.4- 0	0-5.3	54.7-63.1	-	11.6	0-11.7	3.8- 0.3
600-650	1.7	1.4	2.8	7.5	1.5	31.2- 0	0-7.8	37.9-49.3	1.3-0	14.7	0-13.3	6.3- 5.4
650-700	0.9	1.0	18.9	13.0	7.5	10.0- 0	0-3.4	35.4-37.0	-	10.8	2.5- 7.5	12.3-11.7
700-710	0.8	0.8	24.2	24.2	13.5	6.6- 0	0-1.4	16.2-18.4	-	9.5	4.2- 7.2	16.5-15.0

1. Hornblende variant and Hornblende-Chlorite variant, respectively.

Table 19. Profile T2. Normative mineralogical composition of fine earth (equivalent percentages).

Horizon Depth (cm)	Cp Str	Ru	Ms	Al-bite	Epidote[1]	Horn-blende[1,2]	Smec-tite[2]	Chlorite[1,2]	Kaolinite[1,2]	Go	Silica[1,2]	Misc	Excess water[1,2]
A11	-	0.3	0.1	-	-	-	0.2	-	5.2	0.8	92.2	1.2	0.8
A12g	0.1	0.4	0.1	-	-	-	0.2	-	7.4	1.0	88.7	2.1	0.3
IIB1tg	-	0.4	0.5	-	-	-	1.0	-	22.4	2.1	71.8	1.8	1.5
80-150	0.1	0.3	0.3	-	-	-	0.2	-	25.1	2.3	71.7	-	0.1
150-200	0.1	0.4	0.4	-	-	-	0.4	-	29.8	3.0	65.9	-	1.9
200-250	-	0.8	0.3	-	-	-	-	0.4	60.9	8.3	29.3	-	1.7
250-300	0.2	0.6	0.6	-	-	-	0.7	0.8	40.4	5.4	51.3	-	1.2
300-350	-	0.9	0.6	-	-	-	0.6	1.3	58.2	8.0	30.4	-	5.5
350-400	-	1.2	1.2	1.0	0 - 0.5	0.9- 0	0.6	0.4- 1.0	67.2-66.7	10.2	17.3-17.6	-	3.8- 3.9
400-450	-	1.8	1.3	5.4	0.2- 3.7	6.5- 0	1.4	0 - 4.4	52.9-48.4	14.3	16.2-19.3	-	3.8- 4.4
450-500	0.2	1.5	2.0	13.7	4.5-14.8	19.5- 0	1.7	0 -12.9	30.5-17.6	11.4	15.0-24.2	-	2.6- 4.5
500-550	0.2	1.0	1.9	25.0	6.4-18.6	22.9- 0	0.7	0 -15.3	26.1-10.9	6.9	8.9-19.5	-	-0.3- 1.9
550-600	0.2	1.0	2.6	25.2	8.4-16.9	32.4-16.4	1.7-0	0 -11.0	14.3- 4.3	6.7	7.5-15.7	-	-0.6- 0.8
600-650	0.3	1.1	2.6	28.1	6.1-10.6	41.1-32.8	2.3-0	0 - 6.1	8.4- 3.6	5.8	3.4- 8.2	0.8	-2.1--1.4
650-700	0.6	0.8	2.4	38.7	16.1-19.5	18.9-12.5	0.5-0	0 - 4.4	5.8- 1.7	5.7	10.5-13.7	-	-2.9--2.2
700-710	0.6	0.5	1.5	41.3	14.3-18.6	8.4- 0.5	0.2-0	0 - 5.4	8.3- 2.9	3.7	21.2-25.0	-	-4.4--3.5

Cp= Ca-phosphate. Str= Strengite. Ru= Rutile and Anatase. Ms= Muscovite and Illite. Go= Goethite.
Misc= Miscellaneous.

1. Hornblende variant and Hornblende-Chlorite variant of the Epinorm, respectively (sand and silt).
2. Hornblende variant and Hornblende-Chlorite variant of the Goethite norm, respectively (clay).

Table 20. Profile T2. Normative mineralogical composition of parent rock (equivalent percentages).

	Ca-phosphate	Rutile Anatase	Microcline	Albite	Epidote	Hornblende	Magnetite	Silica	Misc.
IIR3	0.3	1.0	2.3	24.2	16.2	35.4	8.8	10.2	1.6

of iron individualizations or nodules (Appendix III). The nodules of Type 1 are almost opaque and have dark red colours. They harden on exposure to repeated wetting and drying and are considered plinthite. Within voids, illuviated clay is often present and sharply separated from the nodules. Hence, the nodules were formed before the cycle of lessivage (see 4.4).

The nodules of Type 2 have a cloudy and translucent appearance with colours ranging from yellow to red. These nodules are related to other iron-diffusion phenomena such as neoferrans and quasiferrans. Neoferrans were also observed around channels with fresh-looking root tissue. Therefore, this second cycle of gleyzation is probably related to the actual hydromorphic conditions.

4.5.4 Geochemistry of the ferrallization and the plinthization process

To study the mineral transformations reported in the preceding sections, the possible phases in the system K_2O-Na_2O-MgO-CaO-Al_2O_3-SiO_2-H_2O must be established and their stability relations studied. According to Helgeson et al. (1969) the following phases may occur in this system at 25 ^{o}C and 1 atm total pressure: microcline, muscovite, nepheline, low albite, chlorite, lawsonite, leonhardite, montmorillonite, kaolinite and gibbsite. Leonhardite has been taken as a substitute for zoisite of which the standard free energy of formation is still unknown. In solution K^+, Na^+, Mg^{2+}, Ca^{2+} and $H_4SiO_4{}^o$ may exist.

To delineate the stability of the various phases, the equilibria between the different minerals and the solution have to be established and their equilibrium constants calculated. With these data the stability fields of the various minerals can be represented in stability diagrams as a function of the activities of the cations and H_4SiO_4 in the soil solution. In these diagrams the upper limit of the dissolved silica is controlled by the solubility of the amorphous silica (Garrels & Christ, 1965; Helgeson et al., 1969).

For practical reasons the system under consideration is divided into a K_2O-Al_2O_3-SiO_2-H_2O system, a Na_2O-Al_2O_3-SiO_2-H_2O system, a MgO-Al_2O_3-SiO_2-H_2O system and a CaO-Al_2O_3-SiO_2-H_2O system. Stability diagrams of these systems at 25 ^{o}C and 1 atm are given in figs 40-43.

As appears from Fig. 40, the transition of K-feldspar into muscovite, kaolinite and gibbsite can be explained in terms of a decreasing silicic acid activity and a decreasing $\{K^+\}/\{H^+\}$ value in the soil solution. As silicic acid is released, an increase in silica can only be understood as residual.

The formation of smectites, kaolinite and gibbsite from Na-feldspar, chlorite

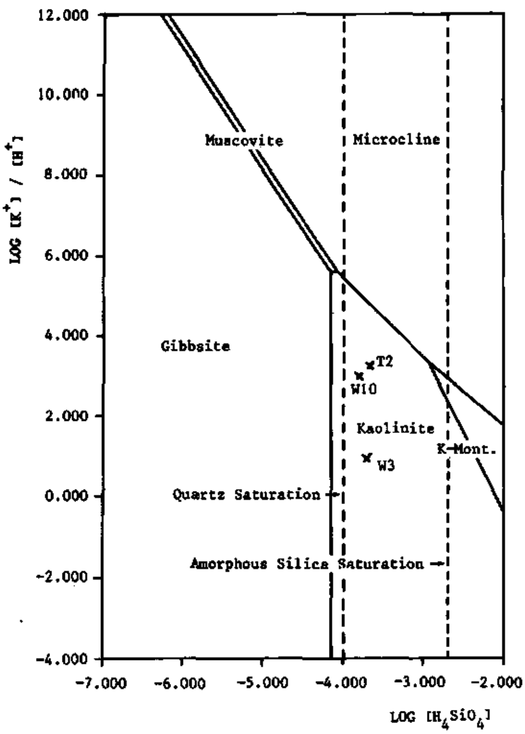


Fig. 40. Stability diagram of the $K_2O-Al_2O_3-SiO_2-H_2O$ system at 25 °C and 1 atm (from Helgeson et al., 1969).

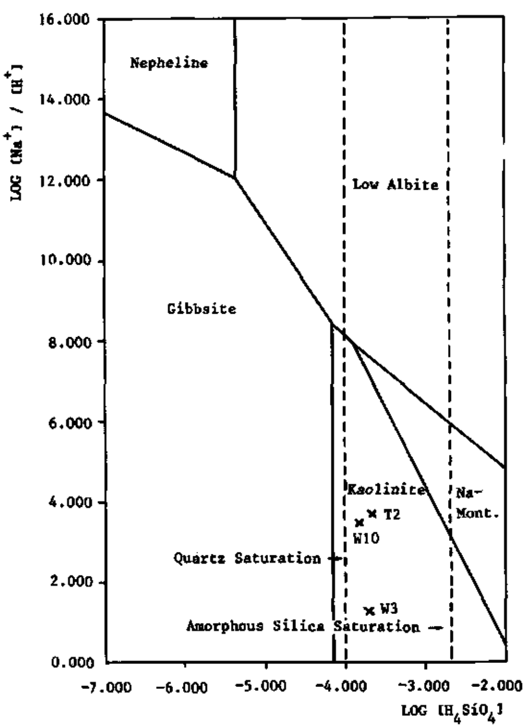


Fig. 41. Stability diagram of the $Na_2O-Al_2O_3-SiO_2-H_2O$ system at 25 °C and 1 atm (from Helgeson et al., 1969).

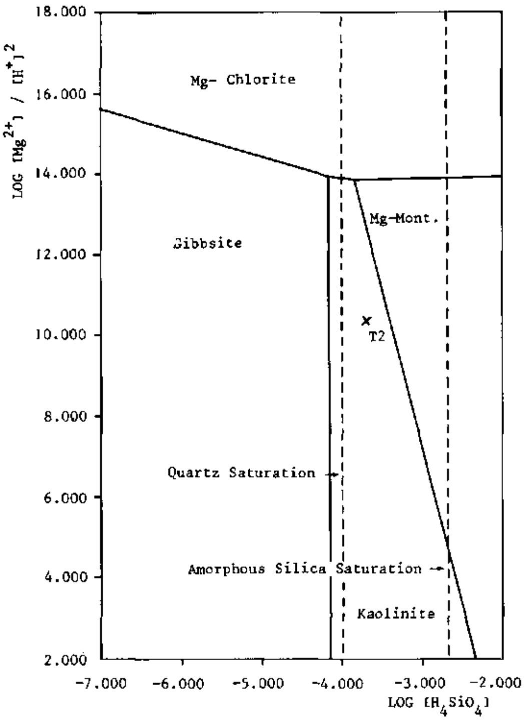


Fig. 42. Stability diagram of the $MgO-Al_2O_3-SiO_2-H_2O$ system at 25 °C and 1 atm (from Helgeson et al., 1969)

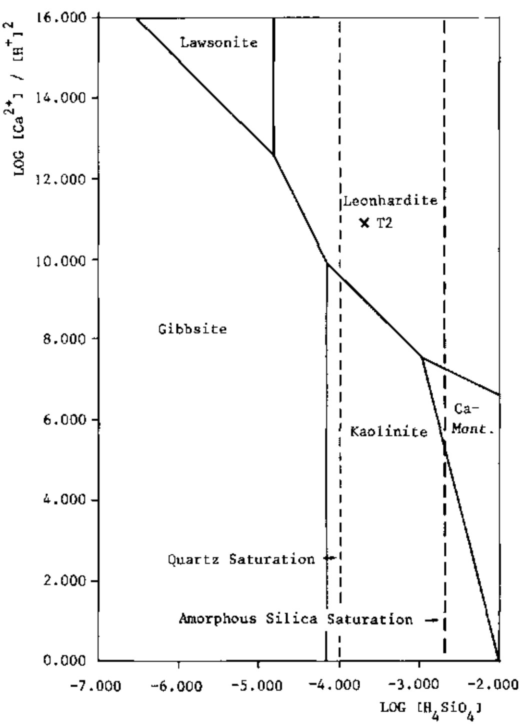


Fig. 43. Stability diagram of the $CaO-Al_2O_3-SiO_2-H_2O$ system at 25 °C and 1 atm (from Helgeson et al., 1969)

and leonhardite can equally be related to a decrease of the $\{Na^+\}/\{H^+\}$, the $\{Mg^{2+}\}/\{H^+\}^2$ and the $\{Ca^{2+}\}/\{H^+\}^2$ values, together with a decrease of the silicic acid activity. These phenomena are consistent with leaching of bases and silica during the ferrallization process.

Thus the nature of the soil solution determines the ultimate composition of the mineral assemblage. This depends on such factors as parent material, rainfall, permeability and drainage.

As can be seen from figs 40-43, chlorite is stable only at a high $\{Mg^{2+}\}/\{H^+\}^2$ value, while smectites are stable at high silicic acid activities. This corresponds to a rather concentrated soil solution or poorly drained conditions.

Muscovite is stable at a high $\{K^+\}/\{H^+\}$ value and moderately high silicic acid activities, so under conditions of moderate drainage. Kaolinite is stable at moderately high silicic acid activities and gibbsite is stable only at low silicic acid activities. This requires moderate to strong leaching.

In figs 40-43, the composition of three drain-water samples from eastern Surinam is indicated. These data are consistent with the high contents of kaolinite in many soils of the Marowijne area.

From figs 40-43 it can be inferred that quartz is not stable in the stability field of gibbsite. X-ray analysis, however, showed the co-existence of gibbsite and quartz in some clay separates of profiles W4 and B5. This means that the equilibrium situation has not yet been reached and that the quartz will eventually dissolve. Accordingly, thin-section analysis revealed many pitted quartz grains.

Plinthization

The plinthization process is essentially a dissolution and redistribution of sesquioxides. Therefore, it is of interest to study the stability relations of the various iron compounds in the soil and the soil solution as a function of the redox potential (Eh) and the pH.

As the soils under consideration have developed in parent materials which are very low in pyrite, the influence of sulphur on the Fe-H_2O-O_2 system will be neglected. Under these conditions the most important dissolved iron species are Fe^{2+}, Fe^{3+} and $FeOH^{2+}$ (Garrels & Christ, 1965). The stable solid species are magnetite (Fe_3O_4) and goethite (α-FeOOH) (Mohr et al., 1972). Amorphous ferric-ferrous hydroxide $\{Fe_3(OH)_8\}$, amorphous ferric hydroxide $\{Fe(OH)_3\}$ and lepidocrocite (γ-FeOOH) are unstable relative to magnetite and goethite, but they may occur as metastable phases in soils (Maignien, 1966; Mohr et al., 1972).

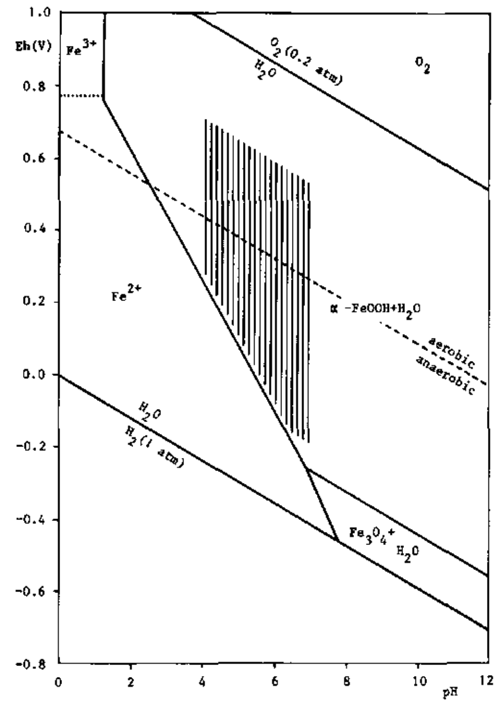


Fig. 44. Eh-pH diagram of stable iron species at 25 °C and 1 atm. Boundary between solids and ions at total activity of dissolved species = 10^{-5}.

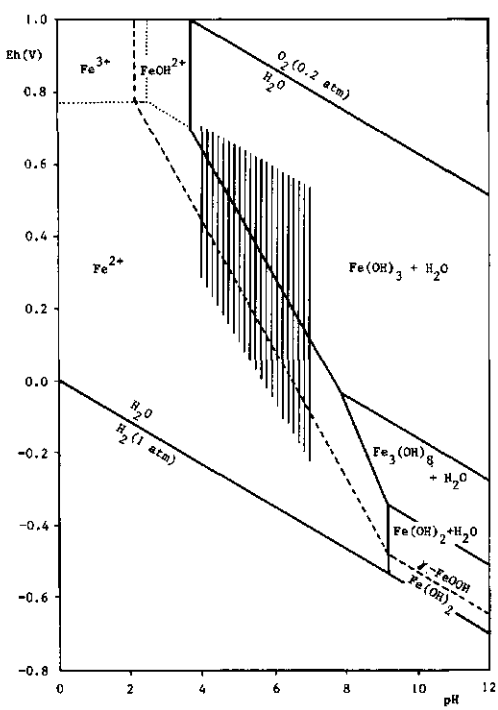


Fig. 45. Eh-pH diagram of metastable iron hydroxides at 25 °C and 1 atm. Boundary between solids and ions at total activity of dissolved species = 10^{-5}. Dotted lines are boundaries between fields dominated by the labelled ion. Dashed lines are limits of the stability field of γ-FeOOH.

With this knowledge two Eh-pH diagrams were drawn, one including the stable iron species and one including the metastable iron hydroxides (figs 44, 45). The procedure for the construction of such diagrams can be found in the book of Garrels & Christ (l.c.).

The stability fields of the various phases in figs 44 and 45 have been delineated at a total activity of dissolved species of 10^{-5}. This value has been chosen on the premise that, if the sum of the activities of known dissolved species in equilibrium with a solid is less than 10^{-5}, that solid will behave as an immobile constituent in its environment. This rule has been developed from experience and seems to correlate well with the observed behaviour of minerals (Mohr et al., 1972).

Furthermore, in figs 44 and 45, a vertically hatched field is drawn, indicating the variations in the Eh of natural aqueous environments for a range in pH from 4 to 7 (Baas Becking et al., 1960). This range includes the pH values observed in eastern Surinam.

As can be seen from Fig. 44, goethite has a large stability field and the Eh-pH range falls within the area of the solid species. This means that the mobility of iron can not be explained by a reduction of well-crystallized goethite. From the standard free energies of formation it can be calculated that a Fe^{2+} activity of 10^{-5}, in equilibrium with goethite at 25 °C and 1 atm total pressure, requires an Eh value of 0.27 V at pH 4 and of -0.27 V at pH 7. These values are physical irrealities in soils with a low organic matter content.

Fig. 45 shows that the stability fields of the amorphous iron species are much smaller than those of the stable phases. To explain the mobility of iron in the pH range observed, the redox equilibria must at least partly be governed by metastable hydroxides. In the Eh-pH field under discussion, $Fe_3(OH)_8$ will dissolve and large fluctuations in the redox potential will lead to a solution and redistribution of brown amorphous ferric hydroxide. Orange coloured lepidocrocite may equally be formed as an intermediate phase. This mineral is stable relative to ferric hydroxide but unstable relative to goethite at 25 °C and 1 atm. It may exist at lower redox potentials than those required for the precipitation of ferric hydroxide (Fig. 45).

In the presence of free water, the metastable phases eventually will crystallize into goethite. According to Garrels (1959) there is a continuous range from amorphous ferric hydroxide to well-crystallized goethite, as far as stability is concerned. Poorly crystallized forms of goethite may still be reduced at low redox potentials, but the well-crystallized mineral is immobile in soils (Fig. 44). This may explain the occurrence of prominent red mottles in Pleistocene soils which now lie in a zone of permanent reduction.

The occurrence of hematite in soils needs some further consideration. At 25 ^{o}C and 1 atm, hematite is in equilibrium with goethite at a water activity of 0.72, so at a relative humidity in the soil of 72%. This can be calculated from the standard free energy change of the hydration reaction of hematite.

The hydration of hematite is written as

$Fe_2O_3 + H_2O = 2\ \alpha\text{-}FeOOH$

hematite goethite

To calculate the equilibrium constant, the following relations have to be used

$$K = 1/\{H_2O\}$$

$$\lg K = -\Delta F^{o}_{r}/1.364 \quad \text{at 25 } ^{o}\text{C and 1 atm total pressure}$$

$$\Delta F^{o}_{r} = (\Sigma\Delta F^{o}_{f})_{products} - (\Sigma\Delta F^{o}_{f})_{reactants} \quad \text{(kcal/mol)}$$

where K is the thermodynamic equilibrium constant, ΔF^{o}_{r} the standard free energy change of the reaction, and ΔF^{o}_{f} the standard free energy of formation. In the present case

$$\Delta F^{o}_{r} = -2 \times 117.3 + 177.7 + 56.7 = -0.2 \text{ kcal/mol}$$

$$\lg K = 0.2/1.364 = 0.146$$

So that

$$\{H_2O\} = 0.72$$

Obviously hematite is stable only in concentrated salt solutions and under very dry conditions (pF >5.5). Its metastable occurrence in some soils of eastern Surinam (Profile W4) may be another indication of a drier climate in the past. The hydration of hematite must be a very slow process.

4.5.5 Micromorphology of the ferrallization process

The development of the plasmic fabric will now be considered with special reference to ferrallitic soils (Oxisols).

Asepic fabrics in eastern Surinam seem to be restricted to surface horizons; they usually intergrade to isotic fabrics which is most pronounced in umbric epipedons (Appendix III, IV). Contaminants, such as organic matter and iron hydroxides, may flocculate and stabilize the clay minerals, thus contributing to the low degree of anisotropy (Brewer, 1964). The asepic fabrics, however, can only partly be attributed to a masking by organic matter, as insepic fabrics were observed in the surface layers of hydromorphic soils. Therefore, the absence of plasma separations in these horizons is probably related to a high faunal activity. Bioturbation may have disturbed preferred orientation between domains, resulting in a disruption of previous orientation patterns. Furthermore, the dominant kaolinitic nature of the clay fraction prevents large effects of shrinking and swelling and the associated pressure orientation.

The plasmic fabric of oxic horizons in eastern Surinam is predominantly insepic. This fabric, however, is related to that of the surface horizons, as a relatively high proportion of the plasma occurs as unoriented domains. With depth the amount of equant to prolate domains that are mutually oriented increases and eventually a mosepic fabric may result. This tendency is correlated with a decreasing faunal activity as expressed by a decreasing bioporosity and a decline of recognizable faunal aggregates (4.2). Mosepic fabrics were also found in cambic horizons and in horizons indicating actual or fossile hydromorphism (plinthite).

Omnisepic fabrics in eastern Surinam seem to be restricted to rotten rock of both granitic and schistose origin.

Summarizing it is concluded that the omnisepic, mosepic and insepic fabrics considered have at least partly been inherited from the parent material. The original patterns of orientation may have resulted from crystallization of secondary minerals during ferrallization or from deposition from a suspension, if the clay minerals were in a peptized state (Minashina, 1958). These patterns are inconsistent with the phenomena due to clay illuviation and stress, described in 4.4.

The tendancies observed suggest a progressive reworking of orientation patterns by bioturbation, corresponding with a conversion of mosepic fabrics into insepic and asepic fabrics. This process, however, is hampered by hydromorphic conditions.

4.6 Podzolization

Podzolization results in the formation of podzols or spodosols.

With Andriesse (1969) a distinction has been made between humus podzols and iron podzols. In the first type, which commonly occurs in eastern Surinam, humus has accumulated, but iron is almost absent. The second type is characterized by an illuvial accumulation of iron, while humus accumulation is not detectable. Both units occur under hydromorphic conditions.

Two characteristic profiles were selected for a detailed study (Fig. 46).

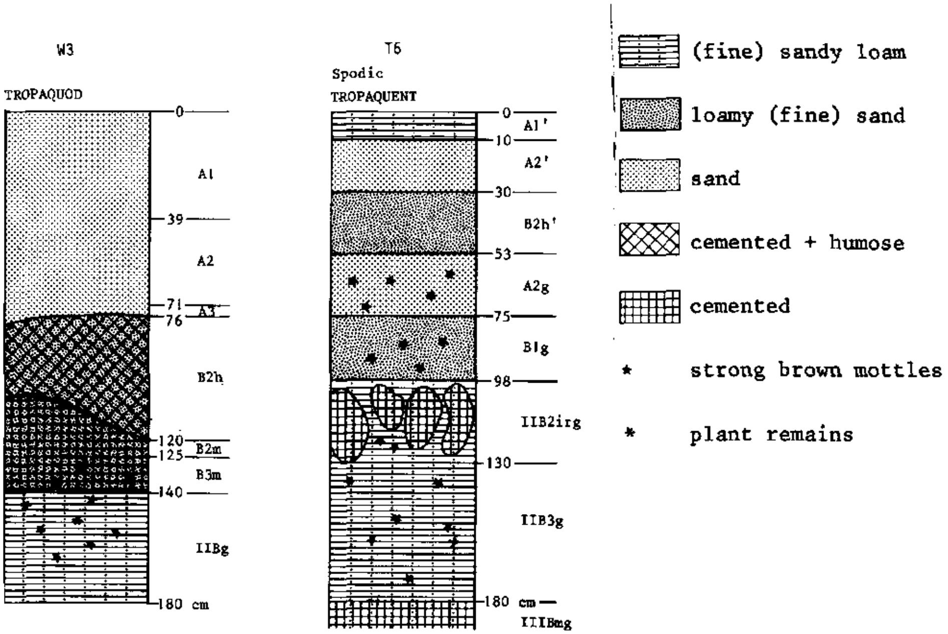


Fig. 46. Sketches of selected podzols.

4.6.1 The formation of a humus podzol (Profile W3)

Profile W3 consists of a humus podzol resting upon a buried B horizon. Analytical and mineralogical data are given in tables 21-25; a profile description and micromorphological characteristics are in Appendix III.

The oldest soil-forming process in the profile is an illuviation of clay. This can be seen from the presence of grain argillans in the hardpan (B2m) underlying the humus illuviation horizon (B2h). There is only a vague transition from the illuviation cutans to the groundmass, which points to a decomposition of the clay.

To study the mineral transformations, the normative mineralogical composition of the soil and the clay fraction were calculated from the chemical data (see van der Plas & van Schuylenborgh, 1970). Furthermore, a microprobe analysis of the plasma was carried out and expressed in terms of the Epinorm (Burri, 1964).

Iron was almost completely removed from the profile as shown by the very low iron contents of the soil relative to the nearby parent rock (tables 10, 22). Soluble iron chelates and ferrous iron must have been leached under reductive conditions.

In the B horizon, kaolinite was decomposed and silica was released, accompa-

Table 21. Quotient SiO_2/Al_2O_3 in humus podzols and the relation with plasmic fabric.

Profile	Horizon	Feature	SiO_2/Al_2O_3		Plasmic fabric
			w/w	mol/mol	
W3	B2h	organo-allophan	0.2	0.4	isotic (true isotropism)
	B2m	organo-allophan	0.3	0.5	isotic
	B3m	organo-allophan	0.4	0.8	isotic
	B2m	groundmass	0.5	0.9	undulic-isotic intergrade
	B3m	groundmass	0.7	1.1	undulic
L2	B2m	ferri-argillan	0.8	1.3	continuous orientation intergrading to undulic

nied by a neosynthesis of allophane-like products and an accumulation of aluminum hydroxide (Table 25). The intensity of the desilication process is clearly reflected in the SiO_2/Al_2O_3 quotients of the plasma which decrease from the bottom to the surface. This corresponds with a change in the plasmic fabric from undulic to isotic (Table 21; see also Veen & Maaskant, 1971).

Hence, in the B horizon, the clay was almost completely transformed into an aluminous gel, which flowed into the packing voids and other cavities between the sand grains. Removal of iron may have promoted this plasma flow due to lowered cohesion in ferri-argillans (van den Broek & van der Marel, 1968). This process could be responsible for the cementation and impermeability of the hardpan (Veen, 1970).

In the A horizon, kaolinite was also destructed, while aluminum hydroxides were leached at a low pH (Table 24). At the same time silica and titanium oxides were residually enriched.

Similar phenomena can be observed in other humus podzols of eastern Surinam,

Table 22. Profile W3. Analytical data on the fine earth.

Horizon	Texture				Org. C %	CEC mEq/100g clay	pH (1:2.5)		Free iron % Fe_2O_3
	gravel >2mm	sand 2mm-50μm	silt 50-2μm	clay <2μm			H_2O	$CaCl_2$ 0.01M	
A1	•	94.4	5.1	0.5	1.2	3.3	4.3	3.3	tr
A2	0.1	94.3	5.4	0.3	1.0	1.3	4.5	3.9	tr
A3	•	93.9	5.3	0.8	0.4	0.7	3.8	3.3	tr
B2h	•	78.6	20.1	1.3	15.5	1.3	4.4	3.7	tr
B2m	•	82.5	16.6	0.9	2.6	3.3	4.7	4.2	tr
B3m	•	82.7	16.7	0.6	0.8	0.7	5.2	5.1	tr
IIBg	0.3	48.6	47.4	4.0	0.8	1.3	5.2	4.6	tr

Table 23. Profile W3. Chemical composition of clay separates and fine earth (weight percentages) and the molar relation silica/sesquioxide.

Horizon	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5	H_2O[1]	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
Clay separates																
A1	61.8	5.2	3.0	0.2	0.1	0.6	-	tr	-	7.1	0.2	27.5	20.2	14.7	54	2.7
A2	27.3	6.2	4.3	0.4	0.1	-	-	tr	-	18.1	0.2	6.7	7.4	5.2	17	2.3
A3	48.4	11.2	3.5	0.4	0.1	-	-	tr	-	21.6	0.2	13.2	7.3	6.1	37	5.0
B2h	20.4	20.1	1.5	0.6	tr	0.2	-	tr	-	3.6	0.4	59.4	1.7	1.6	38	22
B2m	33.1	40.9	1.8	0.3	0.1	0.5	-	tr	-	4.4	-	29.7	1.4	1.3	50	36
B3m	28.5	38.5	1.6	0.2	tr	0.2	-	tr	-	5.6	0.2	21.0	1.2	1.2	47	38
IIBg	33.2	43.6	1.1	0.1	tr	-	tr	tr	0.1	1.6	0.2	19.2	1.3	1.3	79	61
Fine earth																
A1	98.2	0.3	0.1	.	-	-	-	tr	tr	0.2	-	2.3	606	511	3270	5.4
A2	99.9	0.2	0.1	.	-	-	-	tr	-	0.3	-	0.3	730	579	2779	3.8
A3	96.7	0.4	0.1	.	-	-	-	tr	tr	0.5	-	1.9	424	350	2013	4.7
B2h	41.8	14.2	0.2	.	tr	-	-	tr	tr	0.4	0.1	43.6	5.0	5.0	697	140
B2m	76.8	10.0	0.3	.	tr	-	-	0.1	-	0.8	0.1	11.8	13	13	609	47
B3m	82.4	8.8	0.3	.	tr	-	-	0.1	tr	0.9	0.1	7.2	16	16	807	51
IIBg	63.7	21.1	0.5	.	tr	-	-	0.1	tr	1.0	0.1	11.8	5.1	5.1	342	67

1. Data on chemically bound water in the clay fraction are considered unreliable.

Table 24. Profile W3. Goethite normative clay composition (equivalent percentages).

Horizon	Strengite	Rutile Anatase	Kaolinite	Gibbsite	Goethite	Silica	Misc.	Excess water
A1	-	6.8	13.8	-	2.9	71.3	5.2	109.4
A2	0.7	26.1	22.9	-	5.9	34.6	9.8	22.1
A3	0.4	20.0	29.7	-	3.1	40.6	6.2	35.3
B2h	0.7	5.5	81.5	7.5	1.9	-	2.9	351.1
B2m	-	3.7	72.9	17.4	4.1	-	1.9	44.4
B3m	0.1	5.3	70.7	21.5	1.5	-	0.9	18.5
IIBg	0.4	1.4	76.2	21.0	0.8	-	0.2	3.3

but the contrast between the oriented clay bodies and the groundmass is more pronounced. This means that the desilication process has advanced less, which is also expressed in a higher SiO_2/Al_2O_3 quotient of the oriented clay (Table 21: L2)

A later stage of soil formation is the illuviation of disperse organic matter which is found as cutans, sharply overlying the former argillans. A microprobe analysis and the derived normative mineralogical data (Table 25) suggest that these cutans are at least partly built up of allophane-like products. Therefore, the term organo-allophan is proposed. These data may point to a chemical binding of organic matter and allophane (van Schuylenborgh, pers. commun.), which also explains the large amounts of crystal water in the clay separates of the B2h horizon (Table 24).

The polycyclic soil formation in this profile can now be summarized as follows:

(1) lessivage

(2) leaching of ferrous iron and iron chelates

(3) decomposition of clay minerals and removal of aluminum hydroxides from

Table 25. Profile W3. Normative mineralogical plasma composition (equivalent percentages).

Horizon	Feature	Rutile Anatase	Muscovite	Kaolinite[1]	Allophane[1]	Gibbsite[1]	Goethite	Misc.[1]
B2h	organo-allophan	0.2	2.8	27.8-0	0-41.7	67.6-53.7	1.6	-
B2m	organo-allophan	0.1	1.4	36.0-0	0-54.0	61.4-43.4	0.8	0.3
B3m	organo-allophan	tr	2.1	52.4-0	0-78.6	45.4-19.2	0.1	-
B2m	groundmass	1.9	1.8	58.8-0	0-88.2	37.4- 8.0	0.1	-
B3m	groundmass	2.2	4.2	65.4-0	0-88.9	26.0- 0	1.1	0.5-3.6

1. Standard Epinorm and Allophane variant of the Epinorm, respectively.

the A horizon

(4) neosynthesis of allophane-like products

(5) migration and accumulation of disperse organic matter

A ^{14}C estimation of the B2h horizon showed an age of about 17 000 years (GrN 6107: 17 115 ±150 BP). Therefore, the podzolization process must have started already in Pleniglacial times.

Similar data on humus podzols in Surinam have been reported by Veen (1970) and Veen & Maaskant (1971). On the level ridges in the Old Coastal Plain, podzols were found with a thick, intensively bleached A2 and a cemented pan below the B2h. From the existence of organans overlying ferri-argillans it was concluded that a cycle of lessivage had preceded a cycle of podzolization. A break-down of ferri-argillans was deduced from a decrease in the SiO_2/Al_2O_3 quotients in the cutans from the s-matrix to the voids.

4.6.2 The formation of an iron podzol (Profile T6)

Profile T6 consists of an iron podzol, resting upon a buried Bm horizon. A sketch of the profile is given in Fig. 46; analytical and mineralogical data are presented in tables 26-29; a profile description and micromorphological characteristics can be found in Appendix III. The mechanical properties were discussed in 3.3.2.

Table 28 shows that in the A horizon kaolinite was decomposed, while silica was enriched residually. This tendency is most pronounced in the A2 horizon. The liberated alumina was removed, as evident from the trend in the SiO_2/Al_2O_3

Table 26. Profile T6. Analytical data on the fine earth.

Horizon	Texture				Org. C %	CEC mEq/100g clay	pH (1:2.5)		Free iron % Fe_2O_3
	gravel >2mm	sand 2mm-50μm	silt 50-2μm	clay <2μm			H_2O	$CaCl_2$ 0.01M	
A1'	-	71.4	24.9	3.7	5.1	4.7	4.8	3.8	0.4
A2'	-	90.9	8.3	0.8	0.2	0.7	4.8	4.1	0.1
B2h'	-	84.0	14.7	1.3	0.2	3.3	4.9	4.1	0.1
A2g	-	87.6	11.6	0.8	tr	3.3	5.0	4.7	0.1
B1g	-	78.5	12.1	9.4	tr	6.7	5.0	4.0	0.2
IIB2irg	-	70.4	12.8	16.8	tr	11.4	5.1	4.4	5.4
IIB31g	-	77.9	10.0	12.1	tr	11.4	5.1	4.1	0.2
IIB32g	-	74.5	10.8	14.7	tr	19.4	5.1	4.3	0.1
IIIBmg	-	78.8	13.5	7.7	0.2	19.4	5.4	4.6	0.2

Table 27. Profile T6. Chemical composition of clay separates and fine earth (weight percentages) and the molar relation silica/sesquioxide.

Horizon	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5	H_2O	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
Clay separates																
A1'	45.0	26.4	3.0	0.3	tr	tr	0.1	tr	0.1	2.1	0.1	21.8	2.9	2.7	39	14
A2'	45.3	31.9	3.3	0.1	tr	0.1	0.1	tr	-	2.4	0.2	14.4	2.4	2.3	38	16
B2h'	48.2	29.7	3.3	0.2	tr	tr	0.2	0.1	0.1	3.2	0.1	13.1	2.7	2.6	38	14
A2g	52.4	25.4	2.4	0.2	tr	-	0.2	0.1	tr	5.0	0.1	12.0	3.5	3.3	58	17
B1g	51.3	29.4	2.7	0.1	tr	-	0.1	0.1	tr	4.2	0.1	11.9	3.0	2.8	50	17
IIB2irg	41.0	31.0	8.7	0.2	tr	-	0.1	0.1	tr	2.2	0.6	14.3	2.2	1.9	13	5.6
IIB31g	47.0	33.8	2.9	0.1	tr	-	0.1	0.1	tr	3.0	0.1	13.0	2.3	2.2	43	18
IIB32g	46.0	34.5	2.1	0.1	tr	-	0.1	0.1	tr	2.6	0.1	13.4	2.3	2.2	59	26
IIIBmg	42.0	35.4	1.8	0.1	tr	-	0.1	0.1	tr	2.5	2.0	16.6	2.0	1.9	63	32
Fine earth																
A1'	87.1	1.6	0.6	0.1	-	tr	-	-	tr	0.4	tr	9.5	94	76	403	4.3
A2'	97.4	0.5	0.2	tr	-	-	-	-	-	0.1	-	0.7	345	284	1622	4.7
B2h'	95.9	0.9	0.3	-	-	-	-	-	-	0.1	tr	-	192	160	939	4.9
A2g	97.0	0.6	0.3	tr	-	-	-	-	-	0.1	-	0.3	269	197	734	2.7
B1g	91.4	3.3	0.6	tr	-	-	-	-	tr	0.5	-	1.7	47	42	390	8.2
IIB2irg	84.9	6.5	3.5	0.1	-	-	-	-	-	0.5	0.1	3.6	22	17	65	2.9
IIB31g	91.6	4.8	0.7	tr	-	-	-	-	-	0.5	-	2.0	32	30	347	11
IIB32g	91.4	5.4	0.6	tr	-	-	-	-	-	0.5	tr	2.3	29	27	380	13
IIIBmg	90.1	4.9	0.5	-	-	-	-	-	-	0.5	0.2	2.9	31	29	441	14

Table 28. Profile T6. Goethite normative clay composition (equivalent percentages).

Horizon	Strengite	Rutile Anatase	Smectite	Kaolinite	Goethite	Silica	Misc.	Excess water
A1'	0.2	1.9	5.1	74.1	2.7	15.1	0.9	49.7
A2'	0.3	2.1	2.5	84.6	2.7	7.6	0.2	9.4
B2h'	0.1	2.7	2.6	76.5	2.7	13.5	1.9	7.7
A2g	0.1	4.2	2.6	66.1	2.0	24.0	1.0	9.7
B1g	0.1	3.4	1.0	74.9	2.2	17.4	1.0	3.4
IIB2irg	1.1	1.9	2.6	82.7	7.1	3.6	1.0	6.1
IIB31g	0.1	2.4	1.0	86.1	2.3	7.1	1.0	1.6
IIB32g	0.1	2.1	1.0	89.1	1.7	5.0	1.0	2.8
IIIBmg	3.0	2.1	1.0	92.1	-	-	1.8	16.0

quotients of the clay. The increase of the SiO_2/Fe_2O_3 and the Al_2O_3/Fe_2O_3 quotients with depth demonstrate that iron was more mobile than the Si and Al bearing components of the clay.

Thin-section analysis showed that iron had accumulated in the B horizon in the form of normal void and free grain ferrans. In accordance with modern theories this can be explained by translocation of iron chelates followed by immobilization of the oxide (Mohr et al., 1972). The very low organic matter content in the B horizon indicates hydrolysis of the chelates and subsequent removal of the organic ligands (van Schuylenborgh & Bruggewert, 1965).

Micromorphological analysis also revealed the existence of iron diffusion phenomena, such as neoferrans and related nodules, below a depth of 50 cm. These neocutans are due to alternate reduction and oxidation resulting in a redistribution of iron (see 4.5.4).

The genesis of iron podzols is probably related to the nature of the parent material, as these podzols were only found in the environs of rocks rich in

Table 29. Profile T6. Normative mineralogical composition of fine earth (equivalent percentages).

Horizon	Strengite	Rutile Anatase	Smectite	Kaolinite	Goethite	Silica	Misc.	Excess water
A1'	tr	0.4	0.2	4.1	0.5	94.5	0.3	0.9
A2'	tr	tr	tr	1.1	0.1	98.8	-	0.4
B2h'	tr	0.1	tr	2.2	0.2	97.5	-	0.1
A2g	tr	0.1	tr	1.5	0.3	98.1	-	0.2
B1g	tr	0.4	0.1	8.3	0.5	90.6	0.1	1.6
IIB2irg	0.2	0.4	0.4	16.6	2.8	79.2	0.4	3.0
IIB31g	tr	0.4	0.1	12.2	0.5	86.7	0.1	0.7
IIB32g	tr	0.4	0.1	14.0	0.5	84.9	0.1	0.9
IIIBmg	0.2	0.4	0.1	12.1	0.3	86.8	0.1	2.8

hornblende (hornblende-diorites). The hornblende presumably forms the source of the iron hydroxides.

Similar phenomena have been reported from Serawak. In this area, iron podzols were only observed on parent materials with a high concentration of hornblende (Andriesse, 1969). On the other parent materials humus podzols had developed.

4.7 Soil formation as influenced by man

4.7.1 Terra Preta

In the Brazilian Amazon region, patches of so-called Terra Preta (TP) can be found. This soil is characterized by its black surface layer which often contains pieces of artifacts. According to Sombroek (1966) the Terra Preta is a kind of kitchen midden, developed at the dwelling sites of pre-Columbian Indians. It is famed locally for its fertility, which resulted from dung, household garbage and the refuse of hunting and fishing.

Patches of Terra Preta also occur in the Marowijne area, on both well and imperfectly drained soils of the E5 planation surface and the Tm river terrace. They are usually located near navigable waterways.

The influence of human occupation on Terra Preta can best be studied by comparing it with a nearby non-enriched soil. For this purpose, data on two Terra Preta and two reference profiles were collected.

Profile T3 is of the common light-textured variant, having about 20% silt + clay, whereas profile K4 is of the infrequently found heavy-textured variant, having about 40% silt + clay. The blackish surface layer reached to 55 cm in profile T3 and to 75 cm in profile K4. Both Terra Preta were situated at about 400 m from their counterparts (T2 and K5, respectively).

The profiles T3 and T2 were cultivated, while the profiles K4 and K5 were under rain forest.

Analytical and mineralogical data are given in tables 30-35; profile descriptions and micromorphological characteristics are in Appendix III.

Interpretation of the micromorphological data

As explained before, the cultivated soils in eastern Surinam can be distinguished from the non-cultivated soils by the presence of clay skins in the A as well as in the B horizon. Thus ferri-argillans were observed in the profiles T3, T2 and K4, but not in K5.

Comparative studies showed that the fine-textured Terra Preta (K4) is an extreme example of human influence. This is expressed in the percentage of illuviated clay (7%) which is by far the highest value observed in eastern Surinam. Secondly this can be deduced from a decay of the humus form and the microstructure, when compared with those of its counterpart. In the clay-humus complex of the Terra Preta, a significant amount of woody plant remains could be recognized. This humus form may be indicated as a heterogeneous mull, in contrast to the homogeneous mull in profile K5 (Jongerius, pers. commun.; Jongerius & Schelling, 1960).

So in the blackish layer, the bonds between the organic matter and the mineral particles were partly broken down. This was accompanied by a deliquescence of the soil mass and a reduction of the porosity, as evident from flow structures in the plasma. Planar voids developed and the granular structure was partly transformed into a subangular blocky structure. In the epipedon of the non-cultivated soil, neither flow structures, nor planar voids were present.

The micromorphological characteristics of the coarse-textured Terra Preta (T3) are similar to those of its counterpart (T2). The humus form is a homogeneous mull and the microstructure of the epipedon is spongy. For details see Appendix III.

Interpretation of the chemical data[1]

All profiles are kaolinitic in character. The composition of the clay fraction in the TP soils hardly differs from that in their counterparts (tables 30, 33).

In the TP soils, the carbon percentage is higher than in the unenriched soils, especially when cultivated: In profile T3 the organic matter content of the blackish layer is roughly three times as much as the average value for profile T2. In the soils under rain forest, this quotient is only 1.3.

In the Marowijne area, no significant differences in C/N values of the TP soils and their counterparts were observed. In the Amazon region, however, C/N values of TP soils were slightly higher, especially in the lower part of the blackish layer (Sombroek, 1966).

The cation-exchange capacity of the TP soils in eastern Surinam is not as

1. As the number of data presented is not sufficient for a statistical evaluation, differences will be considered significant at a 10% level. This is allowed, as the deviation of the chemical analyses generally is (much) smaller than 10% (van Schuylenborgh, pers. commun.).

high as in similar soils of Amazonia. In the latter, high T values in kaolinitic soils were correlated with relatively high amounts of total phosphorus. In the Marowijne area, no relationship seems to exist between the T value and the amount of P_2O_5 soluble in citric acid.

In the coarse-textured Terra Preta, the base saturation (V) is higher than in its counterpart, but values do not exceed 57%. The enrichment with metallic cations predominantly concerns Ca^{2+}. No such tendency can be observed in the fine-textured Terra Preta, where V is zero in the lower part of the epipedon. Therefore, the blackish colour can not be attributed to a complex formation of Ca^{2+} and organic matter, as suggested for Amazonia by Sombroek. In both TP soils, moderately high base saturation exists in the horizon immediately underlying the blackish layer (48-56%); in their counterparts, these values are only 4 to 5%. In TP soils of Amazonia, base saturations of 30-85% were observed and the exchange complex was dominated by Ca^{2+}.

The coarse-textured Terra Preta is less acid than its counterpart, which may be related to a difference in base saturation. In the soils under rain forest, differences in pH are not significant at a 10% level.

The Terra Preta of eastern Surinam may contain high amounts of phosphorus like that of Amazonia. In the coarse-textured Terra Preta, the amount of P_2O_5 soluble in citric acid is not higher than in its counterpart. In the blackish layer of profile K4, however, values range from 141 to 314 ppm, whereas values of 4-6 ppm were measured in the A horizon of profile K5.

The amount of K_2O extractable in 25% HCl is low in all profiles: values do not exceed 6 ppm.

Summarizing it is concluded that the profiles of Terra Preta considered are different from the non-enriched soils. In the former, which contain pieces of artifacts, the A horizon is darker and its carbon percentage higher. The base saturation is higher, either in the blackish layer, or in the B1 horizon, or in both. The enrichment with metallic cations concerns predominantly Ca^{2+}. In the blackish layer, the pH (T3) and the amount of P_2O_5 soluble in citric acid (K4) may be much higher than in the unenriched A horizons. Furthermore, the human influence may have resulted in a decay of the humus form and the microstructure (K4).

The A horizons of Terra Preta in eastern Surinam do not satisfy the requirements of the anthropic epipedon because base saturation or acid soluble P_2O_5 are too low. Hence, these epipedons are umbric (USDA, 1967).

Table 30. Profiles K4 and K5. Goethite normative clay composition (equivalent percentages).

Profile Horizon	Strengite	Rutile Anatase	Illite	Smectite	Kaolinite	Gibbsite	Goethite	Excess water
K4 A11	1.0	1.9	5.9	1.8	74.8	10.6	4.0	3.7
A12=B21t	1.4	1.7	4.8	1.8	75.8	10.4	4.1	2.6
B22t	1.0	1.5	3.9	1.4	78.6	9.4	4.2	5.1
K5 A1	0.6	1.8	5.9	1.8	74.8	10.4	4.7	4.6
B2h'	0.5	1.8	4.9	1.8	75.6	10.7	4.7	2.6
B1	0.6	1.7	4.9	1.4	77.0	9.7	4.7	6.0

Table 31. Profiles K4 and K5. Analytical data on the fine earth.

Profile Horizon	Texture					Organic matter			P-citr mg/100g	K-HCl25% mg/100g
	gravel >2mm	sand 2mm-50μm	silt 50-2μm	clay <2μm	nat. clay	%C	%N	C/N		
K4 A11	1.9	63.7	11.4	24.9	11.5	1.4	0.09	16	14.1	0.2
A12=B21t	2.7	54.3	12.0	33.7	20.0	0.9	0.06	14	31.4	0.2
B22t	1.1	40.3	9.2	50.5	1.0	0.3	0.02	17	11.3	0.3
B23t	1.0	40.3	10.5	49.2	0.5	·	·	·	3.7	·
K5 A1	1.6	47.5	10.3	42.2	23.0	1.0	0.06	17	0.6	0.4
B2h'	2.7	43.2	13.9	42.9	26.0	0.7	0.05	14	0.4	0.4
B1	1.7	34.7	10.0	55.3	-	0.4	0.04	11	0.3	0.6
B2	1.8	36.8	8.7	54.5	-	·	·	·	0.7	·

Table 32. Profiles K4 and K5. Cation-exchange characteristics of the fine earth.

Profile Horizon	Exchangeable cations (mEq/100g)					CEC mEq/100g	Base saturation %	pH (1:2.5)	
	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}			H_2O	$CaCl_2$ 0.01M
K4 A11	1.0	-	-	-	2.2	5.0	20	4.9	4.1
A12=B21t	-	-	-	-	2.1	5.1	0	4.8	4.1
B22t	2.7	-	-	-	1.8	4.4	56	4.9	4.0
B23t	0.2	-	-	-	·	3.5	6	5.1	4.2
K5 A1	2.7	-	-	-	2.8	5.5	49	4.5	3.9
B2h'	1.8	-	-	-	2.2	4.9	37	4.6	4.0
B1	0.2	-	-	-	2.0	3.7	5	4.9	4.0
B2	0.1	-	-	-	·	3.4	3	5.1	4.2

Table 33. Profiles T3 and T2. Goethite normative clay composition (equivalent percentages).

Profile Horizon	Strengite	Rutile Anatase	Illite	Smectite	Kaolinite	Goethite	Silica	Excess water
T3 A11	0.4	1.1	1.9	8.2	81.9	3.8	2.7	6.4
A12=B11t	0.4	1.1	1.9	5.2	83.6	4.5	3.3	4.0
B12tg	0.4	1.1	1.9	5.2	85.6	4.5	1.3	3.4
IIB21tg	0.4	0.9	1.9	5.2	85.2	6.2	0.2	3.0
T2 A11	0.1	1.0	1.4	3.0	86.5	3.7	4.3	6.8
A12g	1.3	1.0	1.5	3.0	86.7	4.2	2.3	5.4
IIB1tg	0.1	0.9	1.9	4.1	87.1	5.9	-	6.3
IIB21tg	0.4	0.9	1.4	1.0	89.7	5.9	0.7	4.6

Table 34. Profiles T3 and T2. Analytical data on the fine earth.

Profile horizon	Texture				Organic matter			P-citr mg/100g	K-HCl25% mg/100g	Free iron % Fe_2O_3
	gravel >2mm	sand 2mm–50μm	silt 50–2μm	clay <2μm	%C	%N	C/N			
T3 A11	1.1	81.2	11.1	7.7	1.5	0.09	17	0.6	-	.
A12=B11t	2.7	75.2	13.8	11.0	0.8	0.04	20	0.3	-	.
B12tg	7.3	73.3	13.0	13.7	0.2	-	.	0.2	-	.
IIB21tg	13.7	66.3	4.7	29.0	-	-	.	0.2	-	.
IIB22tg	16.8	67.7	6.8	25.5	-	-	.	.	-	.
T2 A11	-	80.6	12.0	7.4	0.4	0.03	13	0.9	-	0.3
A12g	2.1	84.0	8.4	7.6	0.4	-	.	0.4	-	0.5
IIB1tg	1.6	70.8	5.7	23.5	0.2	-	.	0.2	-	1.7
IIB21tg	2.7	70.8	5.6	23.6	0.2	-	.	0.2	-	2.4

Table 35. Profiles T3 and T2. Cation-exchange characteristics of the fine earth.

Profile Horizon	Exchangeable cations (mEq/100g)					CEC mEq/100g	Base saturation %	pH (1:2.5)	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}			H_2O	$CaCl_2$ 0.01M
T3 A11	1.2	0.5	-	-	0.3	3.0	57	6.2	5.2
A12=B11t	-	0.2	-	-	1.0	2.8	7	5.8	4.4
B12tg	0.8	0.2	-	-	0.5	2.1	48	5.2	4.4
IIB21tg	-	0.2	-	-	1.2	2.1	10	5.0	4.0
T2 A11	-	-	-	-	0.7	2.0	0	4.6	4.0
A12g	-	-	-	-	0.7	1.5	0	4.8	4.0
IIB1tg	-	0.1	-	-	1.3	2.4	4	4.5	3.9
IIB21tg	-	0.3	-	-	1.3	2.8	11	4.8	4.1

In the Marowijne area, other soils with umbric epipedons are present that do not contain artifacts (profiles A1, A4, A5). Apart from podzols, these soils are restricted to cultivated areas and they are considered Terra Preta as well.

The base saturation, the pH and the acid soluble P_2O_5 in these soils are of the same order as those in ochric epipedons, either cultivated or not (Appendix IV).

The origin of the black colours in the umbric epipedons is unknown. It may partly be due to finely dispersed charcoal, intimately mixed with the mineral fraction.

4.7.2 Other cultivated soils

The majority of cultivated soils in eastern Surinam has an ochric epipedon (Appendix IV). The humus form in these soils is a homogeneous mull and the microstructure shows the general trend described in 4.2. Micromorphologically, the presence of clay skins in the epipedon is the only general criterium to distinguish arable from non-arable soils (4.4).

Apart from Terra Preta, the chemical composition of the cultivated soils hardly differs from that of virgin soils. The carbon content of the loamy-textured arable soils, however, was found to be lower than in soils under rain forest. In some loamy soils, podzolization was evident from a decrease in the silica/sesquioxide quotients of the clay with depth. This process is not restricted to cultivated soils, but in these soils it is generally more pronounced (Profile A4).

4.8 Summary of the polycyclic soil formation in eastern Surinam

In the preceding sections, several indications for a polycyclic soil development have been discussed. At least four cycles of soil formation can be distinguished.

(1) The first cycle recognized is polycyclic in itself. It is represented by hard sesquioxidic nodules, derived from various planation surfaces (2.6.3). This material is usually reworked (4.5.1). Because of a lack of data no subdivision can be given.

(2) The second cycle included a gleyzation process. In the soils of the Tm river terrace and the E5 planation surface, nodules formed satisfying the definition of plinthite. These nodules may be present in horizons which now

lie above the zone of alternate reduction. The plinthite is often underlain by pallid zones situated above the present lowest groundwater level. This phenomenon can not be attributed to tectonic movements (3.4.2). Therefore, the groundwater level in this cycle reached higher levels than at present.
(3) The third cycle of soil formation started with an illuviation of clay in all soils which now lie outside the recent floodplain. The oriented clay bodies can still be recognized in the cracks of the nodules formed during the preceding cycle. In the third cycle the climate was probably drier than the present humid tropical one, which seems unfavourable for clay illuviation (4.4).
(4) The fourth cycle of soil formation was probably brought about by a change in climate to wetter conditions. In the well-drained soils, the clay skins almost completely disappeared as a result of bioturbation accompanied by ferrallization (4.4). Thus the textural B horizons were transformed into oxic horizons. Furthermore, the soils were continuously reworked by appauvrissement, which resulted in a significant removal of clay from the A horizons (4.3).

In the imperfectly drained soils, the clay skins were partly preserved and impregnated with iron during gleyzation (4.5.3).

In the poorly drained sandy soils, podzolization was active and the clay was transformed into an allophane-like gel (4.6.1).

Recently, cultivation of some well-drained soils has lead to a renewed process of lessivage (4.4). In some abandoned agricultural grounds the illuviation cutans were probably reworked by bioturbation after a regeneration of the rain forest.

A similar polycyclic soil development was recognized in the Old Coastal Plain of Surinam by Veen et al. (1971). A cycle of gleyzation was distinguished during a high seawater level, presumably during the Last Interglacial. This epoch was followed by a cycle of clay illuviation, which was related to a change in climate to drier conditions and a drop in sea level. This cycle would have occurred during some period of the Last Glacial. The next cycle of soil formation, was distinguished in the Holocene, when the climate had changed into the present humid tropical one. Ferrallization and bioturbation were active in the well-drained soils, while gleyzation and podzolization occurred under conditions of impeded drainage.

The dating of the pedogenetic cycles is still tentative. The pedorelicts of the first cycle(s) are probably of Tertiary to Mid Pleistocene age. The nodules of the second cycle were formed during and after the deposition of the Tm sediments when the river valleys were drowned (3.3.2). This cycle may very well be correlated with the epoch of high seawater level, when gleyzation was also active in the soils of the Old Coastal Plain. Therefore, the second cycle may be dated as Eemien. The clay illuviation of the third cycle presumably occurred during some period of the Last Glacial. This view is supported by a ^{14}C estimation of 17 000 years in a B2h horizon overlying a former textural B (4.6.1). The fourth cycle is probably of Upper Pleniglacial to Holocene age.

5 Soil classification

5.1 Properties of diagnostic horizons

For complete definitions of soil classification criteria one is referred to 'Soil Classification, 7th Approximation' (USDA, 1960-1967).

Some selected physico-chemical data on diagnostic horizons in the Marowijne area are given in Table 36. These data were mainly supplied by the Agricultural University of Wageningen and partly by ORSTOM, Cayenne. Variations due to different analytical techniques are included. Additional data on oxic and argillic horizons are in Table 37.

The oxic horizon of eastern Surinam seems identical to the latosolic B horizon of Amazonia. Detailed macromorphological and physico-chemical descriptions of the latter have been given by Sombroek (1966).

Argillic horizons are not frequent in eastern Surinam; they can only be recognized by micromorphological analysis (4.4). In a well-drained position, these horizons have developed in former oxic horizons due to human influences (4.7.1). Argillic horizons in an imperfectly drained position were only found in the sample area Tapatosso, invariably with plinthite (profiles T2 and T3). Similar phenomena have been reported from northern Surinam by Veen (1970).

Cambic horizons are restricted to relatively young soils. The presence of significant amounts of feldspars in the sand fraction is characteristic (Table 36). Silt/clay values are relatively high, exceeding 0.30 in most cases. Primary physicogenic structures predominate.

The cambic horizons largely consist of pre-weathered material, which probably has been derived from strongly weathered Pleistocene soils by appauvrissement (4.3). The feldspars must have been supplied by freshly eroded rocks which are exposed in the rivers in large quantities (3.2.6).

Data on spodic horizons in eastern Surinam are scarce. The occurrence of amorphous materials, composed of organic matter and alumina with high cation-exchange capacities and high water retention is characteristic (4.6.1).

Table 36. Physico-chemical properties of diagnostic horizons in eastern Surinam.

Org. C %	Nat. clay / Total clay x 100	Silt / Clay	Text.[2] quot. B/A	pH-H_2O	pH-$CaCl_2$ 0.01M	Base sat.	CEC clay[3] mEq/100g	Cation[3] retention clay mEq/100g	Feldspars 50-420µm	SiO_2/Al_2O_3 (mol/mol) clay	SiO_2/R_2O_3 (mol/mol) clay	Al_2O_3/Fe_2O_3 (mol/mol) clay
Ochric epipedon												
0.2- 6.7[1] (2.0) 32	26-94 (64) 10	.	.	3.8-6.0 (4.8) 23	3.8-5.4 (4.0) 23	0-49 (15) 19	.	.	.	.	.	.
Umbric epipedon												
0.7- 2.8 (1.1) 9	33-80 (54) 5	.	.	3.9-6.2 (4.9) 8	3.4-5.2 (4.1) 8	0-57 (15) 6	.	.	.	.	.	.
Spodic horizon												
2.6-15.5 (6.7) 4	.	.	.	3.8-4.8 (4.4) 4	.	1 (1) 2	65 -166 (115) 2	.	0 1	.	.	.
Cambic horizon												
0.4- 1.2 (0.5) 5	.	0.29-1.05 (0.54) 7	.	4.8-5.4 (5.1) 4	4.1-4.2 (4.1) 4	0-30 (9) 7	1.8- 16.0 (6.1) 7	1.8-6.1 (3.8) 4	3-35 (17) 5	1.8 (1.8) 2	1.4-1.5 (1.5) 2	6.5-10 (8.3) 2
Argillic horizon												
0.0- 0.9 (0.3) 5	.	0.16-0.36 (0.24) 5	1.8 1	4.5-5.0 (4.8) 5	3.9-4.1 (4.0) 5	0-56 (16) 5	7.2- 15.1 (10.5) 5	4.8-8.9 (6.5) 5	0-tr (0) 2	1.6-2.1 (1.9) 5	1.5-1.8 (1.7) 5	6.9-11 (8.7) 5
Oxic horizon												
0.2- 0.7 (0.3) 18	0- 2 (1) 13	0.06-0.31 (0.16) 19	1-2.7 (1.5) 11	4.4-5.7 (4.9) 15	3.9-4.6 (4.2) 15	0-11 (7) 11	2.7- 14.0 (7.3) 18	2.0-6.5 (4.6) 4	0- 2 (0) 8	1.6-1.9 (1.7) 9	1.3-1.6 (1.5) 9	6.7-14 (8.8) 9

1. Extremes, average and number of observations, respectively.
2. Textural quotient B/A = arithmetical mean of clay contents in subdivisions of B horizon (except B3), divided by arithmetical mean of clay contents in subdivisions of A horizon (cf. Sombroek, 1966).

Table 37. Macromorphological and micromorphological data on oxic and argillic horizons in eastern Surinam.

Oxic horizon	Argillic horizon
Present only in well-drained position.	Present both in well-drained and imperfectly drained position.
When the horizon is clayey, the structure is weak to moderate subangular blocky, or there is no macrostructure and the microstructure is spongy (Kubiena, 1938). It may also have a weak very fine and fine granular structure.	When the horizon is clayey and well-drained, the structure is weak subangular blocky and weak very fine granular, or there is no macrostructure and the microstructure is spongy.
When the horizon is loamy, the structure is weak to moderate very fine and fine granular, or there is no macrostructure and the microstructure is spongy. It may also have a weak subangular blocky structure.	When the horizon is loamy and imperfectly drained, there is no macrostructure and the microstructure is massive.
The porosity is relatively high. Mammillated vughs and interconnected vughs occupy some 30-50% by volume of thin section.	The porosity is lower than in the oxic horizon.
The consistence when moist is friable or very friable	The consistence when moist is firm, friable or very friable.
The transition from epipedon to oxic horizon is mostly gradual; subhorizon boundaries are diffuse.	The transition from epipedon to argillic horizon is clear or gradual; subhorizon boundaries are clear to diffuse.
There is less than 5% by volume that shows phantom structures or lithorelicts.	If the horizon is well-drained, there is less than 5% by volume that shows phantom structures. If the horizon is imperfectly drained, there are common to many phantom structures.
In soils under rain forest, there are no clay skins visible in thin sections. In cultivated soils, clay skins occupy less than 1% by volume of thin section.	Clay skins occupy 1 to 7% by volume of thin section.

5.2 Classification of the soils according to the 7th Approximation

5.2.1 Review of taxa

For complete definitions of taxa one is referred to Soil Classification, 7th Approximation (USDA, 1960-1967). Only soil properties regarded as most characteristic down to Group level and deviations from typic Subgroups are listed below. In this way the reader can easily check the classification and the taxa can be changed after a modification of the system. Furthermore, this review facilitates a comparison with other classification systems. All soils satisfy the criteria of the Tropic Great Groups (see 2.1).

Profile descriptions, analytical and micromorphological data of the soils classified are given in Appendix IV, which is available from the Laboratory of Soil Science, P.O.B. 37, Wageningen, the Netherlands.

The location and classification of some selected profiles has been indicated on the pedo-geomorphological maps (figs 47-49).

(1) Entisols

Mineral soils that have no diagnostic horizon other than an ochric epipedon, with or without an albic horizon.

Tropaquents

Tropaquents are Entisols that

- are saturated with water at some period of the year
- have gray colours associated with wetness within 50 cm from the surface, i.e. chromas are 1 or colours are due to uncoated grains of sand
- presumably have an N value <0.5 in some subhorizon between 20 and 50 cm

Spodic Stratic Tropaquents (Profile T6)

This taxon is restricted to sandy sediments of the Pm alluvial fans in the sample area Tapatosso. Immediately below the A1, there is an albic horizon underlain by another horizon having values >1 unit darker (7th Appr., 1967, p.82).

The presence of sedimentary stratification is expressed in the Subgroup Stratic.

Thapto Plinthaquoxic Tropaquents (Profile T2)

This unit was only observed in the sample area Tapatosso. It has developed in sediments of the Tm river terrace covering regolith of the E5 planation surface. The buried soil shows plinthite that forms a continuous phase from the buried surface downwards. Clay skins are present but in the topsoil the requirements of the argillic horizon are not met.

Troporthents

Troporthents are Entisols that

- have textures finer than loamy fine sand from a depth of 25 cm to more than 1 m
- have an organic matter content that decreases regularly with depth and that

reaches levels of 0.35% or less within a depth of 1.25 m
- are not permanently saturated with water and lack the characteristics associated with wetness as defined for Aquents
- presumably are not dry in some subhorizon between 18 and 50 cm for as much as 90 cumulative days in most years

Aquic Stratic Troporthents (Profile N2)

In the sample area Nason, those Troporthents of the Ph alluvial fans that are saturated with water during some period within 1.5 m from the surface are placed in this Subgroup. There is a marked sedimentary stratification. Petroplinthite or hard sesquioxidic nodules occur in large quantities, but are not diagnostic at Subgroup level.

(2) Inceptisols

Mineral soils that have qualities as discussed below, and that are assumed to be usually moist between 18 and 50 cm, and presumably have a conductivity of the saturation extract of <2 mmho/cm.

Tropaquepts

Tropaquepts are Inceptisols that
- are saturated with water at some period of the year and that have either an umbric epipedon and a mottled horizon with moist chromas of 2 or less immediately underlying the epipedon,
  or an ochric epipedon underlain by a cambic horizon with moist chromas of 2 or less at depths of <50 cm
- have <15% sodium saturation in the upper 50 cm
- presumably have an N value <0.5 in some layer between 20 and 50 cm
- have no plinthite

Stratic Tropaquepts (Profile K1)

These soils are frequent in the poorly drained parts of the recent floodplain. In the sample area Koele, they occupy the major part of the river valley. They have an ochric epipedon underlain by a cambic horizon as indicated above. Sedimentary stratification is apparent in the reference diagram.

Thapto Plinthaquoxic Tropaquepts (Profile T3: Terra Preta)

This Subgroup that has an umbric epipedon forms the counterpart of the Thapto Plinthaquoxic Tropaquents in the sample area Tapatosso. The difference is due to human influences as explained in 4.7.1.

Dystropepts

Other inceptisols that

- have either an umbric epipedon
  or an ochric epipedon and a cambic horizon
- have <50% base saturation in some part of the epipedon or cambic horizon

Aquoxic Stratic Dystropepts (Profile W1)

These soils are common in the imperfectly drained parts of the recent floodplain. There is an ochric epipedon and a cambic horizon, and mottles with chromas <2 occur within 1 m of the mineral surface. The cation-exchange capacity is <24 mEq/100 g clay in some subhorizon within a depth of 1 m. Sedimentary stratification is apparent in the reference diagram.

Oxic Stratic Dystropepts (Profile T1)

This Subgroup is restricted to well-drained levees of the recent floodplain. The soils have an ochric epipedon and a cambic horizon; in all horizons, the cation-exchange capacity is <24 mEq/100 g clay. Sedimentary stratification is often observable in the field. In the cultivated soils, clay skins are present in the A and B horizons, but the requirements of the argillic horizon are not met; the lessivage is due to shifting cultivation (4.4).

Umbriorthoxic Dystropepts (Profile A5: Terra Preta)

These soils were found here and there in sandy sediments of the Tm river terrace in the sample area Albina. The requirements of the Umbriorthox are met except for that of texture as the clay content is <15%.

(3) Spodosols

Mineral soils that have a spodic horizon.

Tropaquods

Tropaquods are Spodosols that

- are saturated with water at some period and have characteristics associated with wetness, such as
  mottling in the albic horizon
  or a moist colour value <4 in the upper part of the spodic horizon and medium mottles of iron in the materials immediately below the spodic horizon
- have no cemented albic horizon and no placic horizon

(Gross)arenic Tropaquods (profiles L2, W3)

This taxon is characteristic of the Pm alluvial fans. The sandy epipedon overlying the spodic horizon commonly has a thickness of 1-2 m (L2: Grossarenic) and less frequently of 75-100 cm (W3: Arenic). The soils have an umbric epipedon (W3) or one that would meet the requirements of an umbric epipedon if plowed to a depth of 25 cm (L2).

(4) Ultisols

Ultisols are mineral soils that
- have an argillic horizon and have base saturation (by sum of cations) of <35% at 1.25 m below the upper boundary of the argillic horizon
- may have an oxic horizon underlying the argillic horizon

Well-drained Ultisols in eastern Surinam are anthropogenic. They have resulted from shifting cultivation as explained in 4.4.

Palehumults

Palehumults are Ultisols that
- are never saturated with water
- have 1.5% or more organic matter in the upper 15 cm of the argillic horizon
- have more than 20 kg organic matter in a unit volume of 1 m^2 to a depth of 1 m below the base of any O horizon
- have an argillic horizon that in the upper 1 m has <10% weatherable minerals in the 20-200 μm fraction
- have such clay distribution that the percentage of clay does not decrease from its maximum amount by more than 20% of that maximum within 1.5 m from the soil surface

Orthoxic Palehumults (profiles A4, K4: Terra Preta)

These soils occupy isolated patches in actually or formerly inhabitated areas. Their cation-exchange capacity is <24 mEq/100 g clay and the cation retention is <12 mEq/100 g clay in the major part of the argillic horizon.

(5) Oxisols

Oxisols are mineral soils that
- have an oxic horizon at some depth within 2 m from the surface or plinthite that forms a continuous phase within 30 cm from the mineral surface
- have no argillic horizon overlying the oxic horizon

Oxisols are widely distributed in eastern Surinam and take up the majority of the freely drained soils outside the recent floodplain.

Orthox

Orthox are Oxisols that

- have no plinthite within 30 cm from the mineral surface and are never saturated with water
- presumably have no period when the soil is dry in any subhorizon below the surface 18 cm for 60 consecutive days or more in most years

Haplorthox

Haplorthox are Orthox that

- have a cation-retention capacity of >1 mEq/100 g clay in all subhorizons of the oxic horizon
- have no sheets of gibbsite or gravel-size aggregates cemented by gibbsite
- have an ochric epipedon and <1% organic carbon in some subhorizon that is within 75 cm from the mineral surface
- have base saturation of <35% in some subhorizon of the oxic horizon within 1.25 m from the mineral surface

Typic Haplorthox (profiles W4, B5, G3, K5, W6)

This Subgroup forms the modal Oxisol under rain forest in eastern Surinam.

Tropeptic Haplorthox (Profile W10, B1)

These soils have developed in fine-textured basin sediments of the Tm river terrace. The oxic horizon has a weak to moderate subangular blocky structure. Plinthite occurs at a depth below 1.25 m.

Plinthic Tropeptic Stratic Haplorthox (Profile A6)

This taxon was observed in fine-textured basin sediments of the Tm terrace. The oxic horizon has a weak subangular blocky structure and does not extend to 1.25 m below the surface. Plinthite occurs within a depth of 1.25 m and sedimentary stratification is present in the solum.

Umbriorthox

Umbriorthox are Orthox that have an umbric epipedon but further meet the requirements of the Haplorthox. In these soils, the umbric epipedon is anthropogenic (4.7.1).

Typic Umbriorthox (Profile A1)

This Subgroup was found in loamy-skeletal sediments of the Albina hills. Clay skins are present in the oxic horizon, but occupy <1% by volume of the thin section. Petroplinthite occurs in large amounts.

5.2.2 Discussion

The classification of Oxisols lags behind that of other orders of mineral soils and probably will be modified in the near future. The division of highly weathered soils rich in secondary oxides of iron, aluminum, or both (laterites in the sense of Alexander & Cady, 1962) is not elaborated. Gibbsi Great Groups have been defined but hardened ferruginous materials have been considered only at family level.

Some suggestions to introduce all lateritic materials into the classification system have been made by Sys (1968). He proposed the new term petroplinthite and two new diagnostic horizons: the plinthic and the petroplinthic horizon.

The term petroplinthite is used for iron or aluminum individualisations which have hardened irreversibly. When moist, it can not be cut with a spade and it appears as hard concretions in a clayey matrix or as a crust or sheet.

A plinthic horizon is a mineral soil horizon, at least 15 cm thick, in which the plinthite (as defined in the 7th Approximation, 1967) constitutes more than 25% by volume of the soil mass.

A petroplinthic horizon is a mineral soil horizon, at least 10 cm thick, where the petroplinthite forms a continuous phase, or at least 20 cm thick where the petroplinthite is characterized by hard concretions in a kaolinitic matrix. In the latter case it constitutes more than 25% by volume of the soil mass.

Plinthic and petroplinthic horizons are considered diagnostic at Great Group level when occurring within a depth of 1.25 m and 1.50 m, respectively. The plinthic horizon characterizes Plinthic Groups; the petroplinthic horizon is most likely an indication for old pedological features and is typical for Pale Groups.

In the 7th Approximation, the argillic horizon is diagnostic at a high categoric level only because this has produced groupings of soils with the largest number of common properties (USDA, 1967, p.12). Hence, the distinction at order level of soils with an argillic horizon from those with an oxic horizon is useful when this difference is correlated with differences in many other soil properties.

In Brazil, soils with a textural B horizon usually differ from Oxisols by structure, porosity, consistence, natural clay content, silica/sesquioxide quotients, CEC values and amount of weatherable minerals (Sombroek, 1966; Bennema, 1966; Bennema et al., 1970).

In eastern Surinam, however, argillic horizons are not indicative of soils that are less weathered than Oxisols (Table 36). Many transitions from oxic horizons without clay skins (Profile K5) to oxic horizons that have changed into argillic horizons (Profile K4) can be found. These data counter the distinction of argillic horizons at order level in these soils. Therefore, in accordance with the principles of the 7th Approximation, it is proposed here to distinguish Argi Great Groups when clay skins occupy more than 1% by volume of thin section (Argiorthox) and Ultic Subgroups when the percentage is between 0.3 and 1% (Ultic Haplorthox, Ultic Umbriorthox, etc.). A percentage lower than 0.3% is equalized to zero.

The determination of the percentage of illuviated clay needs some further consideration. Oxic horizons should not have any subhorizon with as much as 1% of clay skins if the other features of an argillic horizon are present (USDA, 1967, p.31). This value is not unambiguous, since neither the number of points to be counted nor the reliability of the results is taken into account. It was found that the counting result, using for instance 800 points and 95% reliability, should be >1.9% to be sure that on repetition of the counting a value of more than 1% is determined (van der Plas & Tobi, 1965). Therefore, the 1% value of the 7th Approximation should be considered the minimum value of the range around the percentage counted, as determined by the standard deviation (see also Miedema & Slager, 1972).

In summary, the Oxisols of eastern Surinam are no typical Oxisols like those of Brazil. In the former, clay is mobile under specific circumstances, i.e. after a clearing of the rain forest and possibly under savanna (4.4). In the modal Oxisols of Brazil, however, no clay illuviation occurs, not even with a pronounced dry season in the 'cerrado' (Bennema, pers. commun.; Bennema et al., 1970).

5.3 Classification of the soils according to the French system

5.3.1 Review of taxa

For complete descriptions of taxa one is referred to Classification des sols (CPCS, 1967). Only some characteristic properties of soils in the Marowijne area will be mentioned below; 'sous-groupes' will not be discussed.

(1) Sols podzolisés

The concept of the 'sols podzolisés' is closely related to that of the

Spodosols of the 7th Approximation. Diagnostic criteria, dealing with the characteristics of the B horizon, however, are different.

Sols podzolisés hydromorphes

This 'sous-classe', in which hydromorphism is diagnostic, includes the Aquods of the 7th Approximation. The 'groupe' of the 'Podzols à gley' is the only one observed in eastern Surinam. The concept of this 'groupe' is broader than that of the Tropaquods as it is not restricted to tropical regions.

(2) Sols ferrallitiques

The 'Sols ferrallitiques' are related to the Oxisols of the 7th Approximation. The Aquox, however, fall outside this 'classe'. Furthermore, the 'Sols ferrallitiques' may include some soils with an argillic or with a cambic horizon. Criteria for subdivision at lower levels strongly differ in both systems.

Sols ferrallitiques fortement désaturés (en B)

This 'sous-classe' includes all well-drained soils of eastern Surinam. They are characterized by an amount of exchangeable bases <1mEq/100 g soil, by a base saturation <20% and by a pH-H_2O <5.5. As a rule the pH of the A horizon is lower than that of the B horizon. The following subdivision into 'groupes' has been made:

Groupe typique

This taxon forms the central concept of the 'sous-classe'. Processes used to define other 'groupes' do not interfere within the critical limits discussed below.

Groupe appauvrie

In these soils clay (and iron) have disappeared from the A horizon but have not accumulated in the B horizon of the same profile. The textural quotient B/A is 1.4 or more.

Groupe remaniée

In this 'groupe' new soil material has been brought into the upper part of the profile which is as much weathered as the original lower part of the solum in situ. Textures of A and B horizons are hardly different and a stone line is often present in the solum.

Groupe rajeunie ou pénévoluée

In these soils weathering has not yet reached completion because of a relatively short time of soil formation, or the less weathered substratum occurs at a relatively shallow depth due to erosion.

Groupe lessivée

In this 'groupe' clay (and iron) have migrated from the A horizon to the upper part of the B horizon. The textural quotient B/A is 1.4 or more and clay skins are visible in channels and pores and seldom around peds.

(3) Sols hydromorphes

The concept of the 'Sols hydromorphes' has no equivalent in the 7th Approximation. In this 'classe' hydromorphism is sufficiently marked to affect the majority of the soil profile and to constitute the essential element of pedogenesis (CPCS, 1967). In other cases hydromorphism may be diagnostic at 'sous-classe', 'groupe', or 'sous-groupe' level in different 'classes'.

Sols hydromorphes mineraux

This taxon has less than 8% organic matter over a depth of 20 cm; as a rule the content of organic matter is below 4.5%. Hydromorphism appears within a depth of 1 m, either in the form of mottles, indicating reduction or reoxidation after reduction, or as a redistribution of iron or manganese components soluble under reductive conditions.

In the 7th Approximation, these characteristics may be diagnostic at Suborder or Subgroup level in different Orders.

The following 'groupes' have been distinguished in eastern Surinam:

Groupe des sols hydromorphes mineraux à gley

In these soils the groundwater table is oscillating at a shallow depth; gray colours with chromas of 2 or less dominate within a depth of 1.30 m.

Groupe des sols hydromorphes mineraux à pseudogley

This taxon has characteristics associated with wetness due to a lack of infiltration. Water is periodically stagnating in the solum. Gray colours alternate with ochreous and rusty tints from the base of the A1 or the top of the A2 horizon.

Some objections against this classification can be made. As a rule, the taxa are not well-defined as there are too few boundary criteria. A proper classification, therefore, may be difficult, especially when soil qualities are involved which are diagnostic at different levels of classification. In the 'Sols ferrallitiques', for example, the processes used to define the 'groupes appauvries', 'remaniées', 'rajeunies', 'pénévoluées' and 'lessivées' are not mutually exclusive and a distinction at 'groupe' or 'sous-groupe' level is often a matter of taste.

Furthermore, most of the ferrallitic soils are polygenetic and even detailed studies do not always guarantee a proper reconstruction of pedogenesis. The classification of these soils should be based on well-defined measurable characteristics without direct genetic implications. The genetic classification of ferrallitic soils is hazardous and unsatisfactory as will be demonstrated below.

5.3.2 A comparison of soils in eastern Surinam and French Guiana

In the French part of the Marowijne area, soil reconnaissances were carried out by Brugière & Marius (1966) and by Marius & Misset (1968). In these studies soil profiles on different parent rocks were investigated for classification purposes. Two 'classes' have been distinguished: the 'Sols ferrallitiques' and the 'Sols hydromorphes'. Only the 'sous-classes Sols ferrallitiques fortement désaturés' and 'Sols hydromorphes mineraux' have been observed. In this section the latter will not be considered.

A typical characteristic of the ferrallitic soils in French Guiana is the shallow depth of the solum in contrast to the considerable thickness of the C horizon, which may exceed 20 m. This would result from a slow and continuous erosion of the surface layers (Brugière & Marius, 1966) and the process is diagnostic at 'sous-groupe' level ('sous-groupe faiblement rajeunie').

The C horizon is relatively rich in silt and would generally be reached within a depth of 1.5 m (Marius & Misset, 1968). The transition between the B and the C horizon would often be abrupt.

Another characteristic of these soils is the fact that the A horizon is usually lighter in texture than the B1 and B2 horizons. The textural quotient B/A varies between 1.0 and 3.8 (average 1.5). According to Brugière & Marius, this might suggest an absolute accumulation of clay in the B horizon. The difference in texture may, however, be due to other causes than lessivage and this process was not considered diagnostic at 'groupe' level. Marius & Misset, on the contrary, did describe a 'groupe lessivée', but no proof of lessivage was given. Profile descriptions were not elaborated and clay skins were not mentioned.

According to Marius & Misset, the 'groupe typique' is dominant in soils on granitic rocks and the 'groupe remaniée' concerns soils on schists. The 'groupe appauvrie' was observed in sandy soils on granitic rocks with a relatively deep solum.

Some remarks on this classification have to be made. The existence of a 'groupe lessivée' in virgin soils is doubtful. A study of 100 thin sections from soils on various parent materials in the Marowijne area showed hardly any clay skins in well-drained virgin soils (4.4). A clay peak in the B horizon is in itself no proof of lessivage but may be due to a lithologic discontinuity or to differential weathering. The soils under consideration with a textural quotient B/A >1.4 can better be classified as 'appauvris' than as lessivés' (4.3). In soils on schists, the effect of 'remaniement' can clearly be recognized by the presence of stone lines. In soils on granite, these stone lines may occur as well (Profile W4), but sometimes they are absent. This phenomenon is probably related to the content of sesquioxides in the parent rock which is generally lower in granitic rocks than in metamorphic rocks. Soils that have no concretions may have been subjected to colluviation or 'remaniement' as well when the parent rock did not produce such concretions. With these facts in mind it is probable that many 'Sols ferrallitiques ... typiques' are actually 'remaniés'. Detailed granulometrical and chemical studies are necessary for a definite interpretation.

These considerations once more support the opinion that a genetic classification of ferrallitic soils should be rejected.

Table 38[1] Data on B horizons of 'Sols ferrallitiques' in French Guiana and eastern Surinam.

French Guiana (Brugière & Marius, 1966)		Eastern Surinam (this study)
CEC fine earth (mEq/100 g)[2]	< 7.5	< 4.5
CEC clay (mEq/100 g)[2]	5.2-16	1.8-16
Base saturation	1 - 7	usually <20
Σ exchangeable bases (mEq/100 g)	< 0.5	< 0.9
Σ total bases (mEq/100 g)	2.3- 7.3	3.4-12.7
pH-H_2O	4.5- 5.3	4.4- 5.7
SiO_2/Al_2O_3 volcanic and basic rocks	0.1- 1.8	.
SiO_2/Al_2O_3 acid rocks	1.5- 1.9	1.6- 2.1
SiO_2/R_2O_3 volcanic and basic rocks	0.1- 1.7	.
SiO_2/R_2O_3 acid rocks	1.3- 1.7	1.3- 1.8

1. Includes differences due to analytical techniques.
2. Not corrected for organic matter.

The data presented by Brugière & Marius (1966) and Marius & Misset (1968) are insufficient to test the criteria of the diagnostic horizons of the 7th Approximation. The soils described, however, are very similar to those of eastern Surinam, as shown in Table 38.

The available data suggest that most soils of the Precambrian Shield of the Marowijne area are Oxisols, mainly belonging to the Great Group of the Haplorthox.

5.4 Classification of the soils by the Brazilian system as applied in Amazonia

Data on soils of the Brazilian Amazon region have been presented by Sombroek (1966). The classification system followed is that applied until 1960 in the USA as revised by Thorp & 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 (Camargo & Bennema, 1962). The levels of classification are those of the Great Soil Group, its Subgroups and Phases of these.

In eastern Surinam the following units can be observed:

(1) Latosols

Latosols are soils with a Latosolic B horizon corresponding with the oxic horizon of eastern Surinam. The division into Groups is based on the SiO_2/Al_2O_3 quotient of the clay fraction and Subgroups have been distinguished on base of the Al_2O_3/Fe_2O_3 quotient (mol/mol)[1].

For this study only the Kaolinitic Latosols are of interest. These soils have high percentages of silicate clay minerals, expressed in SiO_2/Al_2O_3 values of 1.6-2.0.

In the Marowijne area, the following Subgroups are of interest:

Kaolinitic Latosols having intermediate percentages of iron clay minerals (Al_2O_3/Fe_2O_3 4.0 ca.: Profile W4)

1. The SiO_2/Al_2O_3 and Al_2O_3/Fe_2O_3 values were actually determined on the fine earth with the sulphuric acid destruction. As a rule this would give the same results as the internationally used determination on the clay fraction (Sombroek, 1966).

Kaolinitic Latosols having low percentages of iron clay minerals (Al_2O_3/Fe_2O_3 >4.6)

This unit includes the main Amazon Latosol and is widely distributed in Pleistocene and Tertiary terraces of Amazonia. The Haplorthox of eastern Surinam also belong to this unit (Profile W4 excepted). Comparative studies revealed that the properties of these soils are very similar over large distances. This similarity applies to both the field characteristics and the analytical data (cf. Sombroek, 1966 and Appendix III, IV of this study).

In the Marowijne area, only the following Subgroup after Sombroek was observed:

Kaolinitic Yellow Latosols

This Subgroup comprises deeply and strongly weathered soils, well-drained and permeable, predominantly with colours of yellowish hue. The soils are strongly or extremely acid , and have a base saturation below 40%.

The profiles are well-developed, showing ABC sequence of horizons; the boundaries between these horizons are gradual to diffuse. Clay-sized particles consist predominantly of kaolinite. The soils have a rather weak macrostructure, at least in the subsurface horizon. When dry they are slightly hard or hard. The B horizon is generally slightly finer in texture than the A horizon, and the amount of clay-sized particles in the B is above 15%.

(2) Groundwater Laterite Soils

These soils are imperfectly drained and highly weathered. They have a light coloured and usually coarse-textured A2 horizon. The B horizon is made up of dense, more or less clayey material with abundant, coarse, prominent mottles of red and yellow in a white or light gray matrix (plinthite). The base saturation is low and the silicate clay minerals consist predominantly of kaolinite.

In eastern Surinam, those soils that have been classified as Thapto Plinthaquoxic Tropaquents may fall into this Group (Profile T2).

(3) Groundwater Humus Podzols

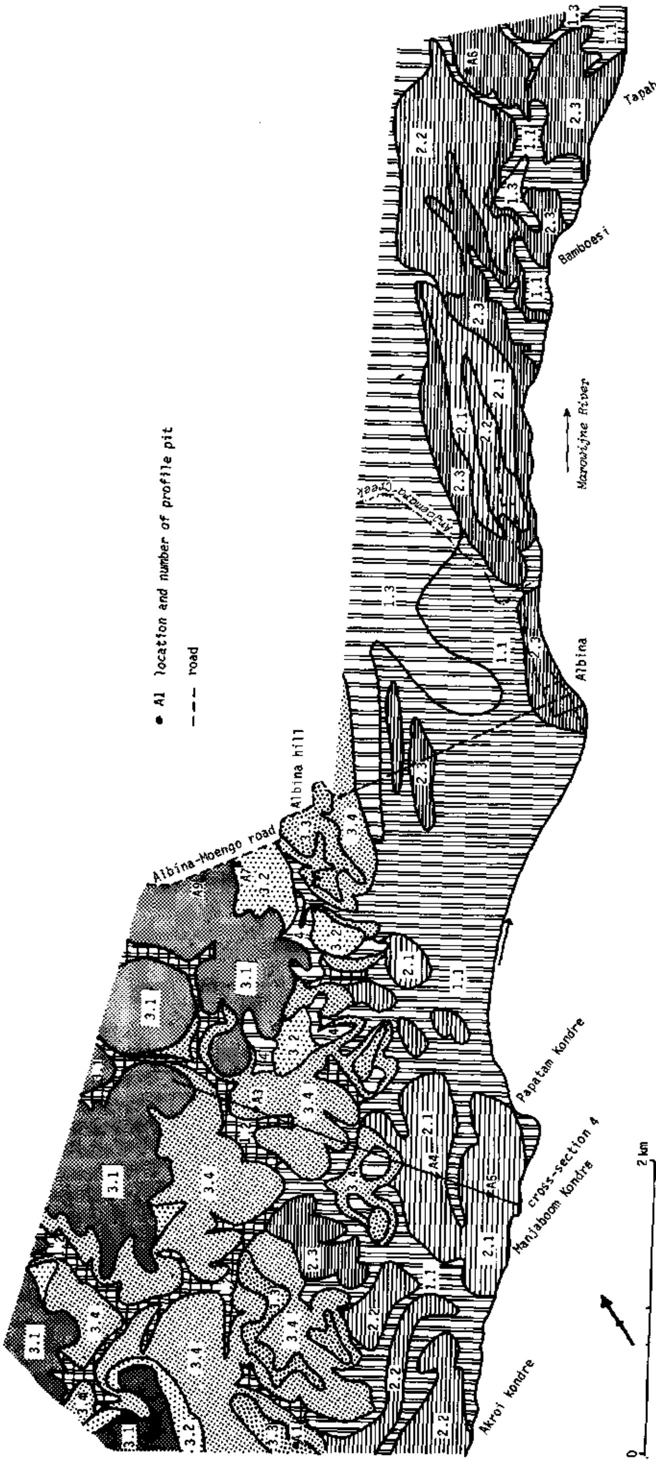
The groundwater humus podzols of Amazonia are probably similar to the Tropaquods of eastern Surinam (profiles W3, L2).

(4) Low Humic Gley Soils

These soils are poorly drained soils of recent non-marine sediments. They seem to be identical to the Tropaquepts and Dystropepts of eastern Surinam. Those soils having abundant, prominent, red mottles in a B horizon with low chromas are probably intergrades to the groundwater laterite soils (Profile W1: Aquoxic Stratic Dystropept)

(5) Terra Preta

Terra Preta is characterized by the presence of a thick, black or dark gray surface layer which often contains pieces of artifacts. These soils are 'old' arable soils which developed at the dwelling sites of Amerindians (see 4.7.1). The Palehumults and Umbriorthox of eastern Surinam belong to this Group.



• A1 location and number of profile pit
– – – road
Albina-Moengo road
Albina hill
Albina
Bamboesi
Tapahoekoe
Marowijne River
Papatam Kondre
Manjaboom Kondre
Akroi kondre
cross-section 4
0
2 km

Fig. 47. Pedo-geomorphological map of the sample area Albina.

1 Soils of the recent floodplain (F)

- 1.1 Clayey over peaty floodplain soils
  poorly drained, gray, strong brown mottled clay on peat soils
- 1.2 Loamy floodplain soils
  poorly drained, gray, strong brown mottled sandy clay loam soils
- 1.3 Peaty floodplain soils
  very poorly drained, dark gray peaty clay soils

2 Soils of the medium-level river terrace (Tm)

sandy and loamy levee and basin soils

- 2.1 well-drained, (strong) brown sandy loam and loamy sand soils
  Profile A4: Orthoxic Palehumult (Terra Preta)
  Profile A5: Umbriorthoxic Dystropept (Terra Preta)
- 2.2 well-drained, (yellowish) brown sandy clay loam soils
- 2.3 well to moderately well drained, (yellowish) brown, red mottled sandy clay loam soils
  Profile A6: Plinthic Tropeptic Stratic Haplorthox

3 Soils of the Zanderij landscape (Z)

- 3.1 Sandy plateau soils (Zb)
  well-drained, white, bleached sand soils
  Profile A9: Oxic Quarzipsamment
- 3.2 Sandy and loamy flank soils (Zn)
  well-drained, reddish yellow to red loamy sand and sandy loam soils
  Profile A7: Psammentic Haplorthox
- 3.3 Loamy-skeletal plateau and flank soils (Za)
  well-drained, yellowish red to red sandy (clay) loam soils with abundant hard nodules consisting of iron-cemented sand
  Profile A1: Typic Umbriorthox (Terra Preta)
- 3.4 Loamy hill soils (Zc)
  well to moderately well drained, (yellowish) brown sandy (clay) loam soils with or without red mottles
  Profile A3: Aquic Tropeptic Haplorthox

4 Residual soils (Regolith)

Loamy hill soils
well to moderately well drained, (weak) red (sandy clay) loam soils

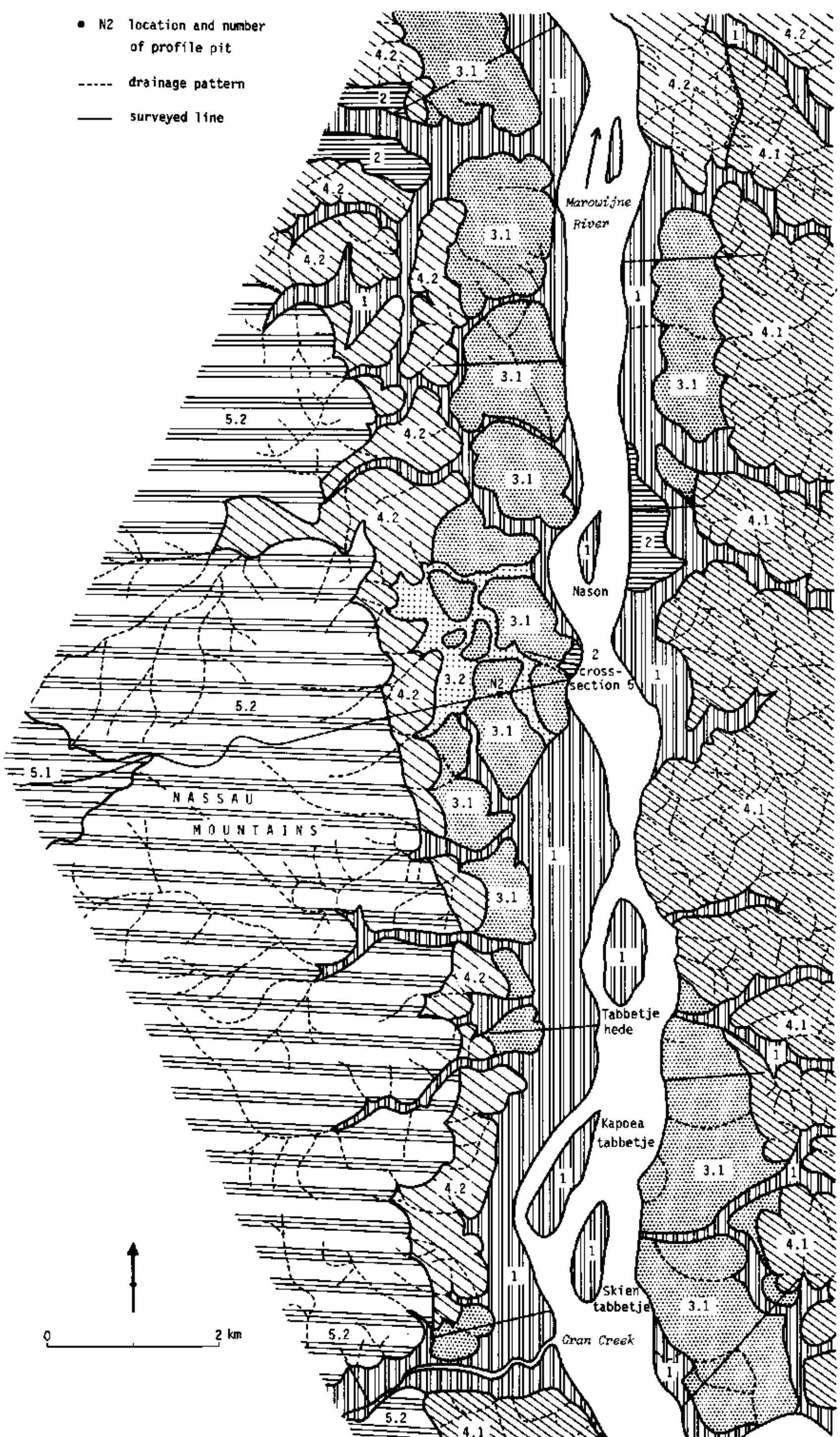

• N2 location and number of profile pit
----- drainage pattern
—— surveyed line
Marowijne River
Nason
2 cross-section 5
N2
NASSAU MOUNTAINS
Tabbetje hede
Kapoea tabbetje
Skien tabbetje
Gran Creek
0
2 km
1
2
3.1
3.2
4.1
4.2
5.1
5.2

Fig. 48. Pedo-geomorphological map of the sample area Nason.

1 Soils of the recent floodplain (F)

Clayey levee and basin soils; association of
(a) well-drained, yellowish brown clay soils
(b) moderately well to imperfectly drained, brownish yellow to pale yellow, red or strong brown mottled clay soils
(c) poorly drained, gray, strong brown mottled clay soils

2 Soils of the medium-level river terrace (Tm)

Clayey basin soils
well-drained, (reddish) yellow, red mottled clay soils

3 Soils of the high-level alluvial fans (Ph) and the high-level terrace (Th)

3.1 Loamy-skeletal and loamy hill soils; association of
(a) well to moderately well drained, yellowish brown to strong brown clay loam soils with abundant quartz pebbles and hard sesquioxidic nodules (Ph)
Profile N2: Aquic Stratic Troporthent
locally covered by
(b) well to moderately well drained, brownish yellow to strong brown sandy clay loam soils with or without red mottles (Th)

3.2 Fragmental valley soils
poorly drained, gray, sand, gravel and stone soils

4 Soils of the Tempati landscape

4.1 Clayey-skeletal hill soils of the Tempati I landscape
4.2 Clayey-skeletal hill soils of the Tempati II landscape
well-drained, (yellowish) red clay soils with abundant hard sesquioxidic nodules

5 Soils of the Brokolonko landscape

5.1 Clayey-skeletal plateau soils
imperfectly drained, yellowish red clay soils with abundant sesquioxidic boulders (crust)

5.2 Clayey-skeletal flank soils
well-drained yellowish red clay soils with abundant hard sesquioxidic nodules and boulders

- - - - drainage pattern

——— surveyed line

• W1 location and number of profile pit

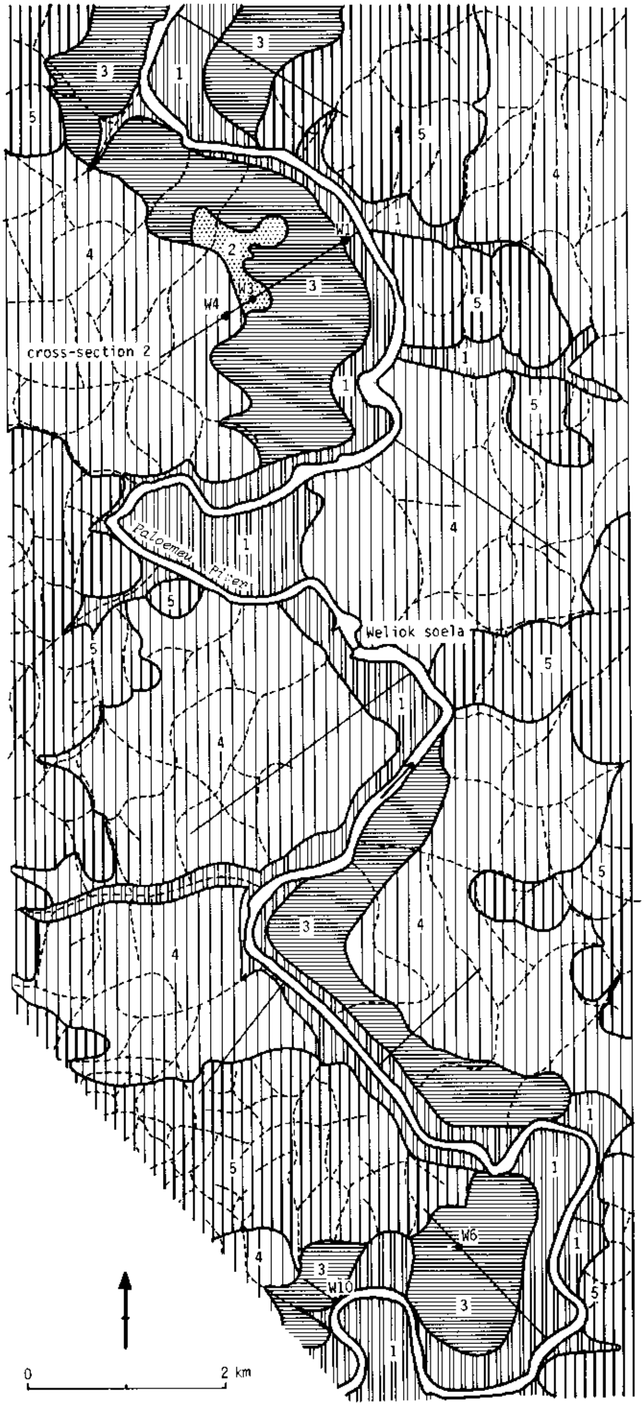


Fig. 49. Pedo-geomorphological map of the sample area Weliok.

1 Soils of the recent floodplain (F)

Clayey levee and basin soils; association of
(a) well-drained, yellowish brown clay soils
(b) moderately well to imperfectly drained, (brownish) yellow, red mottled clay soils
Profile W1: Aquoxic Stratic Dystropept
(c) poorly drained, white, red or strong brown mottled clay soils

2 Soils of the medium-level alluvial fans (Pm)

Sandy fan soils
poorly drained, light grey, bleached sand soils with a weakly to strongly cemented pan (ortstein) at 75-100 cm
Profile W3: Arenic Tropaquod

3 Soils of the medium-level river terrace (Tm)

Clayey and loamy basin soils; association of
(a) well-drained, yellowish brown to yellowish red sandy clay loam soils
Profile W6: Typic Haplorthox
(b) well-drained, yellowish brown to yellowish red clay soils
Profile W10: Tropeptic Haplorthox

4 Soils of the high-level terrace (Th)

Clayey hill soils
well-drained, strong brown to yellowish red clay soils
Profile W4: Typic Haplorthox

5 Soils of the Tapanahony landscape (E30)

Clayey and clayey-skeletal hill soils
well-drained, yellowish brown to red clay soils, locally with abundant hard sesquioxidic nodules

Summary

This study deals with the morphology and genesis of landforms and soils in eastern Surinam. Fieldstudies were made in ten sample areas from the estuary up to the headwaters of the Marowijne River.

Chapter 3 discusses the Quaternary geology, with special reference to the river valleys.

Eight heavy mineral associations were distinguished and their origin established. The influence of weathering on the mineralogical composition of the sand fraction was considered.

Grain-size distributions are presented as cumulative curves on arithmetical probability paper. Thus regolith was distinguished from sediments and the environments of deposition were studied in detail. q and q' values after Bakker were calculated and in some cases the origin of the silt and clay fraction was established. The influence of pedogenesis (clay migration, podzolization and ferrallization) on the size-frequency distribution was considered.

Subsequently, the development of landforms was explained in terms of changes in sea level, tectonic movements and alternations in the climate. It appeared that Quaternary climatic changes were the main cause of terrace formation.

In Interpluvial times, slopes retreated and coarse detritus clogged valley floors. In Pluvial times, vertical erosion predominated and fine material was deposited on top of the gravel and stones. Pluvials in eastern Surinam seem to coincide with Interglacials in temperate regions.

Alluvial fans covered by meandering river deposits or colluvium are characteristic. This sequence occurs at two levels (Fig. 12). The highest fans were deposited on top of a denudation surface of Early Pleistocene age. The lowest fans are presumably of Riss age and lie on the present valley floor. During formation of this erosional surface, resistent rock barriers survived as 'Inselberge'.

The lowest fans were covered by fine material deposited under backswamp conditions, probably during Eemien times. These sediments were correlated with

the Old Coastal Plain deposits of northern Surinam.

In Pleniglacial times, alluvial fans once more originated at the foot of the hilly country and the stream-bed was probably filled with sand. In Late Glacial and Early Holocene times, much coarse detritus was carried to the present shelf area. Peat grew in the Early Holocene in river valleys and the coastal area. These peaty layers were covered by fine-textured sediments of the present meandering rivers.

Chapter 4 deals with pedogenesis.

To interpret the mechanical data, a rectangular 'reference' diagram was used. This diagram was introduced by Doeglas for sedimentological reasons, but it also proved to be useful in the study of genetic relationships in soil profiles.

In addition, thin sections were studied and chemical techniques, including X-ray microprobe analysis, were used. The chemical data were recalculated into the normative mineralogical composition according to the rules of the Katanorm, the Epinorm and the Goethite norm, as indicated by van der Plas & van Schuylenborgh (1970), and Burri (1964).

From the field data and the results of these modern analytical techniques the polycyclic soil development in eastern Surinam was reconstructed.

Four cycles of soil formation were distinguished. The first cycle recognized is polycyclic in itself. It is represented by hard sesquioxidic nodules or petroplinthite of Tertiary to Mid Pleistocene age. This material has usually been reworked.

A second cycle of plinthization occurred in a Pluvial epoch, possibly during the Eemien.

This epoch was followed by a period of 'lessivage', probably in a relatively dry climate during some period of the Last Glacial. Remnants of this cycle are still recognizable in plinthite-bearing soils with a relatively low faunal activity.

The fourth cycle of pedogenesis occurred in the Holocene and possibly started in Upper Pleniglacial times.

In the freely drained soils, remnants of lessivage were almost completely removed by the soil fauna. This phenomenon was accompanied by ferrallization, which mainly resulted in neosynthesis of kaolinite. Thus the former textural B horizons were transformed into oxic horizons. The present textural differences between the A and B horizons in these soils were mainly caused by superficial erosion, combined with biological homogenization. Thus fine material was brought to the surface and removed by surface wash.

In the imperfectly drained soils, the illuviation cutans were partly preserved, and gleyzation was active.

In the poorly drained sandy soils, podzolization resulted in a transformation of the textural B into an aluminous hardpan.

Arable soils originated from shifting cultivation. The existence of clay skins in these soils is characteristic. The clay illuviation is anthropogenic and does not occur under rain forest. Some Amerindian arable soils have an umbric epipedon, usually with potsherds (Terra Preta). Most cultivated soils, however, have an ochric epipedon.

Chapter 5 discusses soil classification: 27 profiles were classified by the 7th Approximation (1967).

Most freely drained soils are Oxisols (Haplorthox, Umbriorthox).

Ultisols are restricted to arable soils (Palehumults).

Spodosols occur in alluvial fans under hydromorphic conditions (Tropaquods).

Inceptisols are present in the recent floodplain (Tropaquepts, Dystropepts).

The remaining soils are Entisols. The clay content is mostly $<15\%$.

The soils were also classified by the French (1967) and the Brazilian (1966) classification system.

Sommaire

Physiographie et sols au Surinam oriental (l'Amérique du Sud)

Ce traité est un exposé de la morphologie et de la genèse du paysage et des sols au Surinam oriental, l'Amérique du Sud. Le travail a été concentré à dix 'sample areas' de l'estuaire jusqu' au cours supérieur de la rivière Maroni.

Le chapitre 3 discute la géologie Quaternaire.

L'existence de huit associations de minéraux lourds a été démonstrée et l'origine de ces associations a été déterminée. Le changement de la composition minéralogique du sable sous l'influence de l'altération a été considéré.

Les résultats de l'analyse mécanique ont été montrés au papier linéaire de probabilité d'après Doeglas. Les caractéristiques du régolith et des sédiments ont été spécifiées et les milieux de déposition ont été étudiés en détail. Les valeurs de q et q' ont été calculés d'après Bakker et l'origine du limon et de l'argile a été déterminée quelquefois. L'influence de la pédogenèse (le lessivage, la podzolisation et la ferrallitisation) à la distribution des fréquences de grains a été considérée.

Ensuite la genèse du paysage a été interpretée en fonction des changements du niveau de la mer, des mouvements tectoniques et des changements du climat. Il était évident que la formation des vallées a été déterminée principalement par les altérations du climat Quaternaire. Il semble qu' il y avait une coïncidence des périodes glacières en Europe aux époques interpluviales au Surinam.

Pendant les périodes interpluviales il y avait un reculement des versants et une déposition de sédiments grossiers dans les vallées. Pendant les époques pluviales il y avait une dominance de l'érosion verticale et une déposition de matériaux fines au dessus des graviers.

La présence de cônes de déjection, couvertes de sédiments d'une rivière à méandres ou des colluvions est caractéristique. Cette séquence existe à deux niveaux (Fig. 12). Les cônes hautes ont été déposées à une surface de dénudation, qui a possiblement un âge de Pleistocène ancien. Les cônes basses se trouvent au fond des vallées actuelles et elles ont possiblement un âge de Riss. Pendant la formation de la base, des barrières rocheuses restaient debout

comme des 'Inselberge'.

En général, les cônes basses sont couvertes de matériaux fines, déposés en milieu lacustrine, probablement pendant l'Eémien. Ces sédiments-ci ont été corrélés aux dépôts de la Plaine Côtière Ancienne du Surinam du Nord.

Pendant l'époque Pléniglacière de nouvelles cônes de déjection se formaient au dessous des collines et les lits fluviaux se remplissaient du sable. Pendant la période Tardiglacière et la Holocène ancienne une grande quantité de sable grossier a été transportée au plateau continental actuel. Pendant la Holocène de la tourbe se formait dans les vallées aussi qu'à la région côtière. La tourbe est couverte de sédiments fines des rivières présentes à méandres.

Le chapitre 4 discute la pédogenèse.

Pour l'interprétation des analyses mécaniques un diagramme rectangulaire a été employé qui montre les rapports de toutes les classes granulométriques étudiées. Cette méthode a été supplémentée par des techniques micromorphologiques et des analyses chimiques, y compris le microanalyse radiographique (X-ray microprobe analysis). Les données chimiques ont été recalculées à la composition minéralogique normative selon les règles du Katanorm, du Epinorm et du Goethite norm, d'après van der Plas & van Schuylenborgh (1970) et Burri, (1964).

Par la combination des études de campagne et les résultats de ces techniques modernes la pédogenèse polycyclique au Surinam oriental a été reconstruite.

Les restants des sols les plus anciens sont composées de concrétions à sesquioxides de l'époque Tertiaire. En général ces materiaux ont été transportés. Une autre période de plinthisation se passait à une période pluviale, possiblement pendant l'Eémien. Cette période a été succédée par une époque de lessivage, probablement de climat relativement sec au Pléniglacial. Des restants de cette cycle ont été préservées à quelques sols hydromorphes à plinthite.

Le cycle suivant se passait à la Holocène et possiblement dès la période Pléniglacière. Dans les sols à drainage libre la faune du sol a presque complètement enlevé les restes du lessivage. Ce processus biologique a été accompagné par la ferrallitisation, ce qui résultait principalement à une formation de kaolinite. Ainsi les horizons B texturals se transformaient en 'oxic horizons'. Cependant les différences de texture entre les horizons A et B actuels ont provenu de l'appauvrissement, accompagnée par une homogénisation biologique. Ainsi les matériaux fines, transportés à la surface ont descendu par l'érosion superficielle.

Dans les sols à drainage imparfait les revêtements ont été préservés partiellement et la gleyification est active.

Dans les sols sableux à drainage pauvre la podzolisation a résulté à une transformation du horizon B textural à une couche durcie alumineuse.

La cultivation récente des sols est la cause d'un nouveau processus de lessivage. Les sols cultivés sont caractérisés par la présence de revêtements. Quelques sols arables ont une 'umbric epipedon', souvent à tessons indiennes (Terra Preta). Cependant la majorité des sols cultivés a une 'ochric epipedon'.

Le chapitre 5 discute la classification des sols: 27 profiles ont été classifiés selon la '7th Approximation' (1967) et la classification française (1967).

En général les sols à drainage libre sont des Oxisols (Haplorthox, Umbriorthox: Sols ferrallitiques fortement désaturés).

Des Ultisols sont restreints aux sols cultivés (Palehumults: Sols ferrallitiques fortement désaturés, lessivés).

Des Spodosols se trouvent aux cônes de déjection à drainage pauvre (Tropaquods: Podzols à gley).

Des Inceptisols existent au flat alluvial récent (Tropaquepts, Dystropepts: Sols hydromorphes minéraux, Sols ferrallitiques fortement désaturés, pénévolués).

Les autres sols sont des Entisols (Tropaquents: Sols hydromorphes minéraux). En général le pourcentage d'argile est moins que 15%.

De plus les sols ont été classifiés selon la classification brésilienne appliquée en Amazonie (1966).

Sintesis

Fisiografía y suelos del este de Surinam (América del Sur)

Se estudio la geogenesis en el cuaternario del este de Surinam, utilizando metodos de campo e investigaciones sedimentario-petrograficas.

Se explico de desarrollo de los valles fluviales en base a cambios en el nivel del mar, movimientos tectonicos y cambios climaticos. Se establecio una estratigrafia preliminar.

Ocho perfiles de suelo fueron seleccionados para un estudio detallado de pedogenesis. Para este fin se conbinaron los resultados del analisis de secciones finas, e investigaciones químicas que incluyeron analisis de micropruebas con rayos X. Para la interpretación de los datos granulometricos se utilizo un diagrama rectangular segun Doeglas. Los resultados del analisis químico total fueron transformados en la composición mineralogica 'normativa' segun los metodos de van der Plas & van Schuylenborgh, y Burri. Asi se estudiaron la homogeneización biologica, migración de arcilla, ferrallización, plinthización, podzolización y la genesis de suelos arables.

Se clasificaron 27 perfiles de suelo de acuerdo a los sistemas de clasificación Norte americano, frances y brasileño.

Acknowledgements

The cooperation with the following departments was highly appreciated:

Agricultural University of Wageningen:
Department of Regional and Tropical Soil Science, Geology and Mineralogy: Prof. Dr Ir P. Buringh, Prof. Dr Ir J. Bennema, Prof. Dr Ir L.J. Pons, Prof. Dr D.J. Doeglas, Dr D.J.G. Nota, Miss A.M.G. Bakker.
Laboratory for pedogenesis and mineralogy: Dr Ir J. van Schuylenborgh, Dr L. van der Plas, R.Schoorl Ing, L.T. Begheijn, A.T.J. Jonker, Mrs A.M. van Doesburg, J.D.J. van Doesburg, A. Engelsma, W.M. Stam, L.M.J. Wennekes.
Laboratory for micromorphology: Dr Ir S. Slager, A.G. Jongmans, Th. Pape, G.J. van de Waal.
Drafting room: Miss J.G. van Silfhout, W.F. Andriessen, G. Buurman.
Photosection: Z. van Druuten.

University of Amsterdam:
Institute for Earth Sciences: Dr P. Maaskant.
Laboratory for Physical Geography and Soil Science: Dr A.W.L. Veen.
Laboratory for Palynology: Dr T. van der Hammen, Dr T.A. Wymstra..

University of Utrecht:
Geographical Institute: Prof. Dr J.I.S. Zonneveld.
Botanical Institute: Dr J. van Donselaar.

University of Groningen: Physics laboratory: Dr W.G. Mook.
Stiboka, Wageningen: Dr E.B.A. Bisdom, Dr Ir A. Jongerius.
ORSTOM, Cayenne: Ir J.M. Brugière, Ir J.F. Turenne.
Pudoc, Wageningen: Dr Ir E. Meijer Drees, R.J.P. Aalpol, Mrs E.M. Brouns.

Much appreciation is conveyed to the following institutes in Surinam:

Department of Soil Survey: H.M Yvel Ing, Ir R.H. Brook, L.A. de Bies, Ch. Lekram, Benakoe, Joco, Sibe.
Geological and Mining Service: Drs R.A. Cambridge, Drs A. Amstelveen, Drs L. Krook, R.A. Albitrouw, Mr Hunkar, Mr Nunes.
Agricultural Experiment Station: Ir W.L. Asin.
Central Bureau for Aerial Survey (CBL): J. Wekker, Mr Hermelijn, Mr Singh.
Department of Forestry (LBB)
Institute Calor
Sunecon: Ir M. Meyer.
WOTRO: Dr Ir J. Ruinard, Apoteki, Bewani, Cornelis, Harry Jama, Kasso.

This study was made possible by funds from the *Netherlands Foundation for the Advancement of Tropical Research (WOTRO), the Hague.*

In conclusion a special word of thanks is due to Dr Ir J. van Schuylenborgh, who contributed much to this study. His valuable help was indispensable for the execution of the laboratory program and the interpretation of the chemical data.
Special acknowledgement is also made to Dr Ir S. Slager, whose constructive criticism has greatly improved this study and its presentation.

Appendix I. Laboratory methods

I.1 General

The laboratory data published in this report were mainly supplied by the Agricultural University of Wageningen, the Netherlands. Methods in use at the Department of Soil Science and Geology are dealt with below. Some additional research was carried out by ORSTOM Cayenne, and corresponding techniques will be discussed as alternative methods. For details see Begheijn & van Schuylenborgh (1971) and Thiais (1967).

I.2 Soil morphology

I.2.1 Description of soil profiles

Soil profile descriptions were prepared according to the conventions of the Soil Survey Manual (USDA, 1962) and the 7th Approximation (USDA, 1960-1967). Biopore nomenclature followed the scheme of Slager (1966). Soil colours were determined with the Munsell Color Charts (1954).

All profiles were described by the author.

I.2.2 Thin sections

Soil samples were air dried and impregnated in vacuo with Vestopal resin, catalyst and accelerator. Subsequently, they were machine-cut, polished and mounted on glass slides (cf. Jongerius & Heintzberger, 1964). Specimens for electron microprobe analysis were polished more carefully and coated with a layer of about 200 Å carbon.

The thin sections were described according to Brewer (1964). The descriptions were made under a polarizing microscope, using alternating plain and polarized transmitted and incident light. The source for incident light was a high pressure mercury lamp. The thin sections were examined quantitatively for clay concentrations: (ferri)-argillans and their disturbed remnants (papules). A point counting method was applied and the standard deviations were calculated after van der Plas & Tobi (1965).

I.3 Physico-chemical properties

I.3.1 Grain-size distribution

Method 1 (Wageningen) To determine the grain-size distribution, the soil was heated with H_2O_2 10% to remove organic matter, and HCl was added to obtain a 0.1 N solution. Salts were removed by suction and washing with water. Peptization was carried out in a 0.003 M Na-pyrophosphate solution, and the grain-size fractions were determined by pipetting and sieving.

Method 2 (ORSTOM) Method 2 is similar to method 1, but no HCl was added to non-calcareous material. The sum of the size fractions plus organic matter is 100%. In this study, however, the mineral particles were recalculated on a 100% base, as usual in Wageningen.

I.3.2 Natural clay or water dispersible clay

Natural clay is the clay pipetted from a suspension that does not contain a dispersing agent. It was obtained after reciprocal shaking for 16 h.

I.3.3 pH

The pH was determined in a 25 ml aqua dest., $CaCl_2$ 0.01M, or KCl 1N extract of 10 g soil, using a combined glass-calomel electrode and a pH meter.

I.3.4 Loss on ignition

Chemically bound water was determined by heating to 900 °C. Correction was made for hygroscopic water by drying overnight at 105 °C.

I.4 Chemical properties

I.4.1 Organic carbon

Method 1 (Wageningen) Organic matter was oxidized by a hot dichromate-sulphuric acid mixture and the colour intensity of the formed chromo ions was measured colorimetrically.
Method 2 (ORSTOM) Organic matter was oxidized by a hot dichromate-sulphuric acid mixture and the excess dichromate was titrated with Mohr's salt in a phosphoric acid medium.

I.4.2 Nitrogen

Method 1 (Wageningen) The organic matter was destroyed by a sulphuric acid-selenium mixture. Ammonia was distillated, after liberation with excess alkali, into a solution with boric acid. Ammonium borate was back-titrated to boric acid with potassium biiodate.
Method 2 (ORSTOM) Similar to method 1, but ammonium borate was back-titrated with sulphuric acid.

I.4.3 Available phosphorus (P-citr)

'Available' phosphorus was estimated by extraction with 1% citric acid and by precipitation as ammonium phosphomolybdate after oxidation of citric acid with aqua regia. The absorbance of the blue complex was measured colorimetrically.

I.4.4 K-HCl

Potassium was dissolved in 25% HCl and determined with a flame photometer.

I.4.5 Free iron

Method 1 (Wageningen) 'Free' iron oxides were dissolved in a weak acid medium after reduction to the ferrous state by dithionite, followed by complexation to EDTA. The Fe-EDTA was digested by treatment with a sulphuric acid-selenium mixture, and iron was determined colorimetrically as the orange-red ferro-orthophenantroline complex at pH 3.5.
Method 2 (ORSTOM) 'Free' iron oxides were dissolved in a weak acid medium after reduction to the ferrous state by sodium hydrosulphite. After digestion of the sulphite by a sulphuric acid-nitric acid mixture, reduction was carried out with silver, and iron was determined by titration with potassium dichromate.

I.4.6 Free aluminum

'Free' aluminum oxides were dissolved in Tamm's oxalate buffer solution. After destruction of the oxalate ions by aqua regia, aluminum was determined colorimetrically with pyrocatechol violet at pH 6.0.

I.4.7 Cation-exchange characteristics

Method 1 (Wageningen) Adsorbed bases were exchanged and complexated by treatment with Li-EDTA solution at pH 7.0. In the Li-EDTA extract, sodium and potassium were determined with a flame photometer. After digestion of the EDTA complex by a sulphuric acid-selenium mixture, calcium and magnesium were determined colorimetrically as the red calcium glyoxal-2-hydroxanil complex at pH 12.4 and as the red magnesium titan-yellow lake at pH 12, respectively.
To estimate the cation-exchange capacity, the adsorbed Li^+ ions were ex-

changed and complexated by treatment with K-EDTA solution at pH 10.0. In the K-EDTA extract, lithium was determined with a flame photometer and the result was corrected for Li in the interstitial solution.

The exchangeable aluminum was determined colorimetrically with pyrocatechol violet after multiple treatment with potassium chloride 1N.

The cation retention was estimated by adding the exchangeable bases and the KCl-extractable aluminum.

Method 2 (ORSTOM) The adsorbed bases were exchanged by percolation with ammonium acetate at pH 7.0. In the extract, sodium, potassium and calcium were determined with a flame photometer. After digestion of the acetate with aqua regia, magnesium was determined colorimetrically with titan-yellow at pH 12.0.

To estimate the cation-exchange capacity, the ammonium ions in the interstitial solution were removed by washing with alcohol and the adsorbed ammonium ions were replaced by treatment with potassium chloride at pH 7.0. Ammonia was determined after distillation as indicated under I.4.2.

I.4.8 Total elemental analysis

Method 1 (Wageningen) Si, Fe, Al, Ca, Ti, Mn, P and K were determined by X-ray fluorescence with a Philips X-ray fluorescence spectrometer PW 1540, provided with a silver tube.

To determine Na, Li and Mg, the inorganic material was decomposed with a hydrofluoric acid-sulphuric acid mixture. After dissolution, Na and Li were estimated with a flame photometer and Mg was determined colorimetrically as indicated under I.4.7.

For the analysis of Fe(II) and Fe(III), the material was decomposed with a hydrofluoric acid-sulphuric acid mixture under reductive conditions. Fe(II) and total iron were determined colorimetrically before and after adding the reductant, respectively.

Method 2 (ORSTOM) To determine the total bases, the material was decomposed by nitric acid. In the solution, phosphates and hydroxides were separated by precipitation with ammonia, followed by filtration. Na, K, Ca and Mg were estimated as indicated under I.4.7.

To determine the total phosphorus content, the phosphates separated from the nitric acid extract were dissolved in nitric acid and ammonia. Subsequently, phosphorus was precipitated as ammonium phosphomolybdate. The precipitate was dissolved in sodium hydroxide and excess hydroxide was titrated with sulphuric acid.

Method 3 (Amsterdam: electron microprobe analysis) The contents of various elements in the plasma of some podzol profiles were measured by Dr P. Maaskant with a Cambridge Electron Microprobe, type Geoscan (cf. Cescan et al., 1968).

I.5 Mineralogical properties

I.5.1 Normative mineralogical analysis

The normative mineralogical composition of the clay and of the fine earth or soil was calculated from the chemical data. The composition of the clay fraction was calculated by the rules of the Goethite norm (van der Plas & van Schuylenborgh, 1970); that of the non-clay fraction by the Epinorm rules (Burri, 1964). These data were combined into the normative mineralogical composition of the fine earth or soil.

In calculating the normative mineralogical composition of some igneous rocks, the rules of the Katanorm were followed (Burri, 1964).

I.5.2 Mineralogical analysis of the clay fraction (<2 μm)

The clay fraction was obtained by sedimentation under gravity. For this purpose, the soil was heated with H_2O_2 10%, sieved through a 50 μm sieve, and peptised by adding NaOH. Thereafter, the fraction <2 μm was coagulated with HCl and saturated with a LiCl solution. Excess salt was removed by dialysing and, finally, the clay suspension was dry-frozen.

Specimens for X-ray diffraction measurements were prepared by pulverising and spreading, with glycol, on a slide.

For mineralogical analysis a Philips diffractometer PW 1050, provided with a cobalt target, was used.

I.5.3 Mineralogical analysis of the silt fraction (2-50 μm)

The 2-16 and 16-50 μm size fractions of some selected samples were pretreated and examined as indicated by Veen (1970).

I.5.4 Mineralogical analysis of the sand fraction (50-420 μm)

The 50-420 μm size fraction was obtained by wet sieving after heating the soil sample with H_2O_2 10%. Iron coatings were removed by boiling in a 5% sodium dithionite solution. Heavy and light minerals were separated in bromoform (sg=2.89).

As for the heavy minerals, 150-300 transparent grains per sample were identified under a Zeiss polarizing microscope. The percentages of these minerals were expressed in mutual proportions, but the number of opaque grains was indicated as a percentage of the total heavy fraction. Identification of the opaque grains took place under a binocular microscope (Krook, 1969c) after separation with a Frantz isodynamic magnetic separator.

Countings were made according to the line counting method: only those grains were considered that passed the intersection of the reticles in some parallel lines on each slide. In examining the samples KK and Mar at the Surinam Geological and Mining Service, the field counting method as proposed by van Harten (1965) was applied (Krook, 1969a). Some grains that could not be identified under the microscope were examined by X-ray spectrography.

As for the light minerals, 300-1000 grains per slide were counted in a liquid with n=1.540. K-feldspar then shows a negative relief and can easily be recognized. Plagioclase, having higher refraction indices, can be distinguished from quartz by cleavage and twin patterns and by its weathered appearance. This method is quick, and it is especially useful when the percentage of plagioclase is low as stated for Surinam by IJzerman (1931) and Krook (1969a).

In some samples, derived from various geomorphological units, the light fraction was partly stained with sodium cobalt-nitrite and partly with hematein buffer after etching by HF fumes (Doeglas et al., 1965). Thus, in soils of eastern Surinam, all feldspar could be identified as K-feldspar, as the number of blue and yellow grains was equal in all slides.

I.5.5 Mineralogical analysis of rocks

The mineralogical composition of some rock specimens was determined by thin-section analysis under a polarizing microscope in order to check calculated norms.

Appendix II. Mineralogical data

					Heavy minerals[1]																		
Sample nr	Depth (cm)	Geomorphological unit	Heavy mineral association	% Feldspars	% Opaque	Tourmaline	Zircon	Rutile	Anatase	Garnet	Staurolite	Kyanite	Andalusite	Sillimanite	Corundum	Epidote	Gr. Hornblende	Augite	Hypersthene	Apatite	Alterites	Other minerals	Distribution of transparent heavy minerals[3]
Sample area Albina[4]																							
52	40– 95	Zb	ZS	·	4	8	22	2	–	1	38	9	14	2	–	–	–	–	–	–	4	–	·[5]
54	70– 90	Zb	ZS	·	17	12	41	4	1	–	28	1	9	1	–	–	–	–	–	–	3	–	·
KK156	·	Zb	ZS	–	21	1	74	2	–	–	19	1	3	tr[5]	tr	–	–	–	–	–	–	tr	·
A7	250–300	Zn	ZS	–	15	1	74	2	–	–	22	tr	tr	1	tr	–	–	–	–	–	–	–	·
A8	100	Za	ZS	–	69	5	29	tr	–	–	56	2	5	1	1	–	–	–	–	–	–	tr	37-53-10
A1-3	140–230	Za	ZS	–	81	5	60	2	–	–	25	1	5	tr	–	–	–	–	–	–	1	tr	47-47- 6
A1-5	260–360	Za	ZS	–	69	4	69	2	–	–	22	–	2	tr	1	–	–	–	–	–	–	–	·
A3-3	40–100	Zc	ZS	tr	49	7	46	3	–	1	32	2	4	3	1	tr	tr	–	–	–	–	tr	59-37- 4
A3-4	100–140	Zc	ZS	tr	47	6	35	4	–	–	45	2	4	1	tr	1	tr	–	–	–	–	1	41-43-16
A3-5	140–180	Zc	ZS	tr	52	5	43	1	–	–	38	3	6	3	tr	tr	–	–	–	–	–	tr	56-31-13
A2-5	108–160	Tm	ZS	2	65	3	47	2	tr	–	37	tr	3	2	–	–	–	tr	tr	–	–	4	39-44-17
A4-4	105–170	Tm	ZS	1	82	7	35	1	–	–	45	1	5	3	–	1	–	–	–	–	–	2	20-47-33
KK196	0	Tm	ZS	1[2]	75	2	67	2	–	–	25	–	2	2	tr	tr	tr	–	–	–	–	tr	·
KK197	0	Tm	ZS	2[2]	88	4	56	tr	–	tr	37	–	1	–	–	–	–	–	–	–	–	2	·
KK201	0	Tm	ZS	2[2]	70	5	65	4	–	–	23	1	1	tr	1	tr	–	–	–	–	–	–	·
KK202	0	Tm	ZS	1[2]	74	2	55	3	–	–	39	–	–	1	–	–	–	–	–	–	–	–	·
KK203	0	Tm	ZS	tr[2]	90	2	28	–	–	–	63	1	2	–	1	3	–	–	–	–	–	–	·
A4-5	240–310	Pl	EZS	10[2]	63	3	52	2	–	–	23	1	4	1	–	12	1	–	–	–	–	1	·
A4-6	310–365	Pl	EZS	1	92	5	32	1	–	–	47	–	4	3	–	3	2	–	–	–	1	2	44-39-17
KK194	0	Fs	EZS	9[2]	63	2	31	1	–	2	37	–	1	–	–	10	16	–	–	–	–	tr	·
KK195	0	Fs	EZS	10[2]	64	4	19	1	–	6	45	2	1	3	–	12	7	–	–	–	–	tr	·
KK199	0	Fs	EZS	2[2]	75	2	31	–	–	3	50	–	2	1	–	10	1	–	–	–	–	–	·
Sample area Nason																							
N3-3	45–170	E	TZ	tr	99	47	16	2	tr	–	13	–	tr	–	–	19	tr	–	–	–	–	3	96- 4- 0
N4	0– 50	Ph	TZ	tr	35	40	5	tr	–	–	54	–	–	–	–	tr	–	–	–	–	tr	–	46-42-12
N2-1	0– 60	Ph	ZM	tr	95	14	65	3	–	–	8	–	6	–	–	2	–	–	–	–	–	2	7-83-10
N2-2	90–115	Ph	ZM	–	81	13	72	1	tr	–	6	tr	3	tr	tr	3	–	–	–	–	–	tr	68-30- 2
N2-3	115–170	Ph	TZ	–	96	30	53	tr	–	–	2	–	2	–	–	10	–	–	–	–	tr	2	80-19- 1
N1-4	70–115	Tm	ZM	–	88	7	64	4	tr	–	6	–	2	–	–	4	1	–	–	–	2	10	82-17- 1
N6	0	Fs	EZM	2	88	3	75	–	tr	–	5	–	6	–	–	6	3	–	–	–	tr	2	64-35- 1
Mar20	0	Fs	EZS	4[2]	62	3	21	–	–	tr	15	–	1	–	–	42	18	–	–	–	–	–	·
Mar23	0	Fs	EZS	7[2]	58	3	9	–	–	2	44	tr	tr	1	–	21	20	–	–	–	–	–	·

Sample area Gransanti																							
G3-3	40- 70	E	ZM	-	75	4	78	2	-	-	8	tr	3	2	-	tr	-	-	-	-	-	2	85-13- 2
G3-4	70-120	E	ZM	-	66	5	79	1	tr	-	6	1	2	tr	-	1	-	-	-	-	-	4	85-12- 3
G1-5	115-150	Tm	ZM	tr	82	10	66	3	-	-	12	1	7	-	-	-	-	-	-	-	-	1	90-10- 0
G2-3	80-170	Tm	ZM	tr	74	8	69	2	tr	-	10	2	2	3	tr	tr	tr	-	-	-	-	3	75-22- 3
G5-1	200-300	Tm	ZM	-	85	9	63	3	3	-	11	-	2	1	-	1	tr	-	-	-	tr	6	91- 9- 0
G5-4	330-380	Pl	ZM	1	89	2	81	1	-	tr	7	1	3	1	-	1	-	-	-	-	1	2	76-24- 0
Mar37	0	Fs	EZM	6[2]	62	1	9	1	-	3	9	1	2	1	tr	55	18	-	-	-	-	tr	.
Sample area Inini																							
I2-3	70-100	E	TZ	-	99	a[5]	c	-	-	-	m	-	-	-	-	f	-	-	-	-	-	-	.
I2-4	120-150	E	TZ	tr	99	m	m	-	-	-	c	-	-	-	-	c	-	-	-	-	-	-	.
I3-1	5- 50	Tm	ZM	-	77	1	92	1	-	-	1	-	4	-	-	1	-	-	-	-	-	tr	79-20- 1
I3-5	160-190	Tm	ZM	-	78	1	83	tr	1	-	-	-	9	tr	-	5	-	-	-	-	-	tr	73-26- 1
I4-4	90-120	Tm	ZM	-	84	2	82	2	tr	tr	2	-	7	tr	-	tr	-	-	-	-	-	3	83-16- 1
I1-4	70-110	Fb	ZM	9	82	tr	78	tr	tr	1	2	-	13	3	-	1	-	-	-	-	-	1	86-14- 0
KK210	0	Fs	EZM	5[2]	86	-	20	-	-	13	14	-	3	tr	-	21	29	-	-	-	-	-	.
Sample area Koele																							
K5-4	100-130	E	Z	tr	73	-	98	1	tr	-	-	-	-	-	-	-	-	-	-	-	tr	-	72-28- 0
K2-5	140-160	Tm	Z	-	81	-	94	1	tr	-	-	-	-	-	-	tr	-	-	-	-	-	5	95- 5- 0
K6-3	75	Pm	Z	1	50	-	99	-	tr	-	-	-	-	-	-	-	-	-	-	-	tr	tr	81-18- 1
K6-5	110-140	Pm	Z	tr	72	-	97	1	tr	-	-	-	-	-	-	tr	-	-	-	-	tr	1	70-30- 0
K3-2	450-520	Pl	EZ	39	86	-	92	-	tr	-	-	-	-	-	-	3	-	-	-	-	-	5	39-46-15
K1-4	135-160	Fl	EZ	35	80	-	70	4	tr	-	-	-	-	-	-	18	tr	-	-	-	-	8	95- 5- 0
K8	0	Fs	EZ	17[2]	65	-	92	-	-	-	-	-	-	tr	-	7	-	-	-	-	-	1	.
Sample area Tapatosso																							
T5-3	38- 50	Ph	.	tr	92	14	50	22	tr	-	-	1	1	-	-	7	2	-	-	-	1	2	84-14- 2
T5-4	42- 58	E	.	-	97	17	51	24	tr	-	-	tr	tr	-	-	3	1	-	-	-	1	2	78-22- 0
T2-4	76-150	E	Z	tr	80	1	87	1	-	1	1	-	2	tr	-	2	1	-	-	-	3	1	66-33- 1
T3-3	75- 90	E	Z	-	83	tr	88	3	tr	tr	-	-	1	-	-	4	-	-	-	-	tr	3	54-41- 5
T2-2	20- 56	Tm	Z	tr	67	3	85	2	tr	-	1	-	1	1	tr	2	4	-	-	-	-	1	91- 9- 0
T6-4	53- 75	Pm	Z	tr	51	2	82	13	tr	-	tr	-	-	-	-	2	-	-	-	-	-	tr	58-42- 0
T6-8	140-180	Pm	Z	-	78	1	77	20	-	-	-	-	tr	-	-	1	-	-	-	-	-	tr	62-35- 3
T1-4	90-160	Fl	EZ	19	66	1	78	1	tr	tr	1	tr	-	-	tr	13	2	-	-	-	-	2	87-13- 0
T9	0	Fs	EZ	10[2]	61	1	77	-	-	tr	tr	-	2	-	-	17	3	-	-	-	-	tr	.
Sample area Weliok																							
W4-5	130-150	E	Z	-	79	-	97	tr	1	-	-	-	tr	tr	-	tr	-	-	-	-	-	-	83-15- 2
W10-4	130-210	Tm	Z	-	80	1	88	3	tr	-	tr	-	-	tr	-	2	tr	-	-	-	-	4	91- 8- 1
W10-7	380-540	Tm	Z	-	84	-	91	2	tr	-	-	-	1	1	-	1	-	-	-	-	tr	3	91- 9- 0
W3-5	105-125	Pm	Z	-	75	2	91	4	-	-	tr	tr	1	1	1	-	-	-	-	-	-	-	64-35- 1
W3-7	140-170	Pm	Z	tr	82	1	90	2	tr	-	tr	tr	2	1	1	-	-	-	-	-	1	1	79-19- 2
W2	200-300	Pl	Z	tr	77	2	87	1	tr	-	-	-	3	-	-	3	-	-	-	-	tr	4	83-14- 3
W10-9	590-620	Pl	Z	4	84	-	97	-	-	-	-	-	-	tr	-	tr	-	-	-	-	2	tr	7-83-10
W11	150-190	Fl	EZ	17[2]	58	tr	83	2	-	-	-	-	tr	1	-	12	2	-	-	-	-	tr	.
W7	0	Fs	EZ	12[2]	73	1	68	tr	-	-	-	-	tr	4	1	12	5	1	2	3	-	3	.

Sample nr	Depth (cm)	Geomorphological unit	Heavy mineral association	% Feldspars	Heavy minerals[1]: % Opaque	Tourmaline	Zircon	Rutile	Anatase	Garnet	Staurolite	Kyanite	Andalusite	Sillimanite	Corundum	Epidote	Gr. Hornblende	Augite	Hypersthene	Apatite	Alterites	Other minerals	Distribution of transparent heavy minerals[3]
Sample area Blakawatra[4]																							
B4-3	43-160	Tm	ZM	-	81	3	83	tr[5]	3	-	-	-	5	1	-	tr	1	-	-	-	-	3	95- 5- 0
B5-4	130-225	Tm	ZM	2	72	6	83	-	-	-	-	-	8	1	-	tr	tr	-	-	-	-	1	86-13- 1
B5-6	260-330	Pl	ZM	5	85	9	70	1	-	-	-	-	13	1	-	2	2	-	-	-	-	2	72-26- 2
B7-4	650-700	Pl	ZM	1	84	6	78	-	1	-	-	-	14	-	-	1	-	-	-	-	-	tr	60-28-12
B2-4	122-160	Fk	ZM	-	72	4	80	3	tr	-	4	-	4	-	-	2	-	-	-	-	-	3	99- 1- 0
B3-4	70-170	Fl	ZM	2	77	3	86	tr	tr	-	tr	-	5	1	-	3	-	-	-	-	tr	tr	95- 5- 0
B8	0	Fs	EZ	11[2]	85	2	78	-	-	-	-	-	1	tr	-	9	6	tr	2	1	-	tr	. [5]

From Kiel (1955), Krook (1969) and this study.

1. 50-420 μm, unless stated otherwise.
2. 44-250 μm (feldspars only)
3. For an explanation see Section 3.2.4.
4. For sampling sites see figs 2-9.
5. a = abundant (>50%), m = many (20-50%), c = common (5-20%), f = few (1-5%), tr = trace (<1%), . = non-determined.

Appendix III.
Soil profile descriptions and micromorphological data

III.1 . Key for interpreting soil profile descriptions.

Colour (Munsell)	W colour of wet soil M colour of moist soil D colour of dry soil			
Mottles	abundance	size	contrast	Shape
	f few c common m many a abundant	f fine m medium c coarse	f faint d distinct p prominent	sr subrounded v vertical
Nodules = Mottles + Consistence				
Texture (Text)	cl clay scl sandy clay scll sandy clay loam cll clay loam sil silt loam l loam		fsl fine sandy loam sl sandy loam cosl coarse sandy loam ls loamy sand lcos loamy coarse sand s sand cos coarse sand	
Structure	grade	size	type	
	w weak m moderate s strong	vf very fine f fine vth very thick	gr granular sbk subangular blocky pl platy sg single grains no ms no macrostructure	
Biopores (Biop) and roots	abundance	size		
	f few c common m many a abundant	f fine l large		
Consistence (Cons)	wet soil		moist soil	dry soil
	ns non-sticky ss slightly sticky s sticky np non-plastic sp slightly plastic		l loose vfr very friable fr friable fi firm vfi very firm	s soft sh slightly hard h hard vh very hard eh extremely hard
Cementation	cw weakly cemented cs strongly cemented			
Horizon boundaries (Transition)	distinctness		regularity	
	a abrupt c clear g gradual d diffuse		s smooth w wavy t tongued b broken	

Profile W4: Weliok (23-2-1968, 30-7-1969)

Location	Fig. 8. Top. map Surinam 1:100 000, sh.75, N 677.1 (3° 13' 50") W 330.1 (55° 25' 15")	Slope Altitude	A class, level (Fig. 17) 173 m + NSP; 18.5 m + level Paloemeu River 6-2-1968
Climate	Am (Köppen); Table 1: Paloemeu (profile described in short dry season)	Hydrology	Soil-drainage class: well-drained Groundwater table: actual 11 m
Vegetation	Rain forest	Diagnostic horizons	Ochric epipedon 0- 70 cm Oxic horizon 70-150 cm
Geology	Pleistocene , colluvial and fluviatile deposits on regolith from alkali-granite	Classification	Typic Haplorthox (7th Appr. 1967)
Physiography	Colluvium (Th) on alluvial fan (Ph) on E15 planation surface		

Horizon Transition	Depth (m)	Colour	Nodules	Text	Structure	Biop	Roots	Cons	Remarks
O	0.02- 0								litter
A1' c s	0 - 0.07	M 10YR 4/4	-	scl	m vf-f gr	a f	c f f 1	fr	
A2' d s	0.07- 0.25	M 7½YR 5/6	10R 3/4 f f-m d eh	cl	m vf-f gr	a f	c f f 1	fr	nodules: rounded
B2h' d s	0.25- 0.70	M 7½YR 5/5	do	cl	w vf-f gr	a f	f f	fr	nodules: spherical to knobbly
B2 d s	0.70- 1.30	M 5YR 5/6	do	cl	w vf-f gr	a f	f f	fr	do
IIB2cn	1.30- 1.50	M 2½YR 5/6	10R 3/4 a m-c p eh	cl	no ms	a f	-	vfr	clayey skeletal

Profile W4, continued (samples taken with Empire drill).

Horizon Transition	Depth (m)	Colour	Mottles/ Nodules	Text	Structure	Biop	Roots	Cons	Remarks
IIB3cn	1.5 - 2.0	10R 5/7	10R 3/4 a m-c p eh	cll	.	.	.	.	clayey skeletal
IICcn	2.0 - 3.5	10R 5/7	10R 3/4 m m-c p eh	scll	.	.	.	.	loamy skeletal
IIIC1	3.5 - 6.0	10R 5/7	-	1	.	.	.	.	5.1-5.2 m: layer of quartz gravel
IIIC2	6.0 - 9.5	10R 5/6	5Y 8/2 2½Y 7/5 c f d	1	.	.	.	.	
IIIC3	9.5 -10.0	10R 5/6	?	1	.	.	.	vfi	
IIIC4	10.0 -20.0+	shades of red	various colours	1	.	.	.	.	
IIIR	?	.	.						a rock sample was taken at some km from the drill hole (site W10)

Profile B5: Blakawatra (29-3-1968)

Location	Fig. 9. Top. map Surinam 1:100 000; sh.75, N 676.2 (3° 13' 20") W 302.2 (55° 39' 45")	Altitude	173 m + NSP; 7.4 m + level Tapanani River 29-3-1968
Climate	Am (Köppen); Table 1: Paloemeu	Hydrology	Soil-drainage class: well-drained Groundwater table: actual >6.1 m, presumed highest 2.8 m below surface
Vegetation	Rain forest		
Geology	Pleistocene, fluviatile deposits on regolith from alkali-granite	Diagnostic horizons	Ochric epipedon 0- 70 cm Oxic horizon 70-200 cm
Physiography	River terrace (Tm) on alluvial fan (P1)	Classification	Typic Haplorthox (7th Appr. 1967)
Slope	A class, nearly level		

Horizon Transition	Depth (cm)	Colour	Nodules	Text	Structure	Biop	Roots	Cons	Remarks
O	2- 0								litter
A1 c s	0- 5	M 10YR 3/2	-	cosl	m vf gr	a f	m f f 1	fr	
A3 g w	5- 70	M 10YR 5/6	-	scll	m vf gr	a f c 1	c f f 1	fr	
B1 d s	70-130	D 7½YR 6/6	-	scll	w vf gr	a f c 1	c f f 1	sh	
B2 c s	130-225	D 5YR 5½/8	-	scll	w vf-f gr w f sbk	a f c 1	f f f 1	h	numerous pedotubules
IIB21cn c s	225-245	D 5YR 6/8	10R 3/4 m c d sr cw	scll	no ms	m f	f f f 1	s	stone line: nodules composed of quartz sand, weakly cemented by sesquioxides, 2-8 cm Ø
IIB22 c w	245-260	D 5YR 6/8	-	scll	no ms	m f	f f f 1	s	
IIB23 c t	260-350	D 7½YR 6/8	-	cosl	no ms	m f	f f f 1	s	some pedotubules

Profile B5, continued.

Horizon Transition	Depth (cm)	Colour	Mottles/ Nodules	Text	Structure	Biop	Roots	Cons	Remarks
IIB24g c b	280-350	D 5Y 8/2	7½YR 5/8 2½YR 6/4 m c d	cosl	no ms	c f	-	s	
IIB25ir c b	320-410	D 7½R 3/8 5YR 5/8	-	cos	no ms	f f	-	cw	ironstone layer, composed of weakly cemented sand
IIIB3cn g w	350-450	D 10YR 7/7	10R 4/6 c c d v cw	cosl	no ms	c f	-	sh	nodules: sand, weakly cemented by sesquioxides
IIICg	390-570	M 10YR 8/1	10R 4/6 5YR 5/8 m c p	sl	no ms	c f	-	fi	some pedotubules
pedotubule g w		M 2½Y 7/2	10R 4/6 5YR 5/8 f m d	sl	w vf gr	m f	f f	vfr	
IIIR1 d t	570-600	vari-coloured		lcos	s vth pl	f f	-	.	
IIIR2 d	600-610	vari-coloured		.	.	.	-	.	
IIIR3	>610	.							hardrock: alkali-granite with many quartz veins

Profile T2: Tapatosso (26-12-1967, 25-8-1969)

Location	Fig. 7. Top. map Surinam 1:40 000, sh.49c, N 771.12 (4° 4' 54") W 400.48 (54° 46' 28")	Altitude	83 m + NSP; 5.0 m + level Tapanahony River 5-12-1967
Climate	Af (Köppen); Table 1: Tapatosso (profile described in short rainy season)	Hydrology	Soil-drainage class: imperfectly drained Groundwater table: actual 4.5 m below surface, presumed highest near surface
Landuse	Shifting cultivation		
Vegetation	Shrubs (Kapoewerie)	Diagnostic horizons	Ochric epipedon 0-50 cm Argillic horizon 50-90+ cm
Geology	Pleistocene, fluviatile deposits on regolith from hornblende-diorite	Classification	Thapto Plinthaquoxic Tropaquent (7th Appr. 1967)
Physiography	Rock defended terrace (E5)		
Slope	A class, nearly level (Fig. 16)		

Horizon Transition	Depth (cm)	Colour	Mottles	Text	Structure	Biop	Roots	Cons	Remarks
A11 g s	0- 19	W 10YR 4/2	-	ls	no ms	a f f 1	c f f 1	ns np vfr	charcoal fragments
A12g=B1tg g s	19- 50	W 10YR 5/1	10YR 4/3 c f f	lcos	no ms	a f f 1	f f	ns np vfr	
IIB1tg d s	50- 80	M 10YR 6/1	7½YR 5/8 2½YR 5/8 a c d v	scll	no ms	m f f 1	f f	fi	plinthite
IIB2tg	80-200	M 5Y 8/1	2½YR 4/8 10R 4/8 a c p v	scll	no ms	f f	-	fi	plinthite, some pedotubules (1-15 cm Ø, 10YR 4/1, friable)

Profile T2, continued (samples taken with Empire drill).

Horizon Transition	Depth (cm)	Colour	Mottles	Text	Structure	Biop	Roots	Cons	Remarks
IIC1g	200-250	5Y 8/1	10R 4/6 7½YR 6/8 a c p	scl1	.	.	.	.	plinthite
	250-300	do	do	cl1	.	.	.	.	do
	300-350	do	do	1	.	.	.	.	do
	350-400	do	do	sil	.	.	.	.	do
IIC2g	400-450	5Y 8/1	7½YR 5/8 m m-c p	1	.	.	.	.	few amphiboles and micas
	450-550	do	7½YR 5/8 c f-m d	fsl	.	.	.	.	do
IIC3g	550-650	5Y 8/1 5BG 7/1	7½YR 5/6 f f d	fsl	.	.	.	.	many amphiboles and micas
IIR1	650-700	5GY 5/1	-	fsl	.	.	.	.	abundant amphiboles
IIR2	700-710	5GY 5/1	-	fsl	.	.	.	.	do
IIR3	>710		.						hardrock: hornblende-diorite: a rock sample was taken at some m from the drill hole

Profile W3: Weliok (24-2-1968)

Location	Fig. 8. Top. map Surinam 1:100 000, sh.75, N 677.3 (3° 13' 55") W 329.4 (55° 25' 10")	Altitude	160 m + NSP; 5.5 m + level Paloemeu River 6-2-1968
Climate	Am (Köppen); Table 1: Paloemeu (profile described in short dry season)	Hydrology	Soil-drainage class: poorly drained Groundwater table: actual -80 cm, presumed highest some dm above surface
Vegetation	Marshy savanna wood	Diagnostic horizons	Umbric epipedon 0- 39 cm
Geology	Pleistocene, fluviatile deposits		Albic horizon 39- 71 cm
Physiography	Alluvial fan (Pm)		Spodic horizon 76-125 cm
Microrelief	Hummocky	Classification	Arenic Tropaquod (7th Appr. 1967)
Slope	A class, nearly level (Fig. 17)		

Horizon Transition	Depth (cm)	Colour	Mottles	Text	Structure	Biop	Roots	Cons	Remarks
O	3- 0								litter and rootmat
A2' a c	0- 1	M 10YR 7/1	-	s	sg	.	.	1	
A1 a s	1- 39	M 10YR 3/1 D 10YR 5/1	-	s	no ms	m f	c f f 1	vfr	charcoal fragments
A2 c s	39- 71	W 10YR 7/1	10YR 3/1 f c d v	s	sg	c f	?	ns np 1	mottles: humus veins
A3 a b	71- 76	W 10YR 3/1	-	s	no ms	m f f 1	f f f 1	ns np vfr	
B2h a b	76-120	W 5YR 3/2 5YR 2/1	-	ls	no ms	f f	-	cw	lamellae of organic matter, some rootprints
B2m c b	105-125	D 10YR 5/4	-	ls	no ms	c f	-	cs	hardpan; accumulated org. matter from B2h between fracture planes
B3m g s	125-140	D 5Y 7/3	$7\frac{1}{2}$YR 5/6 f m d	ls	no ms	c f	-	cw	few ribbons of organic matter from B2h
IIBg	140-190+	W 5Y 7/2	$7\frac{1}{2}$YR 5/6 f f f $7\frac{1}{2}$YR 2/0 c c d	sl	no ms	c f	f f	ss sp fr	isolated pockets of org. matter (fossile organic aggrotubules)

Profile T6: Tapatosso (21-12-1967)

Location	Fig. 7. Top. map Surinam 1:40 000, sh.49c, N 767.36 (4° 2' 52") W 400.06 (54° 46' 59")	Altitude	84 m + NSP; 6.4 m + level Tapanahony River 5-12-1967
Climate	Af (Köppen); Table 1: Tapatosso (profile described in short rainy season)	Hydrology	Soil-drainage class: poorly drained Groundwater table: actual -2.5 m, presumed highest some dm above surface
Vegetation	Marshy savanna wood	Diagnostic horizons	Ochric epipedon 0-75 cm; Albic horizon 10-30 cm and 53-75 cm
Geology	Pleistocene, fluviatile deposits		
Physiography	Alluvial fan (Pm)	Classification	Spodic Stratic Tropaquent (7th Appr. 1967)
Microrelief	Hummocky		
Slope	A class, nearly level		

Horizon Transition	Depth (cm)	Colour	Mottles/ Nodules	Text	Structure	Biop	Roots	Cons	Remarks
A1' a w	0- 10	M 10YR 2/2	-	fsl	w f sbk	c f	m f f 1	vfr	
A2' g w	10- 30	M 10YR 8/1	10YR 4/1 m c f	s	sg	c f	f f f 1	1	mottles: humus veins
B2h' g s	30- 53	M 10YR 4/1	-	ls	no ms	c f	f f f 1	vfr	
A2g d w	53- 75	M 10YR 8/1	7½YR 5/8 c f f	s	sg	f f	-	1	
B1g a t	75- 98	M 10YR 8/1	7½YR 5/8 m f d	ls	no ms	f f	-	fr	rootprints
IIB2irg a b	98-130	M 7½YR 5/8	5YR 4/8 5YR 3/4 m m-c d vh	fsl	no ms	-	-	cw	
IIB31g d w	130-140	M 10YR 8/1	7½YR 5/8 c m d	fsl	no ms	f f	-	fr	mottles around rootprints and biopores
IIB32g c s	140-180	M 10YR 8/1	7½YR 5/8 f f f	fsl	no ms	f f	-	fr	do
IIIBmg	180-190	D 5Y 6/2	7½YR 5/8 f f f	ls-fsl	no ms	-	-	cw	

Profile K4: Koele (8-10-1968)

Location	Fig. 6. Top. map Fr. Guiana 1:100 000, sh. Haut Marwini, N 2° 25' 50", W 54° 26' 10"	Altitude	160 m + NSP; 5.7 m + level Litani River 18-9-1968
Climate	Am (Köppen); Table 1: Oelemari (profile described in long dry season)	Hydrology	Soil-drainage class: well-drained Groundwater table: actual 6.1 m, presumed highest 2.3 m below surface
Vegetation	Rain forest	Diagnostic horizons	Umbric epipedon 0- 75 cm
Geology	Pleistocene regolith from granite		Argillic horizon 40-105 cm
Physiography	Rock defended terrace (E5)		Oxic horizon 105-150+ cm
Slope	A class, 0.1 %	Classification	Terra Preta (Sombroek, 1966) Orthoxic Palehumult (7th Appr. 1967)

Horizon Transition	Depth (cm)	Colour	Mottles	Text	Structure	Biop	Roots	Cons	Remarks
O	2- 0								litter
A11 g s	0- 40	M 10YR 3/1 D 10YR 5/1	-	scl1	m vf gr	a f f 1	f f	vfr	numerous charcoal fragments and potsherds
A12=B21t c w	40- 75	M 10YR 3/1 D 10YR 5/1	-	scl1	w vf gr w vf sbk	a f	f f	vfr	do
B22t c w	55-120	M 7½YR 5/6	10YR 5/2 m c d	cl	no ms	a f	-	fr	mottles: organic matter some charcoal fragments and potsherds
B23t	105-150+	M 7½YR 5/6	7½YR 5/4 f c f	cl	no ms	a f	-	fr	mottles: organic matter

Profile K5: Koele (9-10-1968)

Location	Fig. 6. Top. map Fr. Guiana 1:100 000, sh. Haut Marwini, N 2° 25' 50", W 54° 26' 0"	Altitude	160 m + NSP; 5.9 m + level Litani River 18-9-1968
Climate	Am (Köppen); Table 1: Oelemari (profile described in long dry season)	Hydrology	Soil-drainage class: well-drained Groundwater table: actual >4.2 m, presumed highest 2.3 m below surface
Vegetation	Rain forest	Diagnostic horizons	Ochric epipedon 0- 45 cm Oxic horizon 45-150+ cm
Geology	Pleistocene regolith from granite		
Physiography	Rock defended terrace (E5)	Classification	Typic Haplorthox (7th Appr. 1967)
Slope	A class, 0.1 %		

Horizon Transition	Depth (cm)	Colour	Mottles	Text	Structure	Biop	Roots	Cons	Remarks
O	2- 0								litter
A1 g s	0- 30	M 10YR 4/3 D 10YR 6/3	-	scl	w vf gr	a f f 1	f f f 1	vfr	charcoal fragments
B2h' g s	30- 45	M 10YR 4/2	-	cl	w vf gr	a f	f f f 1	vfr	
B1 d s	45- 85	M 10YR 5/4	-	cl	no ms	a f	f f f 1	fr	
B2	85-150+	M 7½YR 6/6	-	cl	no ms	a f	f f f 1	fr	

Profile T3: Tapatosso (26-12-1967)

Location	Fig. 7. Top. map Surinam 1:40 000, sh.49c, N 771.04 (4° 4' 51") W 400.60 (54° 46' 40")	Altitude	83 m + NSP; 5.0 m + level Tapanahony River 5-12-1967
Climate	Af (Köppen); Table 1: Tapatosso (profile described in short rainy season)	Hydrology	Soil-drainage class: imperfectly drained Groundwater table: actual 4.6 m below surface, presumed highest near surface
Landuse	Shifting cultivation		
Vegetation	Shrubs (Kapoewerie)	Diagnostic horizons	Umbric epipedon 0- 55 cm Argillic horizon 75-130+ cm
Geology	Pleistocene, fluviatile deposits on regolith from hornblende-diorite	Classification	Terra Preta (Sombroek, 1966) Thapto Plinthaquoxic Tropaquept (7th Appr. 1967)
Physiography	Rock defended terrace (E5), flank		
Slope	A class, 1.5 % (Fig. 16)		

Horizon Transition	Depth (cm)	Colour	Mottles	Text	Structure	Biop	Roots	Cons	Remarks
A11 d s	0- 10	W 10YR 2/1 D 10YR 5/1	-	lcos	no ms	a f c 1	m f f 1	ns np vfr	charcoal fragments, some bleached quartz grains
A12=B11t g s	10- 55	W 10YR 3/1½ D 10YR 5/1½	-	cosl	no ms	a f c 1	m f	ns np vfr	charcoal fragments and potsherds
B12tg c t	55-120	W 10YR 5/1 D 10YR 6/1	10YR 5/8 m f f	cosl	no ms	a f f 1	f f	s sp fr	
IIB21tg g b	75- 90	W 2½Y 7/2	2½YR 4/8 7½YR 5/8 a m-c p v	scll	no ms	c f	-	s sp	plinthite
IIB22tg	90-130+	M 2½Y 7/2	10R 4/6 5YR 5/8 a c p v	scll	no ms	f f	-	fr	plinthite

III.3 . Key for interpreting micromorphological data.

Voids	int vughs = interconnected vughs
Cutans	frgr cutan = free grain cutan embgr cutan = embedded grain cutan ch cutan = channel cutan pl cutan = plane cutan nv cutan = normal void cutan f-argillan = ferri-argillan
Glaebules	arg papule = argillaceous papule
Frequency	+ = few <5 % ++ = common 5-20 % +++ = many 20-50 % ++++ = abundant >50 %
Size	v fine = very fine v coarse = very coarse e coarse = extremely coarse
Sharpness of boundary	r sharp = rather sharp r diffuse = rather diffuse

III.4 . Micromorphological data.

Horizon	Depth (cm)	Plasmic fabric	Related distribution	Voids	Cutans + vol% illuviated clay
Profile W4 (Typic Haplorthox)					
A2'	18	argillasepic	porphyroskelic	+++ int vughs	-
B2h'	45	do	do	do	-
B2	90-105	insepic	do	do	-
Profile B5 (Typic Haplorthox)					
B1	70-130	weakly insepic	porphyroskelic	+++ int vughs	-
B2	160-175	do	do	++ vughs ++ planes	-
IIB23	260-350	do	do	+++ int vughs	-
IIB25ir	320-410	mosepic	granular	+ vughs	+++ frgr ferrans, fine-v coarse, prominent
IIICg[4]	500	mosepic?	porphyroskelic	++ vughs	-
Profile W3 (Arenic Tropaquod)					
B2h	76-120	isotic	granular?	+ vughs +++ planes	++++ frgr organo-allophans, thin-v coarse, prominent
B2m	105-125	undulic-isotic intergrade	porphyroskelic	++ vughs ++ planes	++ nv organo-allophans, thin-medium, distinct, isotic; + embgr argillans, faint
B3m	125-140	undulic	porphyroskelic	++ vughs ++ planes	+ nv organo-allophans, like B2m; + embgr argillans, faint
Profile T6 (Spodic Stratic Tropaquent)					
IIB2irg	98-130	undulic	intertextic intergr to porphyroskelic	++ vughs ++ planes	++ nv and frgr ferrans, thin-coarse, distinct, isotic
IIIBmg	180-190	undulic	intertextic	+ vughs	+ nv argillans?, thin-v coarse, faint, undulic-isotic; traces of nv ferrans, thin, distinct

Subcutanic features	Glaebules	Remarks
	+ arg papules[1]; + sesquioxidic nodules[2], e coarse, prominent, sharp, rounded-irregular	1. probably phantom structures 2. pedorelicts, which may include arg papules (X-ray: Kaolinite) and Gibbsite
	do	
	+ arg papules[1]; ++ nodules as above	
	+ ferric nodules[1] v coarse, prominent, sharp, rounded	1. pedorelicts 2. probably phantom structures 3. mainly weathered K-feldspar, transformed into Illite 4. granitic lithorelicts present
	+ arg papules[2]	
	+ arg papules[2]	
embgr neoferrans, coarse, distinct, iffuse ++ embgr and nv eoferrans and quaiferrans, thin-v oarse, distinct, harp	++ arg papules[3]; + ferric nodules[1] v coarse, prominent, sharp, rounded ++ ferric nodules, e coarse, prominent, diffuse, irregular	
	-	
	-	
	-	
nv and embgr neoerrans, thin-coarse, istinct, diffuse	+ ferric nodules, related to neoferrans	
	-	

Micromorphological data, continued.

Horizon	Depth (cm)	Plasmic fabric	Related distribution	Voids	Cutans and vol% illuviated clay
Profile K4 (Orthoxic Palehumult; Terra Preta)					
A11	10	argillasepic intergr to isotic	porphyroskelic intergr to agglomeroplasmic	+++ int vughs	-
A12=B21t	40	do	porphyroskelic	+++ int vughs + planes	nv and ch f-argillans, medium-v coarse, distinct, 7.0 ± 2.2%
B22t	95	weakly insepic	porphyroskelic	+++ int vughs	do 2.8 ± 1.3%
B23t	120	insepic	do	do	do, 1.8 ± 1.0%
Profile K5 (Typic Haplorthox)					
A1	0- 30	argillasepic	porphyroskelic	+++ int vughs	-
B2h'	30- 45	do	do	do	-
B1	65	insepic	do	do	-
B2	120	do	do	do	-
Profile T3 (Thapto Plinthaquoxic Tropaquept; Terra Preta)					
A12=B11t[1]	20- 35	insepic intergr to isotic	intertextic intergr to porphyroskelic	+++ int vughs	nv f-argillans, thin-coarse, distinct, 0.8%
B12tg	48- 75	weakly mosepic	porphyroskelic	do	nv f-argillans, thin-medium, faint, 1.7 ± 0.9%
IIB21tg	75- 90	mosepic	do	do	nv and pl (f)-argillans, medium-v coarse, faint, 1.8 ± 0.9%[4]
IIB22tg	100-125	do	do	++ vughs ++ planes	do 1-4%[4]
Profile T2 (Thapto Plinthaquoxic Tropaquent)					
A12g	19- 50	insepic	intertextic intergr to porphyroskelic	+++ int vughs	nv f-argillans, thin-medium, distinct,
IIB1tg	60	weakly mosepic	do	do	nv and ch f-argillans, thin-coarse, distinct, 1.8 ± 0.9%[2]
IIB2tg	90	mosepic	porphyroskelic	do	do 1.5 ± 0.8%[2]
IIB2tg pedotubule	90	insepic	do	do	do

Subcutanic features	Glaebules	Remarks
-	-	1. mainly related to ferri-argillans; some are phantom structures
-	+ arg papules[1]	
-	+ arg papules[1]; + ferric nodules, fine, distinct, r sharp, irregular	
-	do	
-	-	1. probably phantom structures
-	-	
-	-	
-	++ ferric nodules, v fine-coarse, distinct, r sharp, irregular; + arg papules[1]	
-	+ arg papules[2]	1. contains potsherds 2. some are phantom structures, some are related to ferri-argillans 3. type 2 nodules, related to neoferrans (Section 4.5.3) 4. minimum %: argillans often hardly distinguishable from phantom structures 5. some included in ferri-argillans 6. type 1 nodules (plinthite)
+ nv neoferrans, medium,distinct, r sharp	+ arg papules[2]; ++ ferric nodules[3]	
+++ nv, pl and embgr neoferrans[5] and quasiferrans, thin-e coarse, prominent, r diffuse-sharp	+ arg papules[2]; +++ ferric nodules[3]; +++ sesquioxidic nodules, fine-e coarse, prominent, r diffuse-sharp, irregular[6]	
do	do	
+ nv neoferrans, medium, distinct, diffuse-r sharp	++ ferric nodules[1]; fine-medium, distinct, r diffuse-r sharp, subrounded-irregular	1. type 2 nodules, related to neoferrans 2. minimum % as indicated under T3, item 4. 3. often included in ferri-argillans 4. some are phantom structures, some are related to ferri-argillans 5. type 1 nodules: plinthite, which may include arg papules and argillans 6. matric aggrotubule
+ nv and ch neoferrans and quasiferrans[3]; thin-v coarse, distinct, diffuse	+ arg papules[4]; + ferric nodules[1]; v fine-fine, distinct, r sharp, irregular	
+++ nv, pl and embgr neoferrans and quasiferrans[3] thin-coarse, diffuse-sharp	++ arg papules[4]; ++ ferric nodules[1]; +++ sesquioxidic nodules[5]; e coarse, prominent, diffuse, irregular	
+ neoferrans	++ arg papules[4]; ++ ferric nodules[1]	

References

Alexander, L.T. & J.G. Cady, 1962. Genesis and hardening of laterite in soils. Techn. Bull. U.S. Dep. Agric. 1282.

Andel, Tj.H. van, 1950. Provenance, transport and deposition of Rhine sediments. Thesis, Wageningen.

Andriesse, J.P., 1969. A study of the environment and characteristics of tropical podzols in Serawak. Geoderma 2: 201-227.

Baas Becking, L.M.G., I.R. Kaplan & D. Moore, 1960. Limits of the natural environment in terms of pH and oxidation reduction potentials. J. Geol. 68: 243-284.

Bakker, J.P., 1948. Over tectogene- en morfogene gelijktijdigheid bij de jongere gebergtevorming in West- en Midden Europa in het kader van de denudatieve altiplanatie. Natuurw. Tijdschr. 30: 1-52.

Bakker, J.P., 1955. Over ontstaan en vervorming van de laaggelegen landbouwgronden der bosnegers langs de grote rivieren van Suriname. Gedenkboek Fahrenfort, Wolters, Groningen.

Bakker, J.P., 1957. Quelques aspects du problème des sédiments correlatifs en climat tropical humide. Z. Geomorph. B.1: 3-43.

Bakker, J.P., 1965. A forgotten factor in the interpretation of glacial stairways. Z. Geomorph. N.F. 9: 18-34.

Bakker, J.P., 1968. Die Flussterrassen Surinams als Hinweise auf etwas trocknere Klimate während der Quartairen Eiszeiten. Extr. e tomo VII, (XIV) Actorum Geographicorum Debrecinorum, Debrecen.

Bakker, J.P. & H.J. Müller, 1957. Zweiphasige Flussablagerungen und Zweiphasenverwitterung in den Tropen unter besonderer Berücksichtigung von Surinam. Lautensach-Festschrift, Stuttgart.

Bal, L., 1970. Morphological investigations in two moder-humus profiles and the role of the soil fauna in their genesis. Geoderma 4: 5-36.

Beekman, P.H., 1961. Kaartblad F8: Drietabbetje. Jaarb. Geol. Mijnbouwk. Dienst Suriname 1956-1958:(7).

Begheijn, L.Th. & J. van Schuylenborgh, 1971. Methods for the analysis of soils used in the Laboratory of Soil Genesis of the Department of Regional Soil Science, Wageningen.

Bennema, J., 1966. Report to the government of Brazil on classification of Brazilian soils. FAO EPTA 2197, Rome.

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

Bigarella, J.J. & G.O. de Andrade, 1965. Contribution to the study of the Brazilian Quaternary. Spec. Pap. geol. Soc. Am. 84: 433-451.

Bisdom, E.B.A., 1967. Micromorphology of a weathered granite near the Ria de Arosa (NW Spain). Leid. geol. Meded. 37: 33-67.

Bleys, C., 1953. Over steenbanken bij het Brokopondoëiland (Suriname). Geol. Mijnb. 15: 6.

Boeckel, J.J. van, 1969. Geomagnetic and gravitational investigations in northern Surinam and their structural implications. Thesis, Amsterdam.

Boer, M.W.H. de, 1966. Verslag van een bodemkundige verkenning langs de Litani Rivier en de Koele Koele kreek. Dienst Bodemkart. Suriname (unpublished report)[1].
Boyé, M. & H. Cruys, 1959. New data on the coastal sedimentary formations in French Guiana. Proc. 5th Inter-Guiana Conf.: 145-159.
Brewer, R., 1964. Fabric and mineral analysis of soils. Wiley & Sons, New York.
Brewer, R., 1968. Clay illuviation as a factor in particle-size differentiation in soil profiles. Trans. 9th Intern. Congr. Soil Sci. IV: 489-499.
Brinck, J.W., 1956. Goudafzettingen in Suriname. Leid. geol. Meded. 21: 1-246.
Brinkman, R., 1959. Bodemkartering Albina Zuid. Dienst Bodemkart. Suriname (in-(unpublished report)[1].
Brinkman, R, & L.J. Pons, 1968. A pedo-geomorphological classification and map of the Holocene sediments in the coastal plain of the three Guianas. Soil Survey Papers 4, Neth. Soil Surv. Inst., Wageningen.
Broek, J.M.M. van den & H.W. van der Marel, 1968. Weathering, clay migration and podzolization in a hydromorphic loess soil. Geoderma 2: 121-150.
Brouwer, G.C., Carte géologique détaillée de la France, département de la Guyane. Imprimerie Nationale, Paris.
1961 Feuille de St Jean
1964a Feuille de Paul Isnard
1964b Feuille de Lawa-Abounamy
Brouwer, G.C. & P. Coudert, 1966. Carte géologique détaillée de la France, département de la Guyane. Feuille Maripa Soula.
Brugière, J.M. & C. Marius, 1966. Reconnaissance des sols le long du Maroni et de la Crique Grand Inini. ORSTOM, Cayenne (unpublished report P 79)[2].
Buringh, P., 1960. Soils and soil conditions in Iraq. Ministry of Agriculture, Baghdad.
Burri, C., 1964. Petrochemical calculations based on equivalents. Israel program for scientific translations, Jerusalem.
Camargo, M.N. & J. Bennema, 1962. Some considerations on the major soils of the humid tropics of Brazil. World Soil Resources Rep. FAO/UNESCO: 87-91.
CBL Topographical maps and aerial photographs of Surinam. Centraal Bureau Luchtkartering, Paramaribo.
Cescan, M.P., E.H. Tyner & J. Gray, 1968. The electron microprobe X-ray analyzer and its use in soil science. Adv. Agron. 20.
Choubert, B., 1957. Essai sur la morphologie de la Guyane. Mém. Carte Geol. dét. de la France. Imprimerie Nationale, Paris.
Choubert, B., 1966. Carte géologique de la Guyane française. In: Brugière & Marius, 1966.
Cohen, A. & J.J. van der Eyk, 1953. Classificatie en ontstaan van savannen in Suriname. Geol. Mijnb. N.S. 15: 202-214.
Cotton, C.A., 1940. Classification and correlation of river terraces. J. Geomorph. 3: 27-37.
CPCS, 1967. Classification des sols. ENSA, Grignon.
Damuth, J.E. & R.W. Fairbridge, 1970. Equatorial atlantic deep-sea arkosic sands and ice-age aridity in tropical South America. Bull. geol. Soc. Am. 81 (1): 189-206.
Doeglas, D.J., 1940. The importance of heavy mineral analysis for regional sedimentary petrology. Nat. Res. Council, Washington.
Doeglas, D.J., 1946. Interpretation of the results of mechanical analyses. J. sed. Petrol. 16 (1): 19-40.
Doeglas, D.J., 1950. De interpretatie van korrelgrootte analysen. Verh. ned. geol. mijnb. Genoot. 15: 247-355.
Doeglas, D.J., 1952. Afzettingsgesteenten. Servire, den Haag.
Doeglas, D.J., 1955. A rectangular diagram for comparison of size-frequency distributions. Geol. Mijnb. N.S. 17: 129-136.

Doeglas, D.J., 1960. Sedimentological data for soil mineralogy. Trans. 7th Int. Congr. Soil Sci. VII (13): 534-547.
Doeglas, D.J., 1962. A graphic approach to the interpretation of variations in the size-frequency distribution of silty clays. Bull. fr. argiles, 13 (8): 3-14.
Doeglas, D.J., J.Ch.L. Favejee, D.J.G. Nota & L. van der Plas, 1965. On the identification of feldspars in soils. Meded. Landbouwhogeschool, Wageningen, 65 (9): 1-14.
Dost, H., 1959. Rapport over de bodemgesteldheid van Albina en omstreken. Dienst Bodemkart. Suriname (unpublished report)[1].
Edelman, C.H., 1933. Petrologische provincies in het Nederlandsche Kwartair. Thesis, Amsterdam.
Eijk, H.T.L. van, 1961. Kaartblad H9: De Goeje gebergte. Jaarb. Geol. Mijnbouwk. Dienst Suriname 1956-1958 (5).
Escher, B.G., 1958. Grondslagen der algemene geologie. Wereldbibliotheek, Amsterdam.
Eyk, J.J. van der, 1957. Reconnaissance soil survey in northern Surinam. Thesis, Wageningen.
Fairbridge, R.W., 1968. The encyclopedia of geomorphology. Reinhold Book Corp.
Fölster, H., & T.A.O. Ladeinde, 1967. The influence of stratification and age of pedisediments on the clay distribution in ferruginous tropical soils. Pédologie, Gand, 17 (2): 212-231.
Garner, H.F., 1967. Rivers in the making. Scient. Am. 216: 84-94.
Garrels, R.M., 1959. Rates of geochemical reactions at low temperatures and pressures. In: Researches in Geochemistry: 25-37. Wiley & Sons, New York.
Garrels, R.M., & C.L. Christ, 1965. Solutions, minerals and equilibria. Harper & Row, New York.
Geological nomenclature, 1959. Royal Geol. & Mining Soc. of the Netherlands.
Geyskes, D.C., 1955. De landbouw bij de bosnegers van de Marowijne. Westindische Gids 35: 135-153.
Haan, J.H. de, 1954. Nomadische landbouw. In: De Surin. Landb. 2 (1): 4-8.
Hammen, T. van der, 1961. The Quaternary climatic changes of northern South America. Ann. N.Y. Acad. Sci. 95 (1): 676-683.
Hammen, T. van der, 1963. A palynological study on the Quaternary of British Guiana. Leid. geol. Meded. 29: 125-180.
Hammen, T. van der, 1969. Introduction and short outline of the history of the younger areas of the Guianas. Verh. nederl. geol. mijnb. Genoot. 27: 9-12
Hammen, T. van der & E. Gonzales, 1960. Upper Pleistocene and Holocene climate and vegetation of the 'Sabana de Bogota' (Columbia). Leid. geol. Meded. 25: 261-315.
Hammen, T. van der & T.A. Wymstra, 1964. A palynological study of the Tertiary and Upper Cretaceous of British Guiana. Leid. geol. Meded. 30: 183-241.
Harten, D. van, 1965. On the estimation of relative grain frequencies in heavy mineral slides. Geol. Mijnb. 44: 357-363.
Haug, G.M.W., 1966. Verslag van het veldwerk in het stroomgebied van de Paloemeu. Geol. Mijnbouwk. Dienst Suriname (unpublished report 17/66)[3].
Helgeson, H.C., T.H. Brown & R.H. Leeper, 1969. Handbook of theoretical activity diagrams depicting chemical equilibria in geologic systems including an aqueous phase at one atm. and 0-300 °C. Freeman, Cooper & Cie, San Francisco.
Jongerius, A, 1970. Some morphological aspects of regrouping phenomena in Dutch soils. Geoderma 4 (3): 311-331.
Jongerius, A & G. Heintzberger, 1964. The preparation of mammoth-sized thin sections. Soil Surv. Pap., Neth. Soil Surv. Inst. 1.
Jongerius, A & J. Schelling, 1960. Micromorphology of organic matter formed under the influence of soil organisms, especially soil fauna. Trans. 7th Int. Congr. Soil Sci. III: 702-710.

Kiel, H., 1955. Heavy mineral investigations of samples of Surinam. Geol. Mijnb. N.S. 17: 93-103.
King, L.C., D.K. Hobday & M. Mellody, 1964. Cyclic denudation in Surinam. Geol. Mijnbouwk. Dienst Suriname (unpublished report)[3].
Krook, L., 1965a. Verslag van het mineralogisch onderzoek van de zandmonsters SA, EW, RG, CP en HA op kaartblad 66. Geol. Mijnbouwk. Dienst Suriname (unpublished report)[3].
Krook, L., 1965b. Verslag van het mineralogisch onderzoek van de HA, CP en EW monsters van de kaartbladen 66 en 67. Geol. Mijnbouwk. Dienst Suriname (unpublished report)[3].
Krook, L., 1968a. Origin of bedrock values of placer deposits. Econ. Geol. 63: 845-846.
Krook, L., 1968b. Some investigations on the mineralogy of the sands in the coastal area of Surinam. Geol. Mijnbouwk. Dienst Suriname (unpublished report 1/68)[3].
Krook, L., 1969a. Investigations on the mineralogical composition of the Tertiary and Quaternary sands in northern Surinam. Verh. ned. geol. mijnb. Genoot. 27: 89-100.
Krook, L., 1969b. Climate and sedimentation in the Guianas during the Last Glacial and the Holocene. 8th Inter-Guiana Geol. Conf.
Krook, L., 1969c. Alluvial prospection in tropical regions. 8th Inter-Guiana Geol. Conf.
Kubiena, W.L., 1938. Micropedology. Collegiate Press Inc., Ames, Iowa.
Leopold, L.B., M.G. Wolman & J.P. Miller, 1964. Fluvial processes in geomorphology. Freeman & Cie, San Francisco.
Lindeman, J.C. & S.P. Moolenaar, 1959. Preliminary survey of the vegetation types of northern Surinam. The vegetation of Surinam I (2).
Maignien, R., 1966. Review of research on laterites. Unesco.
Marius, C. & A. Misset, 1968. Reconnaissance pédologique de la Guyane française méridionale. ORSTOM, Cayenne (unpublished report P.100).
Mc Connell, R.B., 1966. The succession of erosion levels in Guyana. 7th Inter-Guiana Geol. Conf. 34.
Miedema, R. & S. Slager, 1972. A quantitative micromorphological study on clay illuviation. J. Soil Sci. (in press).
Milner, H.B., 1962. Sedimentary petrography. George Allen & Unwin, London.
Minashina, N.G., 1958. Optically oriented clays in soils. Soviet Soil Sci: 424-430.
Mohr, E.C.J. van, F.A. van Baren & J. van Schuylenborgh, 1972. Tropical soils. Elsevier, Amsterdam.
Montagne, D.G., 1964. New facts on the geology of the young unconsolidated sediments of northern Surinam. Geol. Mijnb. 43: 499-515.
Munck, V.C. de, 1953. Voorlopige geologische resultaten van de medisch-wetenschappelijke expeditie naar de zuidgrens van Suriname in 1952. Geol. Mijnb. N.S. 15: 152-162.
Munck, V.C. de. Geologische kaart van Suriname 1:100 000. Geol. Mijnbouwk. Dienst Suriname.
1954a Kaartblad 24: Bigiston
1954b Kaartblad 32: Nassau
1954c Kaartblad 23: Java
Munsell Color Comp. Inc., 1954. Munsell soil color charts. Baltimore, USA.
Nota, D.J.G., 1958. Sediments of the western Guiana shelf. Thesis, Wageningen.
Nota, D.J.G., 1967. Geomorphology and sediments of the western Surinam shelf. A preliminary note. Geol. Mijnb. 48: 185-188.
Nota, D.J.G., 1971. Morphology and sediments off the Marowijne River, eastern Surinam shelf. Hydrographic Newsletter. Spec. Publ. 6: 31-36.
Oertel, A.C., 1968. Some observations incompatible with clay illuviation. Trans. 9th Int. Congr. Soil Sci. IV: 481-488.

O'Herne, L., 1961. Geologische kaart van Suriname 1:100 000; kaartblad E8: Lely gebergte. Jaarb. Geol. Mijnbouwk. Dienst Suriname 1956-1958 (4).
O'Herne, L., 1969a. A new interpretation of the stratigraphy of Surinam. In: Meded. 20, Geol. Mijnbouwk. Dienst Suriname.
O'Herne, L., 1969b. De stand der geologische kartering van Suriname. In: Meded. 20, Geol. Mijnbouwk. Dienst Suriname.
O'Herne, L., 1969c. Suriname's bijdrage aan de geologische en tektonische overzichtskaarten van Zuid Amerika. In: Meded. 20, Geol. Mijnbouwk. Dienst Suriname.
O'Herne, L., 1969d. A photogeological study of the basal complex of Surinam. In: Meded. 20, Geol. Mijnbouwk. Dienst Suriname.
Plas, L. van der & A.C. Tobi, 1965. A chart for judging the reliability of point counting results. Am. J. Sci. 263: 87-90.
Plas, L. van der & J. van Schuylenborgh, 1970. Petrochemical calculations applied to soils-with special reference to soil formation. Geoderma 4: 357-385.
Quinn, J.H., 1957. Paired river terraces and Pleistocene glaciation. J. Geol. 65: 149-166.
Roeleveld, W., 1969. Pollen analysis of two sections in the Young Coastal Plain of Surinam. Geol. Mijnb. 48: 215-224.
Schuylenborgh, J. van & M.G.M. Bruggewert, 1965. On soil genesis in temperate humid climate V: The formation of 'albic' and 'spodic' horizon. Neth. J. agric. Sci. 13: 267-279.
Slager, S., 1966. Morphological studies of some cultivated soils. Thesis, Wageningen.
Slager, S. & J. van Schuylenborgh, 1970. Morphology and geochemistry of three clay soils of a tropical coastal plain (Surinam). Versl. landbouwk. onderz. 734, Wageningen.
Sombroek, W.G., 1966. Amazon soils. Thesis, Wageningen.
Strahler, A.N., 1969. Physical geography, 3rd ed. Wiley & Sons, New York.
Sunecon, 1969. Soil survey of the Albina-Moengo road. Unpublished map, Paramaribo.
Sys, C., 1968. Suggestions for the classification of tropical soils with lateritic materials in the American classification. Pédologie, Gand 18 (2): 189-198.
Thiais, J.L., 1967. L'Analyse des sols au centre ORSTOM de Cayenne. Unpublished report[2].
Thorp, J. & G.D. Smith, 1949. Higher categories of soil classification: Order, Suborder, and Great Groups. Soil Sci. 67 (2): 117-126.
USDA Soil Survey Staff, 1960-1967. Soil classification, a comprehensive system, 7th Approximation. Soil Conservation Service, Washington.
USDA Soil Survey Staff, 1962. Soil Survey Manual. Handbook 18, 2nd ed., Washington.
Veen, A.W.L., 1970. On geogenesis and pedogenesis in the Old Coastal Plain of Surinam (South America). Thesis, Amsterdam.
Veen, A.W.L. & P. Maaskant, 1971. Electron microprobe analysis of plasma in an impervious horizon of a tropical groundwater podzol. Geoderma 6: 101-107.
Veen, A.W.L., S. Slager & A.G. Jongmans, 1971. A micromorphological study of four Pleistocene alluvial soils of Surinam. Geoderma 6: 81-100.
Wyk, W.R. van & D.A. de Vries, 1952. Weer en klimaat. Deel II: Het klimaat. Bohn, Haarlem.
Wymstra, T.A., 1969. Palynology of the Alliance well. Geol. Mijnb. 48: 125-133.
Wymstra, T.A. & T. van der Hammen, 1966. Palynological data on the history of tropical savannas in northern South America. Leid. geol. Meded. 38: 71-90.
IJzerman, R., 1931. Outline of the geology and petrology of Surinam. Thesis, Utrecht.

Zonneveld, J.I.S., 1952. Watervallen in Suriname. Tijdschr. K. ned. aardrijksk. Genoot. 69: 499-507.
Zonneveld, J.I.S., 1957. River terraces and Quaternary chronology in the Netherlands. Geol. Mijnb. N.S. 19: 277-285.
Zonneveld, J.I.S., 1968. Quaternary climatic changes in the Caribbean and N. South-America. Eiszeitalt. u. Gegenw. 19: 203-208.
Zonneveld, J.I.S., 1969a. Preliminary remarks on summit levels and the evaluation of the relief in Surinam. Verh. ned. geol. Mijnb. Genoot. 27: 53-60.
Zonneveld, J.I.S., 1969b. Soela's in de Corantijn (Suriname). K. ned. aardrijksk. Genoot., Geogr. Tijdschr. 3 (1): 45-55.

1. Dienst Bodemkartering Suriname, Rust en Vredestraat 79-81. Paramaribo, Suriname.
2. Centre ORSTOM de Cayenne, Boîte Postale 165. Cayenne, Guyane française.
3. Geologisch Mijnbouwkundige Dienst Suriname, Klein Waterstraat 2-4, Paramaribo, Suriname.