SEDIMENT PETROGRAPHICAL STUDIES IN NORTHERN SURINAME

L. KROOK

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STELLINGEN

1. De term "ongesorteerde zanden", die algemeen gebruikt wordt met betrekking tot de afzettingen van de Boven-Coesewijne Formatie in Suriname, is niet juist.

2. De bewering van Oele, dat het voorkomen van de grofkorrelige zanden op de continentale shelf van de Guyana's een gevolg zouden zijn van "plaatselijke omstandigheden" gedurende het Laat-Pleistoceen, waarbij het klimaat geen rol speelde, is in strijd met waarnemingen op het Guyana Schild.

   E. Oele, 1978 - Sand and gravel from shallow seas. Geologie en Mijnbouw 57, p. 45-54.

   Dit proefschrift.

3. De geomorfologische positie van een deel van de bauxietafzettingen in het Bakhuisgebergte in West-Suriname maakt het waarschijnlijk dat deze gevormd zijn in het Laat-Tertiair.

   L. Krook and E.W.F. de Roever, 1975 - Some aspects of bauxite formation in the Bakhuis Mountains, Western Suriname. Annais da Décima Conf. Geol. Interguianas, Belém, Pará, Brasil, 1, p. 686-697.

4. Gezien de behoefte aan gegevens met betrekking tot het verloop van het relatieve zeeniveau in het Laat-Pleistoceen en het Vroeg-Holoceen is het wenselijk de op verschillende diepten van de Guyana shelf voorkomende fossiele koraalriffen te bemonsteren voor ^{14}C bepalingen.

5. De geringe klei-aanvoer tijdens de vorming van de Mara afzettingen in de Surinaamse kustvlakte is geen gevolg van de grote afstand tot de zee, maar van het feit dat de pelitische sedimenten van de Amazone tijdens de rijzende zeespiegel in het Laat-Pleistoceen en het Vroeg-Holoceen grotendeels als limnische sedimenten werden afgezet in het verdronken dal van deze rivier.

   R. Brinkman and 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 No. 4. Soil Survey Institute, Wageningen.

   Dit proefschrift.

6. Door de dikwijls hoge concentraties van zware mineralen in kolkgaten in rivierbeddingen lijken deze bij uitstek geschikt voor bemonstering. Het voorkomen van sterk verweerbare mineralen doet echter vermoeden dat deze ter plaatse door corrasie uit het gesteente zijn vrijgemaakt.

7. Het feit dat gedurende de lage zeespiegelstand in het Laat-Pleistoceen "beachdrifting" langs de kust van de Guyana's een belangrijker rol speelde dan thans is grotendeels een gevolg van het ontbreken van modderbanken in die periode.

Dit proefschrift.

8. De tot dusver opgestelde hypothesen over het ontstaan van soela-komplexen in Suriname berusten niet op voldoende kwantitatieve gegevens.

9. Indien zware mineralen gefraktioneerd worden bestudeerd, verdient het aanbeveling om het zeven in de gewenste korrelgroottefrakties te doen plaatsvinden na het afscheiden van de zware fraktie van het uitgangsmateriaal.

10. De voorstelling van het ontstaan van depressies langs een quasi-stationair polair front in een langgerekte vore, zoals deze dikwijls in meteorologische leerboeken wordt weergegeven, geeft slechts een uitzonderlijk geval weer.

11. In de "grote droge tijd" (half augustus tot begin december), als de Intertropische Convergentie Zone zich ten noorden van Suriname bevindt, treedt, vooral in het binnenland, nu en dan een hevige buienaktiviteit op. Satellietwaarnemingen maken het waarschijnlijk dat deze buien gebonden zijn aan oude polaire fronten die vanuit Brazilië naar het noorden trekken en in de bovenlucht een grote instabiliteit veroorzaken.

12. In de schaatssport is de mijl een afstand van 1500 m. Gezien het dikwijls voorkomende grote verschil tussen de officiële en de werkelijke afstand van een schaatstoertocht schijnt de kilometer over het algemeen een nog grotere devaluatie te hebben ondergaan dan de mijl.

Proefschrift van L. Krook

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Amsterdam, 30 maart 1979

VRIJE UNIVERSITEIT AMSTERDAM

SEDIMENT PETROGRAPHICAL STUDIES IN NORTHERN SURINAME

ACADEMISCH PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN
DOCTOR IN DE WISKUNDE EN NATUURWETENSCHAPPEN
AAN DE VRIJE UNIVERSITEIT TE AMSTERDAM,
OP GEZAG VAN
DE RECTOR MAGNIFICUS DR. D.M. SCHENKEVELD,
HOOGLERAAR IN DE FACULTEIT DER LETTEREN,
IN HET OPENBAAR TE VERDEDIGEN
OP VRIJDAG 30 MAART 1979 TE 13.30 UUR
IN HET HOOFDGEBOUW DER UNIVERSITEIT,
DE BOELELAAN 1105

DOOR

LEENDERT KROOK

GEBOREN TE AMSTERDAM

DRUKKERIJ ELINKWIJK BV – UTRECHT

PROMOTOR : PROF. DR. A.J. WIGGERS
COPROMOTOR: PROF. DR. J.D. DE JONG
COREFERENT : PROF. DR. TH. VAN DER HAMMEN

Aan Em, Roel, Ferdie en Stephen

CONTENTS

PREFACE

The purpose of the present work is to trace the geological history of the sedimentary deposits of Northern Suriname and to study the relationship between the various factors involved in their formation. Such factors comprise the geology of the Precambrian shield, climate, weathering, erosion, transport of the sediments and relative sea-level movements. The starting-point of the author was the study of the mineralogy of the sand fractions of the deposits in order to determine their provenance and their rate of weathering. Combined with the results of other fields of investigation an attempt is made to arrive at a reconstruction of the evolution of the coastal area.

ACKNOWLEDGEMENTS

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Without the kind intervention of Prof. Dr. H.W. Fairbridge the author would have been unaware of the important work done on the Amazon River by Prof. Dr. H. Sioli and Dr. G. Irion.

The author is much obliged to Drs. R.A. Cambridge, Director of the Geological and Mining Service of Suriname, for his permission to use the mineralogical data in this thesis and his intention to publish it in the "Mededelingen" of the Geological and Mining Service.

Much stimulation and aid was obtained from my former colleagues. Dr. Th.E. Wong gave valuable advice on part of the text and sent several samples from exploration holes on the continental shelf. Dr. W. Bosma, Drs. R.V. van Lissa and Drs. J.H.M. Schönberger were helpful in many ways.

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1. THE GEOLOGICAL FRAMEWORK

1.1 Physiography

Suriname is a part of the Precambrian Guiana Shield. In the north this Shield shows a seaward dip and is covered by Late Cretaceous and Cenozoic deposits of the Guiana Basin.

On the Precambrian Shield many different landscapes occur, connected with the geology and the geomorphological stage. The relation of landscape and geology has been used by O'Herne (1969a,b) to construct a photogeological map of Suriname, based on aerial photographs and additional field data.

With respect to the topography of the shield various grades of relief can be distinguished, flat, rolling, hilly and mountainous. Mountainous areas of various types occur which are closely connected with the lithology. The Wilhelmina Mountains, the Kayser Mountains, the Eilerts de Haan Mountains, the Oranje Mountains and the southern part of the Bakhuis Mountains consist of granitic and related volcanic rocks (see figure 1). Some parts of these areas show very rugged terrain with steep slopes. Other granitic areas are relatively low with isolated inselbergs. The Lely Mountains, the Nassau Mountains, the Brownsberg and the northern part of the Bakhuis Mountains are more or less dissected plateaux, capped by bauxite or laterite. The Van Asch van Wijk Chain is a large dolerite dyke. In the central part of the country the Tafelberg occurs, a plateau of nearly horizontal sandstone. The Emma Chain consists partly of sandstone, partly of a dolerite sill.

The drainage pattern of many rivers and creeks shows a relation with faults and joints. The main directions of these are NW-SE and NE-SW. The rivers on the shield have many rapids, often displaying wide, braided patterns.

The main drainage of the country is to the north. The west and east borders of the country are formed by the largest rivers, the Corantijn and the Marowijne. These rivers and the Coppename and the Suriname discharge straight into the Atlantic Ocean. All other rivers are deflected in their lower courses and join the larger rivers at their mouths.

1.2 Climate

Suriname has a humid tropical climate, mainly Am and Af, with some Aw in a narrow belt along the coast (climate according to the system of Köppen). The average annual temperature is 27° C and the average rainfall is 2200 mm, but it varies from less than 1500 mm on part of the coast to more than 2500 mm in the central part of the country. Four seasons can be distinguished: the Short Rainy Season (beginning of December to beginning of February), the Short Dry Season (beginning of February to end of April), the Long Rainy Season (end of

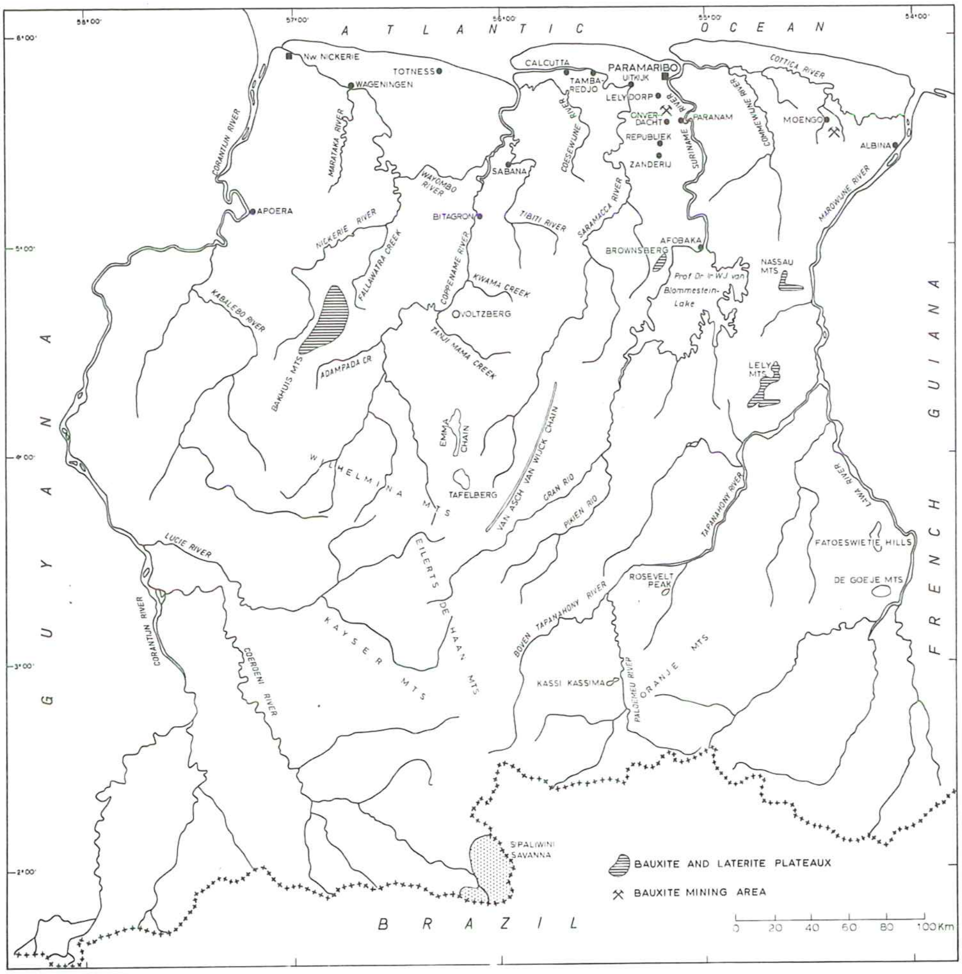


Fig. 1 Map of Suriname

April to middle of August) and the Long Dry Season (middle of August to beginning of December). There is a close relation between the precipitation and the position of the Inter Tropical Covergence Zone.

The humidity of the air is high. The trade winds blow steadily, mainly from the NE, with a velocity of about 5 m/sec. A summary of the climate of Suriname has been given by Van Scherpenzeel (1977).

1.3 Vegetation

The greater part of the country is covered with primary tropical rain forest. A large savanna, the Sipaliwini Savanna is situated in the south of the country. Savanna woodlands and scattered savannas are found in Northern Suriname in a belt more or less parallel to the coast (see 1.4.2). The swamps and marshes in the coastal plain are partly covered with grass and partly with swamp forest and marsh forest. Along the coast and the river mouths a mangrove vegetation occurs.

1.4 Geology

Systematic geological exploration carried out by geologists of the Geological and Mining Service resulted in the Geological Map of Suriname, scale 1 : 500,000 (Geologisch Mijnbouwkundige Dienst van Suriname, 1977; Explanatory Note by Bosma et al., 1977). The Tertiary and Quaternary deposits of Northern Suriname, however, have been mapped mainly by soil scientists of the Soil Survey Department.

Apart from geological fieldwork extensive geophysical and geochemical fieldwork has been carried out. Information of primary interest with respect to the mineral potential of the country has been presented on a metallogenic map of Suriname (Dahlberg, 1975).

Table 1 shows the stratigraphy of Suriname. The numbers refer to the formations on the simplified geological map of Suriname (fig. 2).

1.4.1 The Crystalline Shield

The rocks of the Falawatra Group occur mainly in the Bakhuis Mountains and to the north-east of them. Rocks of the related Coeroeni Group occur in Southwestern Suriname. Both the Falawatra Group and the Coeroeni Group are considerable older than the formations of the Marowijne Group. The latter occur in the north-eastern and eastern part of the Surinam shield, apart from some scattered occurrences in central and Western Suriname (Ston and Matapi Formations). They consist of geosynclinal volcanic and sedimentary deposits which were folded and metamorphosed during the Trans-Amazonian Orogenic Cycle. The magmatism of this cycle is shown by the Granitoid Rocks which cover more than half of the shield area and the Dalbana Rhyolites. Scattered bodies of gabbroic rocks, collectively known as the "De Goeje Gabbro" occur in the country. They have about the same age as the Granitoid Rocks.

The sandstones of the Roraima Formation which cover large parts of Venezuela, Guyana and Brazil, occur only in the central part of the country on and around the Tafelberg.

The Avanavero Dolerites are mainly found in the western and central parts of the country. The Apatoe Dolerites, of Permo-Triassic age, occur mainly in the eastern part of the country and have a N-S to NNW-SSE direction. Dolerites of the same age and younger are found in many countries bordering the Atlantic Ocean. They show a pre-continental drift stress pattern (May, 1971).

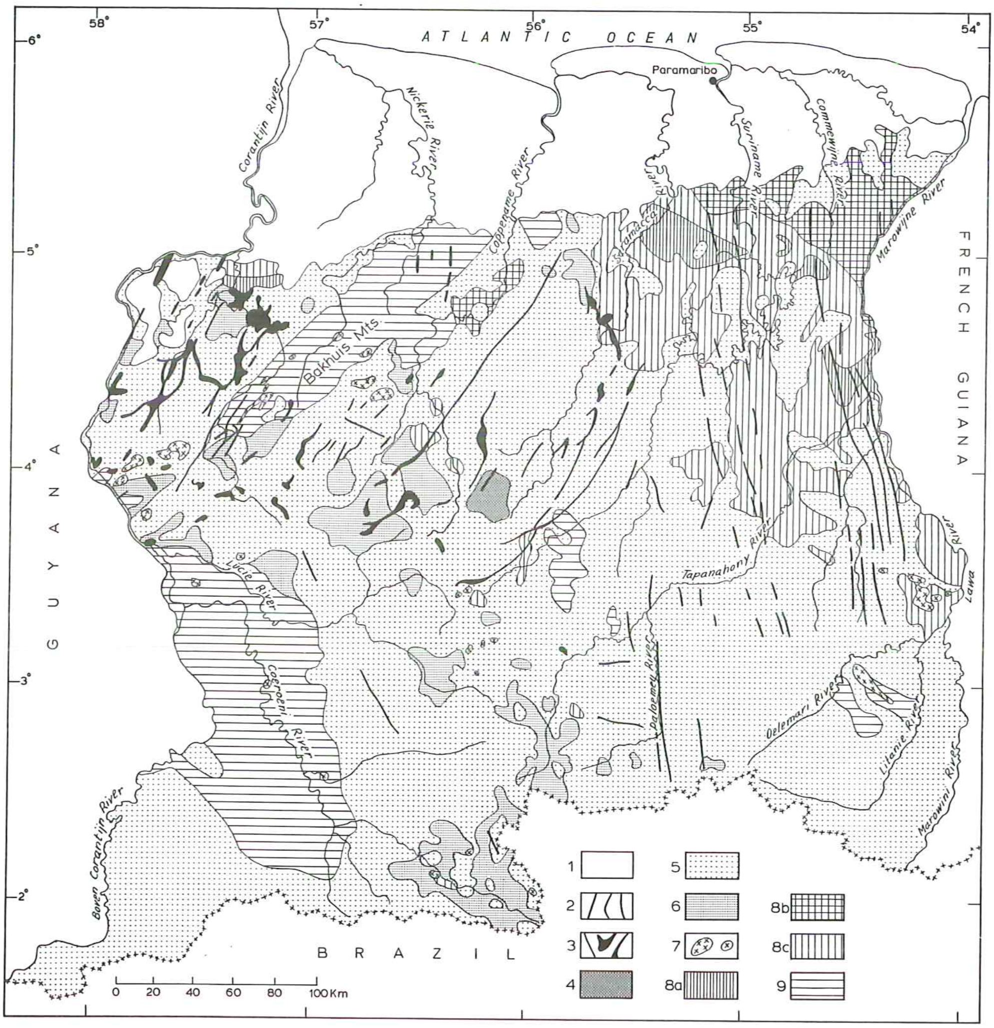


Fig. 2 Simplified geological map of Suriname (after Bosma, 1977 and Geol. Mijnb. Dienst, 1977). For meaning of the numbers in the legend see table 1.

Palaeozoic formations occur only on the southern margin of the Guiana Shield, bordering the Amazon Basin (see fig. 30). The find of reworked Palaeozoic pollen in the Cretaceous deposits of one drill hole (CC-4, near CC-3, see figure 11) in the coastal plain (Noorthoorn van de Kruijff, 1970), suggests that formations of Palaeozoic age once covered a larger part of the shield but were removed by erosion by the end of the Cretaceous.

1.	CORANTIJN GROUP	Cretaceous to Recent	Paleocene to Recent: unconsolidated sands and clays Cretaceous: partly consolidated sands and clays
2.	APATOE DOLERITE	Permo-Triassic 230 ± 10 Ma	Pigeonite dolerite dykes; strike mainly N-S
	Shearing and mylonitization of Nickerie Metamorphic Episode, about 1200 Ma		
3.	AVANAVERO DOLERITE	Precambrian 1660 ± 25 Ma	Sills and dykes of hypersthene bearing pigeonite gabbro and dolerite
4.	RORAIMA FORMATION	1655 ± 20 Ma	Subhorizontal quartzitic sandstones and conglomerates with local tuff intercalations
	Acidic plutonic-volcanic magmatism of Trans-Amazonian Orogenic Cycle:		
5.	GRANITOID ROCKS	1900-2000 Ma	Biotite granites; in the Marowijne area tonalites and muscovite granites; pyroxene granites in Bakhuis Mts; leucogranites associated with Dalbana rhyolites
6.	DALBANA RHYOLITE	1900-2000 Ma	Slightly metamorphosed rhyolitic-dacitic lavas and tuffs including ash-flow tuffs
7.	DE GOEJE GABBRO	1900-2000 Ma	Older gabbroic and ultrabasic intrusives
	Sendimentation, folding and metamorphism of geosynclinal stage of Trans-Amazonian Orogenic Cycle;		
8.	MAROWIJNE GROUP		Geosynclinal metasediments and metavolcanics
	a. Rosebel Formation (Eastern Suriname) Ston Formation (Western Suriname)		Molasse type metasediments: quartzites, graywackes, subgraywackes and conglomerates mainly; greenschist facies
	b. Armina Formation		Flysch type metasediments mainly: schists and phyllites; greenschist and amphibolite facies
	c. Paramaka Formation (Eastern Suriname) Matapi Spilite (Western Suriname)		Metavolcanics and metasediments: spilites, basalts and basic tuffs, rhyolites and dacites; schists, phyllites and quartzites; greenschist and amphibolite facies
	Pre-Trans-Amazonian Orogenic Cycles (?):		
9.	COEROENI GROUP		Biotite gneisses, partly with sillimanite, hornblende gneisses and amphibolites; mostly amphibolite facies
9.	FALAWATRA GROUP	2400 Ma	Charnockitic granulites in central Bakhuis Mts, sillimanite gneisses, pyroxene gneisses and biotite gneisses, amphibolites

Table 1 Major stratigraphic units of Suriname (after Bosma and Oosterbaan, 1972 and Bosma et al., 1977; slightly revised). The numbers refer to the legend of figure 2.

1.4.2 The Coastal Area

The coastal area is underlain by sediments of Late Cretaceous (Maastrichtian and probably older) to Holocene age. The total thickness of these deposits increases from south to north and from east to west. At the mouth of the Marowijne the thickness is only about 200 m, but near Nieuw-Nickerie at the mouth of the Corantijn the depth of the basement is nearly 2000 m (Guicherit, 1969). Depth contours are shown in Enclosure 2.

Only Pliocene, Pleistocene and Holocene strata crop out in the coastal area, apart from some early Tertiary in the bauxite areas (see Enclosure 1). Figure 3 shows a north-south section through the coastal area near Paramaribo with the stratigraphy, the present formation names and the landscapes. In the south the Upper Coesewijne Formation occurs, of Pliocene age. This formation consists mainly of medium to poorly sorted sand to loamy sand and locally kaolinitic clay. About 40% of the deposits, usually the higher parts, are white, bleached sands, while the rest consists of yellowish brown unbleached sands, loams and clays. The sand is generally known as the "Zanderij" sand in Suriname, while they are called the "White Sands" in Guyana and the "Sables Blancs"

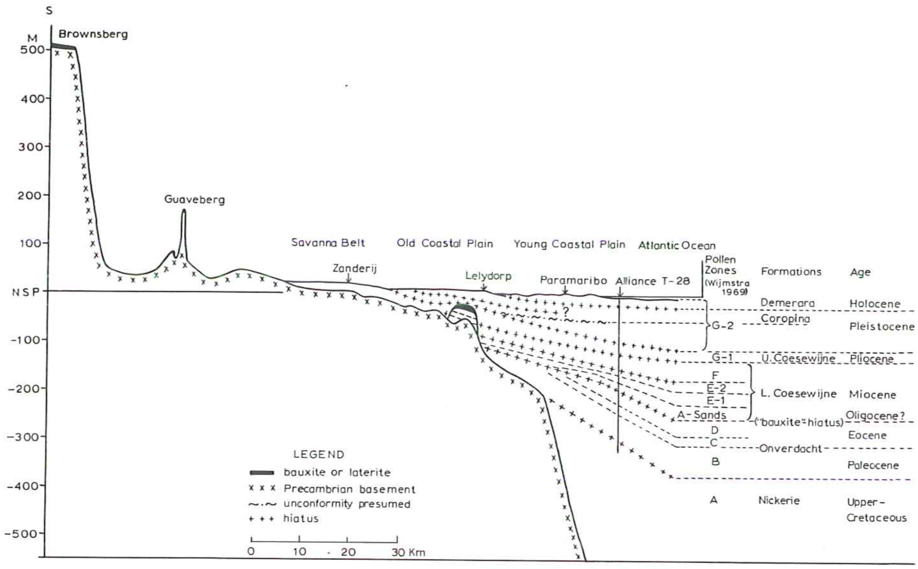


Fig. 3 Simplified N-S section of the coastal area near Paramaribo (modified after Krook and Mulders, 1971)

in French Guiana. The yellow brown sands and loams usually support high rain forest, while the white sands are usually covered with dense and low savanna woodlands and open savannas. Although the latter cover about 7% of the upper Coesewijne Formation, the - flat to rolling - landscape is known as the "Savanna Belt".

North of the Savanna Belt the Pleistocene Coropina Formation occurs which forms the Old Coastal Plain. In the northern part of the Old Coastal Plain well sorted fine sands of the "Offshore Bar Landscape" occur (fig. 4), generally known as the "Lelydorp Sands". The landward part of the Old Coastal Plain is formed by silty clays of the "Old Sea Clay Landscape", also known as "Para Landscape". Both, the sands and the greater parts of the clays are most probably of last interglacial age (Brinkman and Pons, 1968). The Old Coastal Plain was severely eroded during the low sea-level of the last glacial. As a result of this erosion the Old Coastal Plain was divided in many separate remnants of various dimensions, known as "schollen" in Suriname. These separate occurrences could not be drawn on Enclosure 1 for reasons of scale. They have been shown on the Reconnaissance Soil Association Map by Van der Eyk (1957) and furthermore can be distinguished clearly on the topographical maps of Suriname, scale 1:40,000 and scale 1:100,000. North of the Old Coastal Plain and in the erosion gullies in the Old Coastal Plain the Holocene aged Demerara Formation occurs. It consists mainly of clays with cheniers or sandy ridges which are most frequent west of the river mouths. At some places ombrogenous peat occurs. The sandy

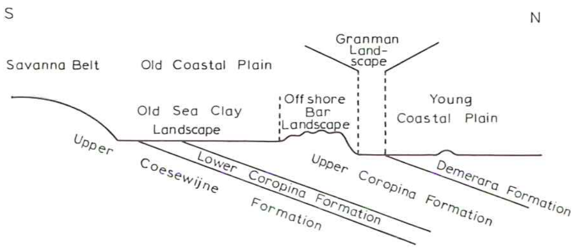


Fig. 4 Relation of stratigraphy and landscape in the Old Coastal Plain of Suriname (modified after Veen, 1970)

ridges can be divided into two groups, the fine sandy ridges and the coarse sandy ridges. The fine sandy ridges contain well sorted very fine sands with medians around 100 µm. Usually they contain some thin clay layers. The name ridge is inappropriate in many cases since they may be very wide. In this case they should rather be termed sand flats. The fine sandy ridges occur from the Suriname River to the west. The coarse sandy ridges are built up of sand with grain sized varying from about 250-450 micron, so in fact they are fine to medium grained. They occur from the Marowijne to the area NW of Paramaribo. Some very narrow ridges are found further west and a few tiny ones occur as far as Wageningen (drill hole site WA-3, 2.4.5.1 and figure 11). Grain size distributions of the sands of the ridges are given by Van der Eyk (1957). Part of some ridges consist of shell grit or unbroken shells. In older ridges the broken shells are locally cemented by calcite to breccia.

The ridges north of Paramaribo have been described in some detail by Geyskes (1952). He distinguished four types of ridges in relation to the part that was submerged during the rainy season. Sections through the ridges show that they are isolated sandbodies on clay, typical cheniers. The thickness of the sand varies from less than 1 m to about 7 m. Some ridges have small dunes, probably never attaining more than about 1 m in height.

Diephuis (1966) studied the formation of the ridges. He found that ridges usually mark an erosion phase of a mudbank. Concentration of the sand occurs by the action of the waves. After the next sequence of mud deposition and erosion another beach is formed and the older beach becomes a ridge. In chapter 4 the origin of the sand will be discussed. An extensive study on the movement of sand and mud along the coast and the formation of beaches and ridges has been carried out by Augustinus (1978).

The knowledge of the coastal area has shown a gradual growth. Middelberg (1908) called all the deposits of Northern Suriname "Alluvium" as distinguished from the crystalline formations of the interior. IJzerman (1931) divided the sedimentary deposits of Northern Suriname into "Continental Alluvia" and "Fluviomarine Deposits". Bakker (1949) recognized three phases of sedimentation, namely the "Bauxite Hill Phase", the "Old Coastal Plain" and the "Young Coastal Plain". In Schols and Cohen (1953) the sediments of the same phase are called the Zanderij Formation, the Coropina Formation and the Demerara Formation, respectively.

In deep drill holes a fourth, diagenetically hardened formation was recognized, the Nickerie Formation. The ages of all these formations were assumed to be Late Tertiary to Holocene.

Table 2 shows the stratigraphy according to Doeve (1957). The division of the bauxite deposits in two ages and their occurrence both at the base and at the top of the Bauxite Formation is after Van Kersen (1955).

Quaternary	Youngest Formation	Recent sediments	
		Demerara Series	
		Coropina Series	
			bauxite
	Bauxite Formation	Zanderij Series	
Tertiary		Nickerie Series	
			bauxite
Mesozoic-Precambrian	Basement Formations		

Table 2 Stratigraphy according to Doeve (1957)

The geology and geomorphology of the coastal area have been studied at a later stage for the greater part by soil scientists. Van der Voorde (1957) studied the ridges of the Young Coastal Plain and the Old Coastal Plain. Van der Eyk (1954, 1957) presented a relation of geology, landscapes and soils of Northern Suriname, based on aerial photographic studies and investigations in the field. In his first study the sandy facies of the Old Coastal Plain was called Lelydorp Landscape, while the silty clay deposits were called Para Landscape. The names were changed into Old Offshore Bar Landscape and Old Sea Clay Landscape respectively in his second study, but both Lelydorp and Para are still often used, especially by soil scientists. The landscape on the Zanderij Formation was called "Dek" Landscape or Cover Landscape.

Drilling for drinking water in the coastal plain lead to some excellent descriptions of the strata encountered at greater depth (d'Audretsch 1950, 1953; Van Loon, 1958). However, since there were no fossils apart from the Holocene clays, no age determinations could be given. All unconsolidated deposits were generally regarded as Quaternary. The find of Paleocene marls at some 20-25 m in bore holes in French Guiana came as a surprise (Van Voorthuysen, 1961, 1969). Since most sediments, however, were absolutely barren with respect to fossils, palaeontology could be of little help. Fortunately a great part of the deposits contained pollen and palynology turned out to be the tool to study the stratigraphy of the sedimentary deposits.

The cores of two deep drill holes in the coastal plain and mine faces in the bauxite belt of Guyana were studied by Van der Hammen and Wijmstra (1964). This resulted in a new stratigraphy of the deposits underlying the coastal plain and those of the bauxite belt of Guyana (former British Guiana). This stratigraphy is generally considered as standard for the whole of the deposits of the Guiana Basin. Table 3 gives a summary of this stratigraphy.

Age	Pollen-zones	Lithostratigraphical units (coastal wells)	
Quaternary to	G-2	Upper Clays: Demerara Clay, Coropina Clay	
Pliocene	G-1?	Upper Sands	
Lower Miocene	F	Upper Sands	
to	E	Intermediate Clays	
Oligocene	E	A-Sands	
			Bauxite hiatus
Eocene	D	Alternating	
	C	Alternating	
Paleocene	B-2	Sands and Clays	
Maastrichtian	B-1	Lower Consolidated	
	A	Sands and Clays	

Table 3 Stratigraphic table for Guyana (after Van der Hammen and Wijmstra, 1964)

In Suriname Montagne (1964) proposed a new stratigraphy of the "young" sediments in Northern Suriname, based on observations in the Onverdacht mining area, see table 4. The sediments underlying the bauxite were called the Onverdacht Series, while the sediments younger than the bauxite received the name Coesewijne Series. Both were subdivided into a lower and an upper part and each of those showed a sequence of coarse sand to kaolinic clay while the top of the Onverdacht Series consisted of bauxite. As seen in the table the age of the plateau bauxite was not yet established.

Holocene	DEMERARA SERIES		
Pleistocene	COROPINA SERIES	LELYDORP SERIES	
		PARA SERIES	
? Pliocene Upper Tertiary Oligo-Miocene	COESEWIJNE SERIES	UPPER-	
		LOWER-	Lowland Bauxite
? Eocene Lower Tertiary ? Paleocene	ONVERDACHT SERIES	UPPER-	
		LOWER-	? Plateau Bauxite ?
Precambrium	BASEMENT SERIES		

Table 4 Stratigraphy according to Montagne (1964b)

The Coropina was subdivided into a lower part, the Para Series and an upper part, the Lelydorp Series. The Para Series consists of coarse sand at the base and fine laminated stiff clays at the top. The sands are possibly reworked deposits of the Coesewijne Series. The purple, red and brownish yellow mottles of the clay indicated a phase of intense weathering. The Lelydorp Series shows fine, well sorted sands in the north and silty to sandy clays in the south. The Lelydorp Series is generally considered to be of last glacial age, while the Para Series might represent an older interglacial. A study of the clay minerals showed a marked difference in composition between the Para Series and the Lelydorp Series (Levelt and Quakernaat, 1968).

In 1966 a section was drilled along the highway from Zanderij to Lelydorp. The samples of the holes were studied and the results were communicated at the Seventh Guiana Geological Conference at Paramaribo (Aleva et al., 1969; Krook, 1969b). The stratigraphy after Montagne (1964b) was used but the term Series was replaced by Formation. This change has been applied consequently by Bosma and Groeneweg (1971) for the entire stratigraphy of Suriname. It was felt that the Lower Coesewijne Formation should comprise all post-bauxite Tertiary deposits, including the A-sands which do not crop out in the bauxite area where Montagne had designed his stratigraphy. The boundary between the Lower and Upper Coesewijne Formation was placed at the transition between pollen zone F (Miocene) and pollen zone G (Plio-Pleistocene). This was changed at a later date by Wijmstra (1971) who correlated the A-sands and the E-zone with the Lower Coesewijne Formation and the F-zone and part of the G-zone with the Upper Coesewijne Formation. The E-zone was divided in a lower, clayey part (E-1) and an upper, sandy part (E-2). The overlying F-zone consists mainly of clay. The term "Zanderij Formation" was used for the part of the Upper Coesewijne which

Montagne:			Wijmstra:				Aleva et al.:
Coesewijne Series	U	kaol. clay				?	?
		coarse sand	Coesewijne	Zanderij Form.	sand	zone G-1	Upper Coesewijne Formation
	L	kaol. clay		Upper	clay	zone F	Lower Coesewijne Formation
		coarse sand		Lower	sand	zone E-2	
					clay	zone E-1 (north of	
					A-sands	bauxite area)	
					Bauxite		

Table 5 Relation of lithology and stratigraphy of post-bauxite Tertiary deposits according to Montagne (1964b), Wijmstra (1971) and Aleva et al. (1969)

is exposed in the Savanna Belt and consists of the characteristic white sands and yellow brown loamy sands.

Table 5 shows the lithological succession and stratigraphy according to Montagne (1964b), Wijmstra (1971) and Aleva et al. (1969). The latter is used in this study (see also figure 3). Montagne's kaolinitic clay on top of the coarse sand is probably of very local occurrence. Thin layers of sandy clay or lignite containing pollen of zone G-1 are often found at the base of the Pliocene deposits in the Savanna Belt. They have been found as far as Zanderij (Aleva et al., 1969) and South of Sabana (Reynolds Suriname Mines, 1974).

Noorthoorn van de Kruijff (1970) introduced another stratigraphy of the coastal plain, based on the occurrence of two "density shifts", i.e. sudden increase in density encountered in several holes drilled for the exploration of oil. These density shifts are indications of the removal of former overlying sediments, followed by deposition of younger layers. The first density shift was found between the Upper Cretaceous and the Paleocene and the second in the mid-Lower Miocene. The first suggests the erosion of about 150 m, the second of about 60 m. The bauxite hiatus does not show a density shift.

Since the density shifts were clear "markers" in all drill holes, the stratigraphy was based on these markers. The Upper-Cretaceous-Paleocene marker was known as RM-10 and the mid-Lower Miocene (MLM) marker as RM-8. Three formations were distinguished: the Nickerie Formation below RM-10, the Calcutta Formation between RM-10 and RM-8 and the Tambaredjo Formation above RM-8. Both markers can be correlated with palynological boundaries: RM-10 between zones A and B and RM-8 between zones E and F.

The importance of the density shifts will be evident in the discussion of the denudational and depositional history in chapter 6.

The Quaternary of Guyana and Suriname has been studied by several workers. Van der Hammen (1963) and Wijmstra (1969, 1971) described the vegetational and climatic history and its geological implications. Brinkham and Pons (1968) gave a detailed classification of the Upper Coropina Formation and the Demerara Formation, deposited during the last interglacial and the Holocene respectively. The results are shown in table 6. In both, the Upper Coropina and the Demerara, a rising sea-level facies and a constant sea-level facies could be recognized. The sediments of the Onoribo phase represent the rising sea-level facies of the Upper Coropina. They consist of dark grey pyrite clay, rich in organic matter. They were first observed in the Onoribo IV mine of the Suriname Aluminium Company near Paranam (Brinkman et al., 1964) and are not found at the surface, except for one outcrop on the lower Coppename River (see 1.4.3). The sediments of the Santigron phase comprise fine sandy offshore bars and silty marine clays.

Formation	Deposit	Phase	Landscape	
		Comowine (1000-0 B.P.)	YOUNG	Young Sea Clay
DEMERARA (Holocene)	CORONIE (facies type; deposited at constant sea-level)	Moleson (2500-1300 B.P.)	COASTAL	Landscape
		Wanica (6000-3500 B.P.)	PLAIN	"Rits" Landscape
	MARA (deposited during rising sea-level 10,000-6000 B.P.)			
UPPER COROPINA (last interglacial)	LELYDORP	Santigron Phase (facies type; deposited at constant sea-level)	OLD	Offshore Bar Landscape (Lelydorp Landscape)
			COASTAL	Old Sea Clay Landscape (Para Landscape)
		Onoribo Phase (deposited at rising sea-level)	PLAIN	
LOWER COROPINA (older interglacial)	PARA			Old Sea Clay Landscape

Table 6 Stratigraphy of Quaternary sediments in the coastal plain of the Guianas according to Brinkman and Pons (1968)

The rising sea-level facies of the Demerara Formation, the Mara Deposits, are exposed in the southernmost part of the Young Coastal Plain and the erosion gullies in the Old Coastal Plain. They also underlie the younger deposits. They comprise soft peaty clays and eustatic clayey peats mostly with a high pyrite content. According to the authors they were formed in brackish *Rhizophora* swamp forest "with a small supply of clay because of the great distance to the sea". It will be shown in chapter 4 that this small clay supply was apparently not so much due to the distance to the sea (which actually was much shorter than the present one since the younger part of the coastal plain did not then exist), but due to the fact that most of the Amazon derived sediments were deposited in the large drowned valley of the Amazon during the rising sea-level stage when only the finest clay reached the sea (Irion, 1976a). Roeleveld (1969) studied the pollen of two drill holes in the Mara deposits in gullies south of Lelydorp. Both sections show a gradual increase of *Rhizophora* in the lower part. From 5.85 m upward in one section *Rhizophora* has grown in situ. A C-14 dating at about 5.5 m depth gave an age of 7240 ± 100 y. B.P.

The constant sea-level facies of the Demerara Formation is represented by the Coronie Deposits. They consist of "normal" marine clays, low in pyrite and organic matter and coarse and fine sandy ridges, partly containing shells. Three different phases can be distinguished: the Wanica phase (6000-3500 y. B.P.), the Moleson phase (2500-1300 y. B.P.) and the Comowine phase (1000 y.

B.P. to Present). They are separated by erosional coast lines, often with shell or sand ridges. In the greater part of the coastal plan the clays and sandy ridges occur at the same level as the recent deposits. East of the Cottica River, however, the elevation of the Wanica deposits is about 1 to 2 m higher, probably due to local uplift (Brouwer, 1953; Brinkman and Pons, 1968).

Veen (1970), in his study on the soil formation in the Old Coastal Plain, used the names Lower Coropina and Upper Coropina as stratigraphical terms instead of Para and Lelydorp, since the latter had also been used as landscape terms. Figure 4 shows the relation of the stratigraphy and the landscapes in the Old Coastal Plain according to Veen. This section also shows the effect of marine abrasion at two different times, viz. abrasion of the Upper Coesewijne Formation and abrasion of the sandy part of the Upper Coropina Formation. The Upper Coesewijne sands were abraded and redeposited in the basal part of the Lower Coropina Formation (see the description above of the Para Series by Montagne). Marine erosion also abraded the Offshore Bar Landscape before the deposition of the Demerara Formation.

1.4.3 The River Terraces

Along the rivers terrace deposits occur at several levels with sediments varying from loamy coarse sand to clay (Brinkman and Pons, 1968). The Suriname River has at least three terraces, the Lower, Middle and Upper Terrace, occurring at respectively 5-9 m, 12-16 m and 18-20 above mean river level (Mulders, 1971).

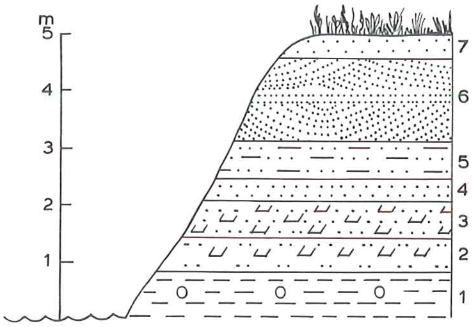


Fig. 5 Section of the right bank of the Coppename River NE of Heidoti

1. black kaolinitic clay with pyrite nodules (Onoribo phase, U. Coropina Formation), 2. white kaolinitic silt (Santigron phase, U. Coropina Formation), 3. white kaolinitic sand, 4. black sand (organic matter), 5. slightly clayey sand, 6. coarse sand with crossbedding, 7. brown structureless sand.

In the Savanna Belt near Bitagron on the Coppename River some five or six terraces have been observed (Krook and Mulders, 1971). Remnants of the youngest of these, the Lower Terrace, are found at several places along the river. This terrace occurs also in the Old Coastal Plain, some 5-8 m above sea-level. The deposits of this Lower Terrace are related - in space and time - with the Upper Coropina deposits of the Old Coastal Plain. Figure 5 is a section of a river-bank of the Lower Coppename (location KK 369A, sheet 20a) which shows the transition of marine to fluvial deposits. These deposits point to the following succession: 1. fast rising sea-level (black clay, Onoribo phase), 2. slowly rising to constant sea-level (kaolinitic silt, Santigron phase) and 3. the seaward growth of the river with the accretion of the coastal plain (fluvial deposits).

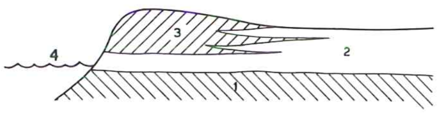


Fig. 6 Schematic section showing lateral relationship of the Upper Coropina Formation and the Lower Terrace

1. Marine deposits (Onoribo phase)
2. Marine deposits (Santigron phase)
3. Fluvial deposits
4. Present river

Figure 6 is a schematic section which shows the probable lateral relationship of the marine Coropina deposits and the fluvial deposits of the Lower Terrace.

The occurrence of the silts of the Santigron phase is quite common on the Lower Coppename. The underlying Onoribo Clays, however, were found at only one location, at a very favourable moment, viz. low springtide during the long dry season.

At some places the fluvial deposits contain gravel. A large outcrop of very coarse gravel occurs at Tjakka Tjakka Ston (sheet 20c).

It is obvious that some high river-banks may be terraces from a morphological point of view, although they consist of offshore bar sands or marine clays only, e.g. the erosion remnant of the Old Coastal Plain on the lower Coppename (Kalebaskreek).

1.4.4 The Continental Shelf

Several aspects of the continental shelf of Suriname have been studied on more than one occasion, partly with the aid of naval hydrographic vessels (Hydrographic Newsletter, Special Publication Nr. 5, 1967; Hydrographic Newsletter, Special Publication Nr. 6, 1971). The morphology and the sediments of the shelf have been studied by Nota (1969, 1971). The shelf has a width of about 150 km while the edge occurs at a depth of only about 100 m. Figure 8 shows a section of the western part of the Surinam shelf. The near coastal part consists of recent silty clays while the seaward part is covered by more or less clayey sands. These sands have been deposited in a near shore or fluvial environment during the low sea-level stand of the last glacial. On the western Gui-

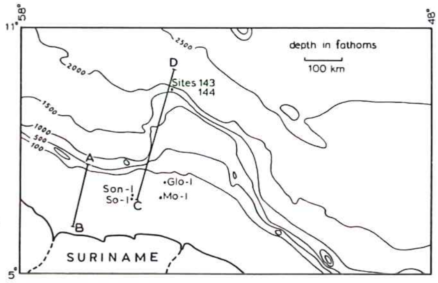


Fig. 7 Map showing the continental shelf and the Guiana Marginal Plateau (after Collette et al., 1971)

ana shelf coarse sands were connected with the 30-40 fathom level (Nota, 1958a, b). Fossil coral reefs occur along the edge of the shelf of Suriname and Guyana, apparently remnants of a fringing reef growing at a sea-level stage of 80-90 m below the present one. Two radio carbon datings of reef material from the shelf of Guyana showed ages of about 12,000 and 17,000 years B.P. (Nota, 1958a,b). On the continental shelf of Suriname a few reefs have also been found at about 70 m depth, while one isolated reef even occurs at a water depth of 26 m. Submarine terraces occur at 26-30 m, 36-38 m, 45 m, 60 m and 90 m depth on the western part of the shelf of Suriname. According to Nota (1969) this morphology is relict of the Late Pleistocene and Holocene transgression. A few drowned river valleys, however, are apparently older.

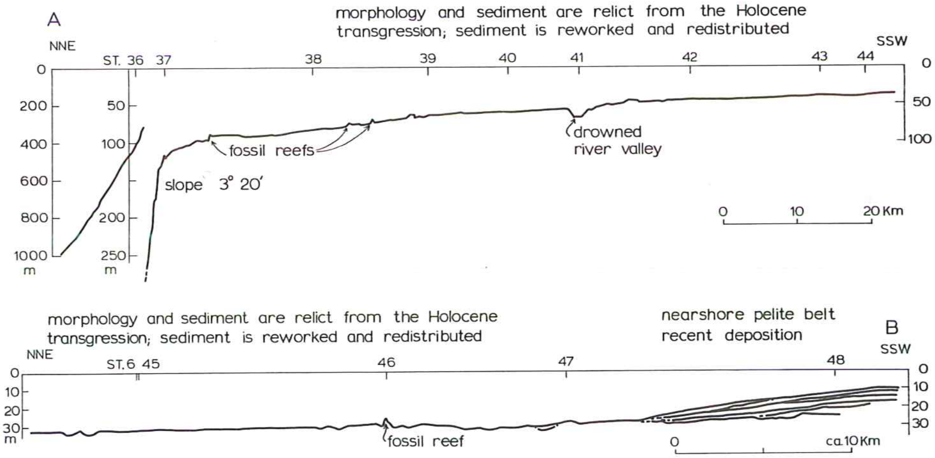


Fig. 8 Section through the western continental shelf of Suriname (after Nota, 1969)
Location of section in figure 7

A large coarse sandy delta occurs off the Marowijne River. This delta would have been deposited during a standstill at -22 m (-12 fathoms) about 8,000 B.P. (Nota, 1971). At the same time a fine sandy tidal flat was formed off the Essequibo River in Guyana (Nota, 1958a,b). According to Van der Hammen (1963) the age of the standstill is too young and should be at least 9,000 years. Contrary to the mainly erosional character of the western part of the Surinam shelf, the eastern part is of a mainly depositional nature, apparently due to the large sediment supply by the Marowijne River.

1.4.5 The Guiana Marginal Plateau

This borderland plateau feature, originally known as the Demerara Rise, occurs to the northeast of Suriname (fig. 7). Figure 9 shows a section through this plateau, based on data from different sources (Collette et al., 1971; Belsky et al., 1972; Fox and Heezen, 1970; Hayes et al., 1971; Wong, 1976). Due to the new stratigraphic data given by the latter author the section differs in an important aspect from the one published before (Krook, 1975), where the greater part of the Miocene was shown as Pliocene.

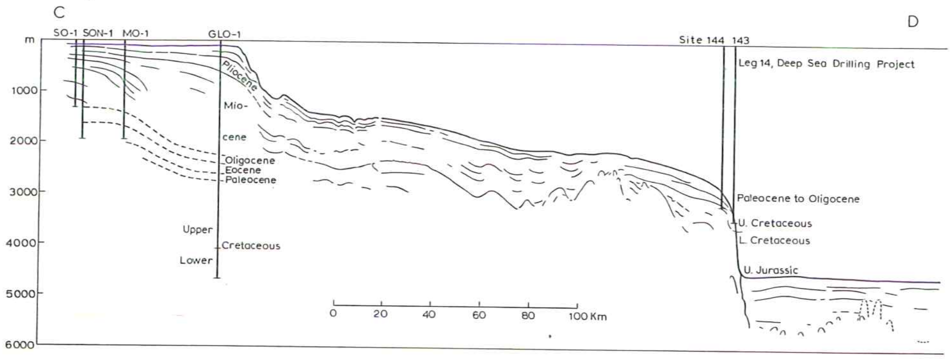


Fig. 9 Section through the continental shelf and the Guiana Marginal Plateau (after Collette et al., 1971; stratigraphical data from several sources, see text)
Location of section in figure 7

Upper Jurassic sandstone was dredged from the northern flank of the plateau. Evaporites of Jurassic age have been shown to occur at several parts of the margin of the Atlantic Ocean such as the Bahama Platform (Mullins and Lynts, 1977) and the equatorial eastern Atlantic (Lehner and De Ruiter, 1977). Since the Bahama Platform in the predrift era was probably situated north of the present Marginal Plateau, according to the first authors, the occurrence of evaporites below this plateau as well as the abyssal plain, may well be assumed.

The Miocene deposits underlying the lower shelf resemble a huge delta. The origin of these sediments will be discussed in chapter 4.

1.5 Paleoclimates and relative sea-level movements

The study on the palynology of the Guiana Basin by Wijmstra (1971) was based on the original paper by Van der Hammen and Wijmstra (1964). However, it was more detailed and the pollen zones were better defined. Several subzones could be recognized and an alternation was established of humid and dry climatic phases and the occurrence of the transgressions and regressions.

With reference to the Quaternary several authors found indications for relatively dry conditions for the glacial stages and more humid conditions during the interglacial stages. Van der Hammen (1963) and Wijmstra (1971) found palynological evidence for a climate with alternating dry and humid seasons during part of the last glacial, but on the whole more arid than the present one. At a later date Van der Hammen (1972) concluded drier conditions in the Amazon area, possibly during a part of the last glacial. The tropical rainforest may have been reduced and split up into large forest islands as was postulated by biogeographers (Haffer, 1969; Müller, 1973; Vanzolini, 1973; Vuilleumier, 1971). Damuth and Fairbridge (1970) and Krook (1970a) arrived at similar conclusions with regards to the climate, but these were based on sedimentological observations.

Age	Stratigraphy Guiana Basin	pollen zones	sea-level movements	climate	remarks
Holocene	Upper	G-2	transgression	mainly humid	
Pleistocene	Clays	G-2	transgressions and regressions	transgr.: mainly humid regr.: partly rel. dry	
Pliocene	Upper Sands	G-1	mainly regressive	rel. dry during regression	
Late Miocene	no deposits		large regression	rel. dry?	no deposits in coastal plain
Middle Miocene	Intermediate	F	transgressive	very humid	
Early Miocene	Clays	E-2 E-1	large regression transgression	rel. dry	denudation
Oligocene?	A-sands	no pollen	transgression	no date	
Late Eocene	no deposits		regression	rel. dry	bauxite formation
Middle Eocene	Alternating	D	transgression?	mainly humid	
Early Eocene	Sands	C-2 C-1	regression transgression		
	and				
Paleocene	Clays	B-2 B-1	regression transgression		
			large regression		denudation
Cretaceous	Lower Consolidated Sands and Clays	A	mainly regressive		

Table 7 Relation of stratigraphy, sea-level movements and climate in the coastal area of Suriname

Table 7 summarizes the most relevant data of Wijmstra (1969, 1971) and Noorthoorn van de Kruijff (1970). More data on climate and sea-level movements will be given in later chapters.

1.6 Cyclic development of landforms

Since the sediments forming the coastal area are mainly derived from the hinterland, a relation between the development of the morphology of the interior and the deposition of the foreland may be expected. According to King et al. (1964) there was a cyclic development of erosional landscape formation and contemporaneous sedimentation by intermittent upwarping of the interior and downwarping of the coastal belt. Principally the order of events was as follows: After an uplift a denudation cycle started which finally resulted in a more or less flat surface sloping toward the coastal area where the products of the erosion formed a coastal plain. Renewed uplift and downwarping lead to another cycle which ended in a second denudation surface at a lower level and young coastal deposits covering the older ones separated by a hiatus marking a period of relative inactivity. In Suriname the following erosion levels were recognized: Early Tertiary Surface, Late Tertiary I Surface and Late Tertiary II Surface.

The Early Tertiary Surface, of Paleocene-Eocene age, is a very smooth surface which has only been preserved where it was protected by a duricrust of bauxite or laterite. Numerous remnants of this level are found, mainly in Eastern Suriname. Well known examples are the Brownsberg (500 m), the Nassau Mountains (600 m), the Lely Mountains (700 m) and the northern part of the Bakhuis Mountains (300-450 m). The summit level of the inselbergs in SE Suriname probably also represents this surface (Zonneveld, 1969b). The erosion products, originated during the formation of the surface, the "correlate deposits", are the Paleocene and Eocene sediments in the coastal plain. On part of these sediments bauxite was formed. The Early Tertiary Surface is part of a surface which occurs all over South America and is known - on this scale - as the Sul-Americana Surface (King, 1967).

The Late Tertiary I Surface of Oligocene - Early Miocene age shows a rolling landscape of which only little has been preserved in Suriname, contrary to Guyana where it shows a conspicuous laterite covered surface (McConnell, 1966). Its correlate deposits are the "A-sands" and the Miocene sediments.

The Late Tertiary II Surface (Pliocene) is composed of wide pediplains related to the main river valleys. Some parts are covered with laterite which best reserved the original surface. The greater part, however, is more or less dissected and in some areas the original surface is recognized only by its summit level. Considerable differences in elevation may occur between pediplains belonging to adjacent river systems, due to the difference of the distances to the sea (Verhofstad, 1969). In such cases river captures are common.

According to King et al. (1964) the sediments of the Upper Coesewijne Formation are the correlate deposits of the Late Tertiary II Surface. Recent observations, however, have cast doubt upon this assumption and there is evidence that the sediments have been deposited at a later date.

The Late Tertiary II Surface has been subject to a more or less cyclic erosion during the Late Pliocene and the Quaternary which accounts for the relatively large sediment supply during this period.

In chapter 6 a new approach will be given of the denudation surfaces and their correlate deposits.

1.7 The mineral resources of the coastal area

1.7.1 Bauxite

From an economic point of view bauxite is the most important mineral in the coastal area. It was formed mainly on early Tertiary sediments. A small part, however, near St. Helena, south of Onverdacht, occurred directly on bedrock, where it has long since been mined. The bauxite is found in two areas, viz. the Onverdacht-Paranam-Lelydorp area south of Paramaribo and the area east and south-east of Moengo. In both areas several deposits occur, all of which have been developed or are going to be developed into mines. In the section of figure 3 the position of the Lelydorp deposit is shown. Several sections through the bauxite deposits of the Onverdacht-Paranam-Lelydorp area have been shown by Aleva et al. (1969). The coastal plain bauxites show a slight dip ($\frac{3}{4}^{\circ}$-1°) to the north. They are covered by sediments of the Coesewijne Formation, the Coropina Formation and, locally, the Demerara Formation. The southern part of the bauxite in the Moengo area occurs on low but distinct plateaux, while the northern part is covered by younger sediments, see figure 10.

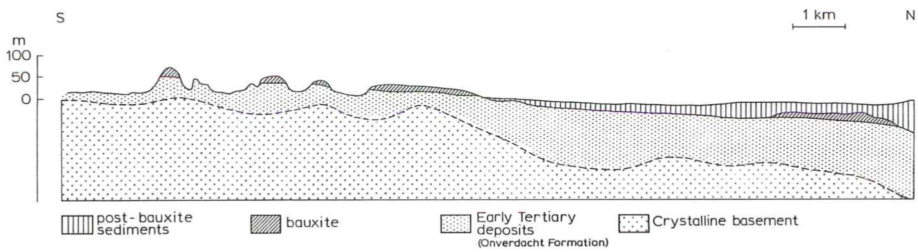


Fig. 10 Section through the bauxite deposits of Moengo (after Janssen, 1977)

About the origin of the bauxite in the coastal plain several theories have been developed which have been summarized by Krook (1969b). Extensive studies on the bauxites of the Guianas were carried out by Bleackly (1964) and Van Kersen (1965). The latter author recognized bauxites of different ages, but this was disproved at a later date when more data had been obtained. By palynological dating of the strata below and above the bauxite the age of the formation of the bauxite could be placed at the transition between the Eocene and the Oligocene (Wijmstra and Van der Hammen, 1964).

Aleva (1965) made a detailed study of the bauxite of Onverdacht. He showed that the deposits overlying the bauxite influenced the bauxite in two ways, viz. by resilification of the top layers and by leaching of the iron, also from the upper part of the bauxite. He also found evidence for the fact that the bauxite had originated from a sediment that was coarser grained than the sediment which formed the underlying kaolin, either silt of arkosic sand. Krook (1969b) found pre-bauxite sediments in drill holes in the coastal plain which were relatively rich in feldspar. He agreed with Aleva that the original sediments were relatively unweathered at the time of deposition. Valeton (1971) and Valeton et al. (1973) on the other hand, who found that original sandstone strata had been altered into gibbsite bauxite whereas the fine grained layers were only kaolinized, nevertheless held that the original sandstone was of a strongly weathered nature. The pre-bauxite sediments would have contained only quartz, detrital hematite and kaolinite and no feldspar.

The mining of the bauxite started in 1922 in the Moengo area and in 1941 in the Paranam area. The production increased steadily and amounted to about 7 million tons in 1974. Since 1965 part of the bauxite has been processed into alumina by the Bayer process. The present production is about 1 million ton per annum. The red mud resulting from the process is stored in a lake near Paranam. According to Logomerac (1969) it contains considerable Fe, Al, Ti, Zr, V, U and Th. Later studies showed that economic exploitation of the red mud was not feasible as yet, but future processes may change this situation. In 2.4.3 the heavy minerals in a sample from the red mud will be discussed. The building of a dam in the Surinam River near Afobaka and a hydro-electric plant in 1964 resulted in an output of about 150 megawatt which is mainly used for the production of aluminium by the Hall-Herault process which at present amounts to 50,000 tons per year. The coastal plain bauxite is generally of a very good quality (partly chemical and abrasive grade) and in the past several companies have explored in the potential "bauxite belt". Only in the vicinity of the known deposits, however, have new deposits been found. West of the Onverdacht-Paranam-Lelydorp area no bauxite has so far been encountered, but future finds must not be excluded. A summary of the exploration activities has been given by Van Lissa (1975).

1.7.2 Kaolin

Kaolinitic clay has been encountered in deposits of the Coesewijne Formation at several outcrops and in many drill holes. It has never been given serious attention. The most promising kaolin deposits occur below the bauxite, where they form considerable reserves. At Onverdacht the kaolin may be as thick as 20 m. The kaolins are of a good quality and contain little iron (Schols, 1950; Bosma et al., 1973). However, they have not been utilized so far.

1.7.3 Gold

It was found in recent years that gravels at the base of the Upper Coesewijne Formation near the Marowijne and the Saramacca Rivers contained gold. At present these deposits are being evaluated by the Geological and Mining Service of Suriname (Wong and Van Lissa, 1978).

1.7.4 Gravel and sand

In the lower courses of the Saramacca, Suriname and Marowijne Rivers sand and gravel are being dredged. The coarse sands are well suited for industrial purposes. The gravel is partly used for the production of concrete and partly as a filler in asphalt for road construction.

The bleached Upper Coesewijne sands have been studied extensively as the possible raw material for glass production. According to Salzgitter (1966) the surface layers contain 99.2 to 99.8% quartz. The rest is mainly accounted for by loss on ignition due to the occurrence of organic material. Very little iron and aluminium occurs. The heavy mineral content is usual less than 0.1%. The minerals are only of a stable nature. At present the sands are used for road construction and for the production of concrete in the construction works of the projects being carried out in Western Suriname.

The well sorted fine grained Upper Coropina sands near Lelydorp are used in wall plastering (Bosma et al., 1973). The sands from the ridges of the Demerara Formation are used for road construction and several other purposes.

1.7.5 Shells

Shells occur in the younger ridges in the Demerara Formation. Locally they are exploited for pathways etc. Shell breccias are often hardened by diagenesis at some depth. From these porous limestones building stones can be sawn. The renewed fortress Zeelandia at Paramaribo is partly built with these stones.

1.7.6 Clay

Clays from the Coropina and the Demerara Formations have been exploited from 1944 to 1970 for the manufacturing of bricks. At present no more use is made of clays.

1.7.7 Ground water

Most ground water in the coastal plain is obtained from boreholes. Four main aquifers have been distinguished by Dixon (1971a): C-1 and C-2 in the Upper Coesewijne Formation, C-3 in the sandy layers and lenses of the lower Coesewijne Formation (Intermediate Clays) and C-4 in the A-sands. The water in most aquifers is replenished in the coarse sands of the Savanna Belt.

The two main well fields to provide Paramaribo and surroundings are at Zorg en Hoop (Paramaribo) and at Republiek.

Extensive information on the water supply has been given by Dixon (1971b), while a summary with the most important data appeared in Bosma et al. (1973).

1.7.8 Hydrocarbons

Much exploration for oil has been carried out in the coastal plain and on the continental shelf. The first exploration well was drilled in 1929 near Nieuw-Nickerie. At about 100 m depth some asphalt indications were found.

In 1942-1943 another hole was drilled near Nieuw-Nickerie which reached basement at 1469 m (Link, 1953). In 1965 a hole drilled for water by the Geological and Mining Service near Calcutta hit oil in the A-sands and in the sands of the Intermediate Clays (Coleridge et al., 1966). A flow test showed about 2 bbls per day. Later wells in the same area had comparable results. The next year some oil was found at about 300 m depth in the Onverdacht Formation in two wells at Tambaredjo.

Elf Petroleum Suriname drilled four holes in 1968 NW of Paramaribo (Weg naar Zee) and found traces of oil. In 1969 and 1970 Shell Suriname drilled 24 exploration holes, widely spaced in the coastal plain, apart from a cluster of five holes near Calcutta. This exploration drilling only showed some oil indications in the Calcutta and Tambaredjo area and west of Calcutta near the mouth of the Coppename.

Exploration drilling has also been carried out offshore (fig. 11). Stratigraphic data of some of the holes on the continental shelf have been used in the section of figure 9.

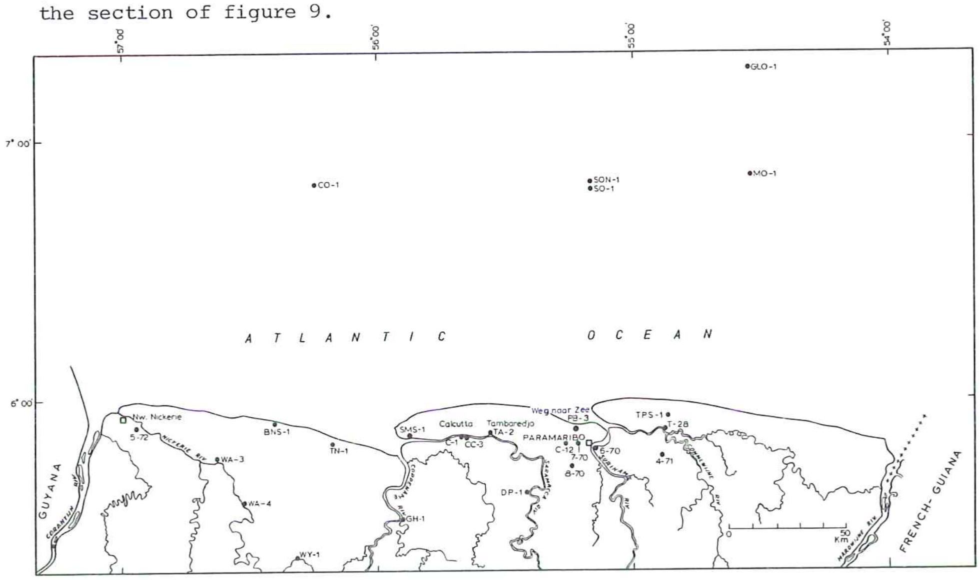


Fig. 11 Locations of drill holes in the coastal plain and on the shelf

2. MINERALOGY OF THE SEDIMENTS

2.1 Previous work

Several studies have appeared on the mineralogical composition of Surinam sands. IJzerman (1931) gave a description of heavy minerals encountered in the coastal sedimentary deposits. Druif and Ter Meulen of the Technical University at Delft wrote several internal reports about Surinam detritals on behalf of the Geological and Mining Service. Zonneveld (1951) compiled both data from IJzerman and Druif and Ter Meulen. Bakker, Kiel and Müller (1953) studied the heavy minerals from some bore holes in the Moengo mining area. Kiel (1955) gave an account of heavy minerals from Northern Suriname. Montagne (1964b) presented heavy mineral data from sands of Paleocene to Pleistocene age encountered in drill holes and mines faces of the Onverdacht bauxite mining area. Zonneveld (1969a) showed results of studies on heavy minerals of the Savanna Belt, the Old Coastal Plain and the Young Coastal Plain.

2.2 General remarks on the present work

The present work shows the results of several studies on heavy minerals, mainly carried out at the Geological and Mining Service of Suriname. Part of these studies have already been published.

Initially the author studied heavy minerals from creeks and colluvium in the shield area. These samples had been panned with a "batea" or gold pan for the purpose of alluvial prospection. Most results were published in internal reports. A study on the detritals of the Coppename-Tibiti area appeared in Arjomandi et al (1973).

Apart from the concentrated samples from the interior the author started studying river sands, samples from drill holes in the Onverdacht-Paranam-Lelydorp bauxite area and from sediments in the coastal plain (Aleva et al, 1969; Krook, 1969a). In a later study the relation of climate and sediment supply was discussed (Krook, 1970a) while in two papers the relation of placer deposits and paleoclimate was emphasized (Krook, 1968b; 1970b). Many data on the mineral composition and the provenance of the Upper Coesewijne Formation were given by Krook and Mulders (1971).

After the former studies the author obtained samples from a score of deep drill holes in the coastal plain, while only recently he received several samples from two offshore drill holes and from the continental shelf of French Guiana and Northern Brazil.

The samples providing the data for the present study can be subdivided into surface samples, river bottom samples, continental shelf samples and drill hole samples.

The so called surface samples have usually been taken with a hand auger at a depth of about 1 m. In a few cases samples from several depths were obtained to study the relation between the soil formation and the weathering of the minerals.

From the river bottoms grab samples were taken with a bottom sampler or by hand during low water stages in the long dry season.

The samples from the drill holes (see fig. 11) do not all have the same quality. Only three of the holes in the coastal plain were cored (C-1, C-12 and T-28) and consequently provide the most reliable data. From the other holes the samples have been taken from the drilling mud. The "cuttings" from the water holes have been taken with the utmost care by experienced drillers since the grain size of the sands encountered was of great importance. Contamination, however, may have occurred on some scale. According to Noorthoorn van de Kruijff (1970) the cuttings from the oil exploration holes would be of little value for sampling because of caving, disintegration and mixing in the mudstream. When drilling basement the greater part of the cuttings would consist of loose material from the wall of the hole. However, this view appears far too pessimistic. The transition to basement can be observed very clearly in the composition of the heavy minerals in a number of holes (see Encl. 3: TN-1, CC-3, PB-3, WA-4). Other sudden changes are also apparent from the mineral content (e.g. TN-1, TA-2, PB-3). The reliability of CC-3 is questionable, since no change occurs below the bauxite hiatus. On the other hand, however, the transition to the basement is abrupt.

The - strongly simplified - lithology as shown in the graphs (Encl. 3) has been derived mainly from cuttings and from logging. The oil exploration drill holes were logged by an Induction Electrical Log and a Compensated Gamma Ray/ Formation Log (Noorthoorn van de Kruijff, 1970). The logging data were interpreted for the Geological and Mining Service and the author by Van Lissa (personal written communication). The water test wells were logged by Single-Point Resistivity and Self Potential Logs. They were partly interpreted by Dixon (1971a and b) and partly by Van Lissa (personal written communication). The lithology of C-1, C-12 and T-28 was described from the cores. Data are from Coleridge et al (1966), Amstelveen (1969) and Wijmstra (1969), respectively.

In the laboratory the heavy minerals were separated from the fraction of 44-420 μm. Most samples, however, had a smaller maximum grain size. In some cases the heavy minerals were studied in relation to grain size. Frequently the light fractions were studied as well, mainly because of the feldspar content. The maximum grain size of the light fractions was taken at 250 μm because of the general decrease of the feldspar content with increasing grain

Heavy Min. graph		Fig. and/or Encl.	zi	tm	mo	ga	eh	ru	st	ad	si	ky	hy	pg	met. minerals	other minerals
dr. hole	5-72	Fig. 11 + Encl. 3	x		x	x	x		x		x				ad ky co	tm ru xe sn
dr. hole	WA-3	Fig. 11 + Encl. 3	x		x	x			x		x				ad ky co	tm ru xe sn tp ho ep an ca
dr. hole	BNS-1	Fig. 11 + Encl. 3	x		x	x	x		x		x				ky ad co	tm ru ct tp sn an
dr. hole	TN-1	Fig. 11 + Encl. 3	x		x	x	x		x		x				ad ky co	tm ct ru tp ap xe hy
dr. hole	C-1	Fig. 11 + Encl. 3	x	x			x		x			x			ad si co	ru mo ga tr xe sn zo
dr. hole	CC-3	Fig. 11 + Encl. 3	x	x	x				x			x			ad si co	ga ru xe ep ho tp sn
dr. hole	TA-2	Fig. 11 + Encl. 3	x						x						ky si ad co	ru tm ga mo xe ap
dr. hole	C-12	Fig. 11 + Encl. 3	x	x					x						ad ky si co	ru ga xe
dr. hole	PB-3	Fig. 11 + Encl. 3	x	x	x		x		x						ad si ky co	ru ga an tp xe sp
dr. hole	T-28	Fig. 11 + Encl. 3	x	x			x		x						co ad ky si	ru ga mo xe sn an tp
dr. hole	TPS-1	Fig. 11 + Encl. 3	x	x		x	x		x						ad si co ky	ru mo an hy au tp tr
dr. hole	WA-4	Fig. 11 + Encl. 3	x		x	x			x		x				ky ad	tm ru xe ap ca an
dr. hole	WY-1	Fig. 11 + Encl. 3	x						x		x				ad ky co	tm ru ho ga ep mo xe an
dr. hole	GH-1	Fig. 11 + Encl. 3	x	x		x			x	x	x					ho ep co ru tp xe mo ap ky an di
dr. hole	DP-1	Fig. 11 + Encl. 3	x			x	x		x						si ad ky co	ru tm mo an br
dr. hole	7-70	Fig. 11 + Encl. 3	x	x			x		x						ky si ad co	ru mo ga xe an ct tr
dr. hole	8-70	Fig. 11 + Encl. 3	x	x		x	x		x						ad si ky co	ru mo xe tr tp ca an vi du
dr. hole	6-70	Fig. 11 + Encl. 3	x	x		x	x		x						si ad ky co	ru mo xe sn an
dr. hole	4-71	Fig. 11 + Encl. 3	x	x		x	x		x						ad si co ky	ru mo an sp tp ap cd tr
dr. hole	CO-1	Fig. 11 + Fig. 13	x	x		x	x		x		x					ru mo ky ad co au en tp an sn hy ct
dr. hole	GLO-1	Fig. 11 + Fig. 13	x	x		x	x									an ru sp hy st ct tr au si ad co mo
dr. hole	KK-VIII	Encl. 2 + Fig. 15	x	x					x							ad si ky ru xe co mo tp ep
dr. hole	B-2	Encl. 2 + Fig. 15	x	x	x			x	x							ad ky si xe co ep sn
U. Coes. Form.		Encl. 2 + Fig. 14	x	x				x	x	x					si ky co	mo tp sn xe an du
f.s. ridges, Wan.		Encl. 2 + Fig. 23	x	x			x		x						ad si ky co	ru ga an tp tr cd mo ap sp au en sn xe hy br
f.s. ridges, M.C.		Encl. 2 + Fig. 23	x	x		x	x		x						ad si ky co	ru an sp tr au cd mo hy tp ap
c.s. ridges, Wan.		Encl. 2 + Fig. 24	x	x			x		x						ad si ky co	ga ru an mo
c.s. ridges, M.C.		Encl. 2 + Fig. 24	x	x		x	x		x						ad si co ky	ru mo an tr hy ap cd
Beaches		Encl. 2 + Fig. 24	x	x		x	x		x						ad si ky co	ru tr ap mo an hy en di ct
Corantijn R.		Encl. 2 + Fig. 16	x			x	x		x		x					ad ky ru mo hy co an xe tr sn pm sp
Nickerie R.		Encl. 2 + Fig. 18	x			x	x		x		x	x			ad co	tp sn mo ru pi hy ca au
Coppename R.		Encl. 2 + Fig. 19	x	x			x		x	x	x		x		ky co	ru ga au mo tp de tr xe au ca en ap pi sn br
Saramacca R.		Encl. 2 + Fig. 20	x	x			x	x	x						ad si ky co	mo ga xe an tp
Suriname R.		Encl. 2 + Fig. 20	x			x	x		x						si ad ky co	tm mo ru ap sp hy en au tr br pi di cd
Marowijne R. and Lawa R.		Encl. 2 + Fig. 21	x			x	x		x						ad si ky co	tm mo ru hy tr di pi an en xe br
Cont. shelf		Fig. 26 + Fig. 27	x	x			x		x					x	ad si ky	ga ru ct tr tp au di sp mo pi cd ap

Table 8 Minerals and groups of minerals represented in heavy mineral graphs of drill holes, rivers, sandy ridges, beaches etc.

ad	andalusite	ct	chlorite	ho	hornblende	sp	sphene
an	anatase	cz	clinozoisite	hy	hypersthene	st	staurolite
ap	apatite	di	diopside	ky	kyanite	th	thorite
at	anthophyllite	du	dumortierite	mo	monazite	tm	tourmaline
au	augite	eh	epidote - horn-blende group	pg	pyroxene group	tp	topaz
bi	biotite			pi	pigeonite	tr	tremolite
br	brookite	en	enstatite	pm	piedmontite	vi	viridine
ca	cassiterite	ep	epidote	ru	rutile	xe	xenotime
cd	chloritoid	ga	garnet	si	sillimanite	zi	zircon
co	corundum	gp	glaucophane	sn	spinel	zo	zoisite

Table 8a Abbreviations used in table 8

size. All samples, heavy and light, were studied in an immersion fluid, not in Canada balsam. The advantage of this method is not only that it saves time on laboratory work, but unidentified grains can easily be taken apart for examination by X-ray diffraction.

Only rarely the samples received a HCl treatment. When the samples were flooded by pyrite - quite common in deep drill hole samples - they were boiled with diluted HNO_3.

From the heavy fractions the percentages of the opaque grains were determined. The opaque grains were analysed with a binocular microscope. After this the percentages of siderite and biotite were determined from the transparent grains. From the remaining transparent minerals a hundred grains were counted. The entire slide, furthermore, was searched for other minerals which were noted as traces. From the light fractions three hundred grains were counted because of the usually low content of feldspar.

The field counting method according to Van Harten (1965) was used. In samples with a granular variation the percentage of smaller grains counted by this method will be somewhat higher than when counted by the line counting method. De Boer (1972), however, compared the two methods in the study of the Marowijne sands and found the differences insignificant.

The results of the countings have been represented graphically as far as possible. The graphs of the drill holes in the coastal plain have been placed on one sheet (Encl. 3) for correlation purposes. On the left side of these graphs the percentages of the feldspar are shown. The graphs representing the drill holes on the continental shelf (CO-1 and GLO-1), the drill holes in the Coesewijne Formation (KK VIII and B-2), the surface sands of the Coesewijne Formation, the rivers, the beaches, the sandy ridges and the continental shelf appear in the text. They show the feldspar contents, as far as determined, on the right side of the graphs, while data on grain size are also given. Since on these graphs only the most important minerals occur, a selection of the samples has been given in tables 12-22 together with other samples which have been represented graphically. The locations of the samples mentioned in the text and in the tables are shown in Enclosure 2. Enclosure 4 shows the legend of the heavy minerals.

The compositions of the heavy fractions of the various drill holes, rivers, ridges etc. show great differences. Therefore the number of minerals and groups of minerals vary from one graph to another. Table 8 shows which minerals have been represented in the separate graphs.

2.3 General characteristics of detrital minerals in Suriname

Some characteristics of detrital minerals in Suriname such as occurrence, provenance, stability and other relevant features will be described under the following headings: 1. opaque heavy minerals, 2. transparent heavy minerals, 3. light minerals. General optical properties will not usually be mentioned since these can be found in textbooks.

A relatively wide range of detrital heavy minerals will be described, not only for the coastal area, but also several which have only been found in the interior. The light minerals received relatively little attention since they are of less importance than the heavy minerals. The feldspar content is usually the main objective.

2.3.1 Opaque heavy minerals

Chromite. This is locally found in creeks and weathered rocks of the interior and derived either from chromite ore bodies (Emma Range, see Bisschops, 1969; Upper Saramacca area, see Den Hengst, 1975) or as accessories in basic volcanic rocks (Fatoe Swietie Hills, Lawa area, see Krook, 1968c). Chromite grains are well determinable as long as octahedral shape can be recognized. They were never found in samples from large rivers, possibly due to a high degree of rounding which makes it difficult to distinguish them from ilmenite.

Columbite-tantalite. These minerals usually occur as flat prismatic or tabular grains which are found, locally, near pegmatite deposits, e.g. near Jorka Creek, lower Marowijne area (Montagne, 1964a).

Copper. A few small grains of native copper have been detected in alluvial deposits in the Lawa area, possibly derived from dolerite dykes.

Goethite. Although part of the limonite consists of goethite, the name goethite was used in this study only for conspicuous well rounded grains with the brown lustre of fresh horse-chestnuts. These grains, showing an X-ray diffraction pattern of goethite, are rather common in the sands of some rivers, notably the Suriname River and, to a lesser extent, the Marowijne River. The beautiful lustre seems to be typical of recent river bottom sands, since the grains have never been found in surface samples.

Gold. A mineral of local origin, found as flat, rounded or irregular grains, frequently pitted. The grains occur in a secondary position in stream placers and in colluvium. Gold is mostly derived from hydrothermal quartz veins in metamorphic rocks of the Marowijne Group, especially the Paramaka Formation (see 1.4.1). The occurrence and provenance of the gold has been extensively described by Brinck (1956). Gold may be found in concentrates, either natural or artificial, but there is little chance of finding it in samples taken for the purpose of provenance and correlation. Lately gold has been found in base gravels of the Upper Coesewijne Formation (Wong and Van Lissa, 1978) and in gravels of Pleistocene terraces.

Hematite. This is usually found as irregular to rounded reddish brown to dark brown grains, either detrital or authigenic by the oxidation of magnetite or pyrite. It is quite common, often derived from laterite crusts or lateritic soils. The so called "iron beans" consist mostly of hematite. Small, rounded, dark grey hematite grains are abundant in the heavy fractions of crushed sandstone of the Roraima Formation. These frequently show octahedral shapes, indicating alteration from magnetite.

Hydro-ilmenite. This is an alteration product of ilmenite. It has the same appearance as the latter, but is of brownish colour. It is rather common, especially in the sands of the Onverdacht and the Coesewijne Formations. It will be further discussed in chapter 3.

Ilmenite. Ilmenite is the most abundant opaque mineral, occurring in almost all samples. It alters into hydro-ilmenite, leucoxene or rutile. It usually occurs as irregular subrounded to rounded grains with a bluish grey submetallic lustre. The grains are sometimes platy. Often partly covered by white yellowish leucoxene. Black sand concentrates consist mostly of ilmenite. It is derived from all kinds of igneous and metamorphic rocks.

Leucoxene. This is a white to yellowish alteration product of ilmenite, occurring either as grains or as a crust on ilmenite. It is very common in highly weathered sediments and soils. See also alterite.

Limonite. Yellow to brown, usually dull grains. Limonite is an alteration product of iron ores and ferromagnesian minerals. It is of common occurrence. Pseudomorphs after pyrite have been observed, but these are quite rare, due to their rather low hardness.

Maghemite. Small, irregular to platy brownish grains, highly magnetic. It is usually classed as magnetite of which it is an alteration product.

Magnetite. This occurs as highly magnetic greyish to black grains, partly brownish due to alteration to maghemite, hematite or limonite. The grains are usually angular and anhedral, less frequently rounded. Sometimes octahedral grains are observed, with sharp edges. It is less common than other iron oxides and ilmenite in sediments, probably due to its instability with respect to tropical weathering. Although usually said to be derived from basic and ultrabasic rocks (e.g. Milner, 1962, p. 141), magnetite also occurs in acid igneous rocks and is very common in crushed unweathered granite.

Marcasite. This is a rare, highly unstable mineral, often confused with pyrite, unless crystal forms are carefully observed. Marcasite is orthorhombic. In a few cases characteristic quintuplets have been noticed (see Escher, 1954, p. 242). It has been found in drill hole samples from the coastal plain where it was probably authigenic. Marcasite alters into a dustlike substance after being exposed to the air for some time.

Pyrite. This yellow to whitish metallic mineral may be euhedral (cubic, dodecahedral or pyritohedral) or anhedral. It may also be found as fine rather dark, grapelike clusters. Most pyrite is found in drill holes in the coastal plain where it is undoubtedly authigenic. These pyrite grains frequently show fine cellular vegetal structures. In the Onoribo clays of the Upper Coropina Formation pyrite nodules have been found. In the clayey deposits of the Demerara Formation pyritized micro organisms such as foraminifera are common. Pyrite is very unstable under oxidizing conditions.

Pyrrhotite. A yellowish metallic mineral, slightly resembling pyrite. It has been detected in a few samples from the interior by its high magnetic susceptibility. It is not known from samples in the coastal area.

Rutile. Although this mineral is usually transparent large grains may appear opaque, even with the aid of the upper condenser. They may be recognized by their prismatic shape. In case of doubt the large grains may be crushed.

2.3.2 Transparent heavy minerals

Actinolite. A fibrous clino-amphibole, rarely found in Surinam sedimentary deposits. Of local occurrence, in Coppename area. It is hardly known from sands in the coastal area.

Alterite. This alteration product, so typical of Quaternary sands in NW Europe, hardly occurs at all in Suriname. According to Bakker (1957a) alterite is formed by the weathering of epidote in the tropical forest conditions of Suriname, but this has never been observed by the present author. Often grains are observed which are greyish semi-transparent between crossed nicols, but these can all be recognized as leucoxene by reflected light. In recent Amazon deposits many grains occur which might be termed alterite. However, since their origin from epidote was still clearly discernible, they were counted as the latter mineral. They apparently had been formed in a different climatic environment, e.g. the Andes Mountains.

Anatase. A rare mineral which usually occurs as traces in recent fine sandy beaches and ridges together with sphene and an occasional grain of brookite. It is also found - in the merest traces - in recent Amazon deposits on the shelf of Northern Brazil, but it is slightly more common on the shelf of French Guiana. It usually occurs as subrounded grains, either tabular or bipyramidal. Anhedral grains can be identified by the extremely high refractive index and the colour which may be either yellow brown or steel blue. Zonation with the alternation of both colours is common.

Andalusite. Occurs as prismatic to anhedral grains, usually subrounded to rounded. It may have dark inclusions. The chiastolite variety has not been found. This was also observed by IJzerman (1931). Andalusite is easy to recognize if typical pink to colourless of light green pleochroism occurs. Prismatic grains have a negative elongation. Anhedral grains without pleochroism may be hard to distinguish from topaz, but the axial angle (2V) is greater and with negative sign. Colourless andalusite shows a light green fluorescence colour (Krook, 1970b).

Anthophyllite. A colourless, relatively rare, ortho-amphibole. It is often difficult to distinguish anthophyllite from sillimanite, as grains as well as in thin sections.

Apatite. An easily identifiable, though rare, mineral. Apatite is very unstable in tropical soils, but apparently more stable with respect to interstratal solution in hard sedimentary rocks, since it is a main constituent in the heavy fractions of crushed, unweathered Roraima sandstone, where it occurs as perfectly rounded grains.

Augite. This occurs mainly as prismatic grains, often with "cockscomb" ends. A rather uncommon, unstable mineral which is usually found in recent deposits. Augite grains occur in low percentages in recent Amazon deposits where they are strongly weathered.

Barite. Angular to subrounded barite grains have been detected in samples from deep drill holes in the coastal plain. They were especially frequent in hole GLO-1, where the grains were relatively well rounded. The occurrence of barite in the sands of a green clay layer at a depth of about 130-140 m in a drill hole at Zorg en Hoop in Paramaribo was mentioned by d'Audretsch (1953), who saw this as indication of marine origin. Since this barite had been obtained from core samples, it probably was an authigenic mineral in the deposits. In most deep drill hole samples, however, it may have been derived from the drilling mud, of which it is often a constituent.
At first sight rounded barite grains may be mistaken for basal sillimanite grains. However, they are usually rather "cloudy" and rarely show a good interference figure. If they do, the axial angle (2V) is somewhat larger than in sillimanite.

Biotite. This mineral occurs mainly in recent beach sands and less frequently in river sands. It may occur in quantity where quiet depositional conditions prevail as in river meanders in the process of being cut off. Biotite seems to be rather unstable. Samples from drill holes generally show a high content of fresh or bleached biotite when basement has been reached. It is not present in samples concentrated by panning due to the "winnowing" effect.

Bronzite. A rare ortho-pyroxene which has been mainly found in recent deposits in the Coeroeni River area.

Brookite. A very rare mineral which, however, is easily detected because of its anomal interference colours and its biaxial interference figure with characteristic crossed dispersion. It occurs as small grains in sediments on the shelf of Brazil and French Guiana, in fine grained sandy ridges and in some rivers.

Cassiterite. This economically important mineral has been found at several localities in the interior where it was mainly related with pegmatites (Jorka Creek, lower Marowijne, see Montagne, 1964a) or granites (Tanjimama Creek, upper Coppename area, Krook, 1965). It was further, though rarely, found in some drill hole samples and in terrace and levee deposits of the Coppename River and as traces in black concentrates of the lower Marowijne River (KK 474, 2.4.1.3, Marowijne River). Cassiterite may be confused with rutile, except in smaller grains, where interference colours may be recognized, contrary to rutile. The zinc test for the diagnosis of cassiterite as described by Milner (1962) has always yielded positive results.

Chloritoid. A rare and obscure mineral in Surinam sands, detected by its mica-like habit and biaxial positive interference figure.

Clinozoisite. See epidote.

Corundum. This mineral occurs mainly as anhedral subangular to subrounded grains, usually colourless, occasionally light blue. Its high refractive index, low birefringence and negative uniaxial figure are positive determination properties. However, anomalous biaxial interference figures up to about 35^{o} have been found in grains from the Paloemeu area. Corundum is rather common, but in low percentages. The red variety, ruby, has been found a few times but is extremely rare. Typical small grains of corundum have been found in the Surinam River near Paranam, but these turned out to be alumina grains from the nearby calcining plant.

Diamond. One diamond of about 100 μm has been found by the author in a sample of the Upper Coesewijne Formation (KK 465, table 14) near Powaka east of Zanderij. The diamond, exhibiting a trigonal symmetry axis, was not worn. Three earlier finds of microscopic diamonds in the coastal area have been known, one in a ridge of the Wanica phase, one in fine sands of the Upper Coropina south of Lelydorp and one just north of Zanderij in the Upper Coesewijne sands. Schönberger (1977) gives a summary of these finds. He suggests that in the past the Suriname River supplied the diamonds. Diamonds - of much larger dimensions - do indeed occur in the drainage area of the Suriname River, viz. in the region NW of Afobaka, where exploration has continued since 1948 (Van Kooten, 1954; Schönberger and De Roever, 1974; Schönberger, 1975).

Diopside. This unstable clino-pyroxene has occasionally been found as a rare constituent in recent deposits.

Dumortierite. A rare mineral, easy to determine because of its conspicuous pleochroism (x = blue, y = violet, z = colourless). It resembles blue tourmaline, but the maximum absorption is parallel to the fibration direction of the polarizer. Dumortierite was found in several samples of weathered rocks and creeks west of the Coppename River near Bitagron (Arjomandi et al, 1973) and also in samples of weathered and fresh bedrock in drill hole PB-3 NW of Paramaribo. It is derived from high grade metamorphic rocks such as cordierite granites and cordierite quartzites in the Coeroeni area and in a migmatic garnet-sillimanite gneiss in the Bakhuis Mountains (Kroonenberg and De Roever, 1975).

Enstatite. A relatively rare ortho-pyroxene, probably because of its instability. Usually prismatic. May have inclusions, which, in case of magnetite, renders the grains moderately magnetic. Occurs in traces in river sands. Derived from basic igneous and metamorphic rocks.

Epidote. This is a mineral of frequent occurrence in recent and subrecent deposits. It may also be found in post-bauxite Tertiary sediments, especially in

fine sandy marine clays (drill holes TN-1 and GLO-1) but it is very rare in older sediments. Epidote is derived from metamorphic rocks of the greenschist facies and from granites. Anhedral subangular grains are common, but euhedral grains occur as well.
Well rounded grains as in European Quaternary deposits are unknown in Suriname. Three other minerals of the epidote group occur: piedmontite, clinozoisite and zoisite. *Piedmontite* occurs locally. It is recognized by its characteristic colour and pleochroism (yellow-violet-red). Pure piedmontite seems to be rare. Most grains show a zonation of piedmontite and common epidote. *Clinozoisite* is a very rare detrital mineral in the interior of the country. It is found frequently, however, in the fine coastal beach and ridge sands where it occurs as very small grains showing typical anomalous blue interference colours. It has been counted as epidote. In bore hole GLO-1 and in recent deposits of the Amazon clinozoisite is also quite frequent. In the table showing the latter samples it was counted as a separate mineral. *Zoisite* is similar in appearance to clinozoisite, but with a smaller axial angle. It is very rare.

Garnet. A very common mineral encountered in the interior and in Cretaceous, Tertiary and Quaternary deposits in samples from drill holes in the coastal plain and in recent and subrecent beaches and ridges. It does not occur in the deeply weathered Tertiary sands in the south of the coastal area (Onverdacht and Coesewijne Formations). Garnet is apparently unstable in weathering profiles, but stable with respect to intrastratal solution. Almandite, of pink colour, is most common in the beaches and ridges. Small grains may appear colourless. Yellow-brown to orange-brown spessartite has been found in samples from the interior, notably the upper Saramacca area and the Coeroeni area. Euhedral forms of garnet such as dodecahedrons are relatively rare. Almandite is usually highly irregular and corroded, but spessartite has more rounded forms. It may, however, occur as cubes with slightly convex crystal faces. Almandite usually contains many inclusions.
Garnet is derived mainly from metamorphic schists (notably from the Armina Formation, together with staurolite), gneisses and rocks of the granulite facies, but provided mainly by the erosion of fresh rocks. In recent deposits most garnet is found in the coarse sandy beaches derived from the Armina Formation in French Guiana.

Glaucophane. Only one grain has been detected of this specific amphibole, viz. in a fine sand off the mouth of the Amazon River.

Hornblende. This is a very common mineral but, due to its relative instability, is confined to recent and subrecent deposits mainly, with a few exceptions such as drill hole TN-1 where it is very frequent from the Early Miocene to the present and GLO-1 where it is abundant from the late Miocene to the present. Several varieties of hornblende have been found, but green hornblende is the most common one. It is derived from a score of igneous and metamorphic rocks and usually occurs as angular prismatic grains, frequently corroded. Although *oxyhornblende* has not been found in deposits derived from the interior a typical red-brown variety with almost straight extinction occurs in the fine sandy beaches and ridges, the recent Amazon deposits and the drill holes TN-1 and GLO-1.

Hypersthene. Although confined mostly to recent river sands (Coppename, Tibiti) and of rare occurrence in older deposits, hypersthene is the most frequent of all pyroxenes. It shows a pleochroism from pink or red-brown to green while cockscomb ends are common. Hypersthene is derived from basic igneous rocks (dolerites and gabbros) and granulites (Falawatra Group). The former are of very limited and local importance, the latter provide the relatively high content of hypersthene in the Coppename River. Hypersthene occurs in recent Amazon deposits and in drill hole GLO-1 as small, euhedral grains with a faint pleochroism of greenish to yellowish brown.

Kyanite. A typical metamorphic mineral, which is rather common in low percentages in sediments of different ages. Detrital grains in Suriname are usually colourless and blue grains are relatively rare. It is abundant in the Cretaceous and Early Tertiary sands of the drill holes in the Calcutta area. It is also very common in the Nickerie River where it has been derived from metamorphic rocks of the Falawatra Group, probably sillimanite gneisses.

Monazite. A mineral which occurs more frequently than usually assumed, probably because, as an accessory mineral in several kinds of crystalline rocks, it is rarely distinguished from zircon. IJzerman, however, identified it in thin sections from biotite granites. It is very common in concentrated samples taken during prospection trips in the interior due to good recovery during panning (Theobald, 1957; Krook, 1970b). Monazite usually occurs as subrounded to well rounded grains, yellow to light-brown, frequently with reddish stains of cerium oxide. East of the Coppename River (sheet 20 and 29) an orange variety has been found. Occasionally biaxial positive interference figures with a small axial angle (2V) can be observed. In the drill holes in the coastal plain there is a remarkable increase of monazite with depth. All river sands contain monazite, if mostly in traces. Some weathered bedrock samples show relatively high contents of monazite (see 2.5). Monazite is mostly derived from granites, biotite gneisses and high grade metamorphic rocks. It seems rather peculiar that monazite is often identified as zircon when the differences are quite striking, except with rounded grains of both minerals, but then colour and refractive index may be decisive. It is somewhat more difficult to distinguish monazite from xenotime.

Olivine. Probably due to its extreme instability this mineral has never been found in sand samples in Suriname, although it occurs in most gabbros and dolerites (IJzerman, 1931).

Piedmontite. See epidote.

Pigeonite. This is a rare clino-pyroxene which occurs locally near hypersthene-pigeonite dolerite dykes. It resembles hypersthene with respect of colour and pleochroism but it has inclined extinction and is of positive sign. The grains are frequently corroded. Pigeonite has never been found in the coastal deposits but occurs as traces in some rivers.

Rutile. One of the most stable heavy minerals, found in low percentages in almost all sandy deposits, but abundant in part of the Coesewijne Formation. Rutile is usually of primary origin, but it may also be formed by the alteration of ilmenite (see chapter 3). It occurs as opaque or translucent, yellow-brown, red-brown prismatic or short, rounded grains, identified by colour, very high refractive index and extremely high birefringence. It is derived from igneous rocks, especially from leucogranites and most probably also from the Rosebel Formation.

Sapphirine. A metamorphic mineral of extremely rare occurrence in Suriname. It has been found in a few samples from the Tapanahony area only. It has been described since as a constituent of high grade gneisses in the Bakhuis Mountains by De Roever (1973).

Scheelite. Only a few grains have been detected in samples from the Coeroeni area by the use of ultraviolet light. Scheelite has a light blue fluorescence colour.

Siderite. This occurs as an authigenic mineral below the ground water table where reducing conditions prevail, either as rhombohedral or spherulitic light-brown grains. It rarely occurs as dark grey spherulitic detrital grains in the interior. The bulk of the heavy fraction may consist of siderite, often together with authigenic pyrite. In such a case boiling with diluted hydrochloric acid may be applied. Usually, however, the percentage of siderite was determined, but not counted with the transparent heavy minerals, similarly to the method applied to the opaque grains (see 2.2). Siderite can also be removed with a hand magnet since it is strongly paramagnetic. In the literature opinions differ with respect to its magnetic susceptibility. It is non-magnetic according to Milner (1962) and Tickel (1965), whereas Hurlblut (1971) states that it becomes magnetic on heating. The present author shares Flinter's (1959b) opinion that siderite is strongly magnetic.

Sillimanite. A very common metamorphic mineral, especially in the western part of the country and in the lower Coppename area where it is derived from sillimanite gneisses of the Coeroeni Group and the Falawatra Group respectively. The grains are usually prismatic or slightly fibrous. Highly fibrous aggregates, known as *fibrolite*, are also common, mainly as coarse grains. Typical of Western Suriname and the lower Coppename area is a sillimanite with a striation parallel to the C-axis which is pleochroic from red-brown to colourless with the maximum absorption normal to the fibration plane of the polarizer (see also IJzerman, 1931). This variety of sillimanite does not occur east of the mouth of the Coppename River.
In deeply weathered soils and in drill holes small, more or less rounded, sillimanite grains are often found, displaying biaxial or a-centric pseudo uniaxial interference figures. The origin of these grains will be discussed in chapter 3. See also barite.

Sphene. Due to its instability this is a rare mineral. It occurs as traces with anatase and brookite in fine coastal sands. It is easy to identify by its high refractive index, interference figure and anomalous interference colours due to inclined dispersion. Sphene from the coastal sands is yellow-brown, whereas sphene from the interior is usually dark brown. It is derived mainly from acid igneous and metamorphic rocks.

Staurolite. This is one of the most abundant heavy minerals in sediments of all ages in NE Suriname. It is much less frequent in the western part of the country. Staurolite occurs usually as "sherry coloured" subangular to subrounded, clearly pleochroic grains. It is derived mainly from the staurolite-garnet mica schists and from a part of the metagraywackes and phyllites of the Armina Formation, but locally also from the Paramaka and Rosebel Formations.he

Thorite. A rare mineral which occurs as small oblong, prismatic, brown to red-brown grains with aggregate polarization. It is derived from certain granitic rocks, e.g. in the Kwama Creek area, upper Coppename.

Topaz. Occurs as subangular to rounded colourless grains. Coloured varieties are very rare in Suriname. It may be confused with colourless andalusite or basal grains of sillimanite. In this case interference figures may prove diagnostic. Topaz is mainly derived from contact metamorphic rocks.

Tourmaline. A very common mineral, found in varying amounts in almost all sedimentary deposits. It is usually prismatic, but basal grains - by cleavage // (0001) - also occur. Grains are angular or rounded, rarely fibrous. Well rounded grains are very rare in Surinam sediments, but are of normal occurrence in the shelf sands off the Pará River in Northern Brazil. Very angular grains usually indicate derivation from nearby quartz-tourmaline veins. Several varieties of tourmaline occur, of which the dark-brown *schorlite* is the most common one. Less frequently found are *indicolite* (blue) or *verdelite* (green, lithium-bearing). Tourmaline is derived from acid igneous rocks, pegmatites, some mica-schists and quartz-tourmaline veins. It occurs in greater contents in sediments in Eastern Suriname than in Western Suriname. The Marowijne River, however, supplies very little tourmaline.

Tremolite. A colourless or pale-green clino-amphibole of relatively rare occurrence. It is derived from metamorphic rocks.

Viridine. This is a manganese bearing variety of andalusite with anomalous interference colours and characteristic yellow-green pleochroism. It was found as traces in drill holes SW of the Onverdacht bauxite area (Aleva et al, 1969) and also in a few samples in the interior, e.g. the upper Coppename area, the upper Suriname River area and the Coeroeni area.

Willemite. Only once detected with ultra-violet light by its green fluorescence colour, in samples from the Paloemeu area. Further prospection for this mineral gave negative results.

Xenotime. This mineral occurs usually as rounded bipyramidal grains or subangular fragments of greyish to light-brown or greenish colour, frequently "clouded". Although not exactly common, it is far from rare on a tropically weathered crystalline shield, since it belongs to the chemically very stable minerals. It occurs as traces in most rivers, but is extremely rare in the sandy ridges. It is also found in the Upper Coesewijne Formation, in most deep drill holes and in some weathered crystalline rocks, where it may even be abundant (see 2.5). Xenotime is derived from acid igneous and metamorphic rocks. Milner's opinion (Milner, 1962) that xenotime is exceedingly difficult to differentiate from coloured zircon is not shared by the author. The somewhat lower refractive index is clear when the upper condenser is used. The birefringence of xenotime is notably higher than in zircon. Furthermore prismatic grains, so typical of zircon, are relatively rare. It is slightly more difficult, however, to distinguish xenotime from monazite. When magnetic separation is applied, there is no problem, since xenotime is moderately magnetic, monazite slightly magnetic and most zircon non-magnetic.

Zircon. This is the most common of heavy minerals on the weathered shield and in the sediments derived from it. It occurs in several different varieties with respect to shape, colour, internal cracks, inclusions, zoning and even refractive index and birefringence. Euhedral colourless grains do occur in Surinam detritals, but they are relatively rare. Brownish to dark pink zircon with numerous cracks and inclusions is the most common type. This slightly metamict zircon with both lower refractive index and birefringence is known als *malacon.* The entirely isotropic variety has never been found. The deviating properties have probably been caused by radiation. Malacon is notably more radioactive than normal zircon due to the high content of U and Th. It also contains more Pb and Y. In ultraviolet light it was found that zircon fluoresces with a bright yellow colour, whereas malacon is not fluorescent (Krook, 1970b). According to Baker (1962) Hf causes the fluorescence of zircon. This element, however, occurs in zircon as well as the non-fluorescent malacon. Zircons of all types vary from euhedral grains with sharp edges to well rounded grains. On the average the grains are prismatic and only slightly rounded. Zircons of the Roraima Formation are usually small, well rounded and pink. They may be found also in sediments derived from this Formation and from some weathered schists and gneisses. Occasionally rounded zircon is found in the centre of a bigger grain which is apparently a second generation overgrowth. Zircon is derived from all kinds of rocks. It is an accessory mineral of acid igneous and metamorphic rocks mainly, but it occurs also in weathered basic igneous rocks, although in minor proportions compared to the "ore" minerals.
Zircon is one of the most stable minerals. It is usually found in the fine fractions, but not necessarily confined to fine-grained sediments, since in sands from rivers draining granitic areas it may form the bulk of the heavy minerals, while the recent silty fine sands of the Amazon contain only traces of zircon.

Zoisite. See epidote.

2.3.3 Light minerals

Calcite. This occurs with *aragonite* as small shell fragments in beaches and recent sandy ridges. It disappears by treatment with hydrochloric acid.

Chamosite. One of the constituents of small green pellets found in recent ridges and beaches. See 2.4.5.4.

Chlorite. Small micaceous greenish grains with low birefringence, difficult to determine more precisely. It occurs both in the heavy and light fractions of recent marine fine sands and sandy clays. Chlorite has been found in older deposits in drill holes TN-1 and GLO-1.

Feldspar. Since feldspar is relatively unstable with respect to quartz, especially in humid tropical conditions, it is usually a minor constituent in the light mineral fractions. It readily disappears in normal soil conditions but it may survive in the arid micro-climatic conditions on large granite boulders and on inselbergs. Recent deposits contain some feldspar, usually *orthoclase* and *microcline*, much less *albite* and *oligoclase*. Since the detrital feldspars, apart from microcline, are rarely twinned, the latter apparently are less stable than untwinned feldspars. In fluvial deposits the feldspar contents of the natural levees are higher than those of the river beds, probably partly due to the smaller grainsize. Relatively high contents of feldspar have been found in the Cretaceous sands and in part of the Early Tertiary sands from drill holes. In samples from the bedrock below the Coesewijne Formation north of Zanderij *sanidine* has been found, characterized by its small axial angle (2V). Most feldspars can be identified by their shape and usually negative relief as compared with quartz (Becke's line).

Gibbsite. Although this is economically the most important mineral in Suriname (bauxite), it has rarely been found in sands. Gibbsite grains may be found near bauxite deposits, as colourless aggregates, difficult to identify by the aggregate polarization. It may be confused with kaolinite. Well developed crystals are apparently very rare.

Graphite. Rounded, dull, black, extremely soft grains have been found in the light fraction of a weathered schist in the Begi Gado mine near Moengo (see fig. 12, KK 456; also table 12). Graphite schists occur locally in the Armina Formation, but because of the low hardness of graphite (1-2) it may hardly be expected in sediments.

Gypsum. Traces of this mineral have been found in sands of Cretaceous, Tertiary and Quaternary age, encountered in drill holes in the coastal plain. They occur as white, subangular, euhedral grains, often with typical twinning, according to (101) (swallow tail). Part of the gypsum has been altered to *anhydrite* which, however, still exhibits the original crystal forms.

Kaolinite. This is found as colourless, dirty or brownish aggregates, never as well formed crystals. Although it is abundant in some sediments, it is usually washed away with the clay fraction.

Muscovite. Of minor occurrence, in recent deposits mainly. It also occurs in some weathered crystalline rocks, to be distinguished from bleached biotite by its interference figure.

Opal. This is found as a minor constituent in river bottom sands (especially the Marowijne River) and in fluviomarine deposits, mostly in the form of fine needles and delicate tubes of organic origin.

Quartz. The most abundant of all detrital minerals. It occurs in all grain sizes. Detrital quartz is on the average subangular. Rounded grains occur in the Roraima Formation, but they are rare in all later deposits. Roraima quartz grains are dull, but in rivers and creeks transporting these sands they become polished. Quartz is usually colourless, but part of the Roraima quartz is pink. Most quartz grains show undulatory extinction. Inclusions are frequent. In some quartz grains of the Upper Coesewijne Formation extremely fine needles of rutile have been observed. Although very stable, quartz grains may show effects of corrosion which may cause ragged surfaces as in the Onverdacht Formation below the bauxite. The opposite effect, viz. slight rounding of sharp edges, has been observed in the Coesewijne Formation (Krook and Mulders, 1971).

Under suitable conditions quartz may disappear entirely by solution as is shown by the formation of the coastal plain bauxites from arkosic or clayey sands.

Vivianite. Opaque blue grains consisting of aggregates of this mineral have been found only in the fluviomarine fine sandy clays of the lower Coppename River. Vivianitic clay in the Miocene of the Alliance drill hole (T-28) has been mentioned by Wijmstra (1969).

2.4 The mineralogy of the weathered bedrock and the sediments of the Cretaceous and the Cenozoic

2.4.1 Weathered bedrock

It has been mentioned above that many samples have been taken from weathered bedrock, small creeks, gullies and colluvium for the purpose of "alluvial prospection". The study of these samples revealed that, generally, the bulk of the minerals was formed by the stable minerals such as ilmenite, zircon, tourmaline, rutile, monazite, the metamorphic minerals and a few others. Less stable minerals such as epidote, garnet, amphibole and pyroxenes were of more local occurrence. This is not surprising since most of these minerals have been weathered before the regolith was eroded and consequently only the more stable minerals are transported in creeks and gullies.

For the present study a few samples have been analysed from different formations. They will be discussed in a stratigraphical order.

2.4.1.1 The Falawatra Group

Rocks of the Falawatra Group are exposed in the northern part of the Bakhuis Mountains and in the lower Coppename River area. In part of the latter area (sheet 28b) only very few samples of unweathered bedrock have been found. The nature of the basement, however, can be inferred from the heavy minerals in samples of the weathered rocks, small creeks and colluvium. The samples of the Falawatra Group have varying compositions, of which a few are shown in table 12. In some (KK 445, 361 and 423) zircon is predominant, in others metamorphic minerals (KK 437) or tourmaline (KK 444). Some samples contain traces of dumortierite. KK 424 contains a relatively large amount of monazite, viz. 32%. The same content is also found in the weathered bedrock of drill hole KK-1 north of KK 424, at a depth interval from 14.5 - 32.5 m.

South of the road from the Tibiti to the Coppename alluvial prospection samples showed zircon, sillimanite, andalusite and additional monazite (Arjomandi et al., 1973).

From the Bakhuis area no samples have been analysed. However, the sands of the Nickerie River, which are mainly derived from this area, contain much sillimanite and kyanite, apparently derived from the sillimanite gneisses. Orthopyroxenes from the granulitic rocks hardly occur in the Nickerie River. This may be due to their unstable nature. The Coppename River, however, contains a relatively large amount of hypersthene which is derived from the Bakhuis Mountains via the Adampada Creek (see 2.4.5 and fig. 19).

2.4.1.2 The Paramaka Formation (Marowijne Group)

KK 399 (table 12) is a sample of the weathered Paramaka Formation. The basic origin is clearly shown by its extremely high content of ore minerals, hematite and ilmenite. The transparent part consists mainly of very fine zircon while a few epidotes still survived the weathering. There is no trace of amphibole, originally the dominating heavy mineral. The Paramaka Formation locally supplies some staurolite, e.g. in the upper Tibiti area and in the Lawa area.

2.4.1.3 The Armina Formation (Marowijne Group)

On the geological map of Suriname (Bosma et al., 1977) this formation is divided into two petrographical units, viz. metagraywackes and phyllites, and staurolite-garnet mica schists. The latter occur around the granite outcrops in NE Suriname (fig. 2). The first are situated south of these, near the Marowijne River and along a part of the Coppename River.

The weathered rocks of the Armina Formation supply much staurolite as can be observed in table 12, not only from the staurolite-garnet schists (KK 243, 266, 397 and MM 6), but also from the metagraywackes and phyllites near the Marowijne (MAR 3 and 24). The Armina Formation along the Coppename does not provide staurolite. KK 293 and 312 are graywackes of this area. They contain mainly zircon. The first is only slightly weathered as can be deduced from the high biotite content. KK 291, an ortho-quartzite, also contains mainly zircon.

The northern part of the Coppename occurrence is relatively rich in sillimanite (Arjomandi et al., 1973).

KK 276, colluvium derived from the Armina Formation, reflects the presence of quartz-tourmaline veins. However, tourmaline may also be a primary constituent of a schist. This is shown by KK 456, a graphite schist. This schist has also a high content of xenotime

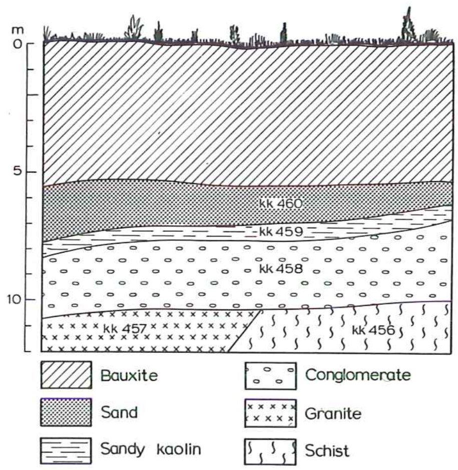


Fig. 12 Section showing sample locations in the Begi Gado mine near Moengo

(see also fig. 12).

The Armina Formation supplies most of the staurolite occurring in NE Suriname and adjacent French Guiana. Less intensely weathered outcrops also supply much garnet. Most of the staurolite and the garnet in the sand of ridges and beaches is derived from French Guiana.

2.4.1.4 The Rosebel Formation (Marowijne Group)

This formation may also show staurolite, although generally less than the Armina Formation (MM 23, table 12). Zircon is usually dominant. KK 418, a weathered schist, reveals only zircon and no ore minerals. Samples taken during gold prospection in the Rosebel Formation always showed much rutile. A high rutile content also occurs in the Upper Coesewijne sands north of the Rosebel outcrops.

2.4.1.5 Granitoid rocks

Deeply weathered granites and granodiorites in the interior usually provide mainly zircon and some epidote as may be concluded from the study of hundreds of alluvial prospection samples. The light fractions of these samples contain only little feldspar. However, there is a different kind of weathering on inselbergs and large boulders of granite due to the fact that these are not covered by soil. The result is an arid micro-climate on these bare rock surfaces which causes mainly physical weathering by loosening of the mineral grains and only little chemical weathering.

KK 296 (table 13) has been taken from an arenaceously weathered granite on a steep bank of the Kwama Creek and contains much feldspar and epidote. KK 342 is from loose material on a large porphyritic granite boulder at Kaaimanston on the Coppename River where weathering may have been mainly physical, since the sample contains much hornblende, biotite and even apatite.

Some interesting samples have been taken near and on the Voltzberg, a large granite inselberg (fig. 1). KK 300 represents the typical products of inselberg weathering and contains much epidote and feldspar. KK 301 is from a young soil on the granite where weathering is somewhat more advanced. KK 304 is a sample of loose material found under a huge granite boulder where the heavy fraction is almost entirely zircon but the light fraction contains 24% feldspar and 4% biotite.

Bakker (1975a, 1960) did some detailed studies on the weathering of inselbergs and arrived at about the same conclusions. However, his observation that epidote weathers to alterite is not shared by the present author. Alterite seems to be a product of weathering in relatively cold areas and has rarely been observed in Surinam sediments (see 2.3). The weathering of epidote in the humid tropics apparently leaves no traces.

The results of the study of weathering products on boulders and inselbergs might give an indication on the origin of the unstable minerals which are present in the riverbeds. It has long been taken for granted that rivers in tropical lowlands would contain mainly stable minerals, since the sediments were derived from deeply weathered rocks (Bakker, 1968). However, as will be shown below in the description of river sands, all rivers and large creeks contain a fair amount of unstable minerals such as epidote, hornblende, garnet and even hypersthene. Since the small creeks and superficial gullies supply stable minerals mostly, as is evident from the examination of many samples, the unstable minerals would be provided by the larger rivers. This would be not so much by depth erosion as by the exfoliation of boulders and outcrops of bedrock in the rivers during the low water stage in the dry season (September - November), a process that has been suggested by Kroonenberg (1967).

Granitic rocks are sometimes reached by drill holes in the coastal plain. An example is the bedrock in drill hole WA-4 (encl. 3) which shows 82% hornblende, 10% epidote, 5% sphene, 2% apatite and 1% zircon, a composition which is quite characteristic of unweathered granite.

A few deeply weathered rocks of granitic appearance have been sampled near Albina (KK 455, table 13) and in the Begi Gado mine (KK 457). Both samples contain very high percentages of monazite. At the last location the granite seems to be intrusive in the graphite schist (fig. 12).

2.4.1.6 Unknown formations

Rocks of unknown formations have been encountered in several drill holes in the Young Coastal Plain and in some holes south of the Onverdacht mining area. The samples from TN-1 and CC-3 contain apatite, a mineral which is typical of unweathered crystalline rocks. The bedrock in drill hole 4-71 mainly contains garnet.

Drill hole PB-3 poses an interesting problem. According to Noorthoorn van de Kruijff (1970) the basement occurs at 648 m. The composition of the samples, however, makes it quite probably that the basement reaches to about 510 m. In this supposed basement two different associations occur: a lower association of garnet, tourmaline, some zircon and a little monazite and an upper association with predominant tourmaline, considerable zircon and a relatively high content of monazite. It seems that the lower association represents the unweathered part of the basement, while the upper association is the weathered part without the unstable garnet. It has to be admitted that the stable part is extremely thick for a weathered zone (about 110 m, from 510-620 m depth) which suggests that a part of it is allochthonic. In this case it might have been derived from nearby weathered rocks, possibly by mass processes or slump.

The holes drilled between Zanderij and Onverdacht (Aleva et al., 1969) reached bedrock part of which contained high percentages of monazite and some xenotime (see drill hole B-2, fig. 15). According to the present geological map of Suriname (Geol. Mijnb. Dienst Suriname, 1977; Explanatory Note by Bosma et al., 1977) the rocks exposed nearby are biotite gneisses.

2.4.2 The Cretaceous

The Cretaceous sediments underlying the coastal plain consist of terrigenous sediments only. Van der Hammen and Wijmstra (1964) describe them as "consolidated sands and clays" and dated the upper part as Maastrichtian. Clays are dominating at the western margin of the basin (near Georgetown, Guyana), while near the axis of the basin the sediments consist mainly of sands with some lignite layers. According to Noorthoorn van de Kruijff (1970) the Cretaceous (Nickerie Formation) sediments are unconsolidated and comprise sands and kaolinitic clays mainly, with some gravel beds. At the base red beds occur. All authors agree on a continental facies, possibly fluvial. Although the upper part of the Cretaceous has been dated as Maastrichtian, the great thickness underlying the western part of the Surinam coastal plain suggests that older ages might occur as well.

In a seaward direction the Cretaceous thickens considerably (see fig. 9) and the base was found to be of much older age. At the outer shelf (GLO-1, see fig. 9 and fig. 11) a marine platform facies occurs. The sediments are mainly terrigenous with more shales than sandstones. A few limestone layers are found. From the Middle Albian to the end of the Maastrichtian one transgressive phase was observed, followed by two regressive phases (Belsky et al., 1972). On the middle part of the shelf (CO-1, see fig. 11) the Cretaceous sediments, comprising shales and sandstones, show a regressive character (Belsky et al., 1972).

Sediments of the Cretaceous have been sampled from the following drill holes: WA-3, BNS-1, WA-4, CC-3, PB-3 and CO-1.

WA-3 contains mainly zircon and alternating amounts of garnet and sillimanite. Monazite is relatively abundant in the lower part of the hole. The feldspar content is rather high.

In BNS-1 there is a marked difference between the part from 625-950 m and the part from 950-1350 m. The first has a zircon-garnet association, while the latter contains mainly zircon. The lower part shows a relatively high content of monazite. The light fractions have not been studied.

WA-4 went through only about 50 m of Cretaceous before reaching basement rocks of granitic composition (see 2.4.1.5). Zircon predominates, followed by sillimanite, staurolite, some other metamorphic minerals and monazite. The deepest sample has 25% feldspar. TN-1 resembles WA-3 with abundant zircon and some peaks of garnet and sillimanite. The feldspar content is moderate to high. In the Calcutta hole CC-3 an entirely new association occurs, viz. with abundant staurolite and kyanite, while garnet and sillimanite hardly play a role. Monazite also occurs. PB-3 shows mainly zircon and staurolite and high contents of feldspar.

Most samples from the Cretaceous underlying the shelf (CO-1, fig. 13) are from shales which contain a rich variety of minerals. The association consists of zircon, tourmaline, garnet, staurolite and sillimanite. Most sillimanites are small, rounded basal grains. In the uppermost Cretaceous, where sandy deposits prevail, no staurolite occurs. The feldspar content is generally high and has an average of 32%.

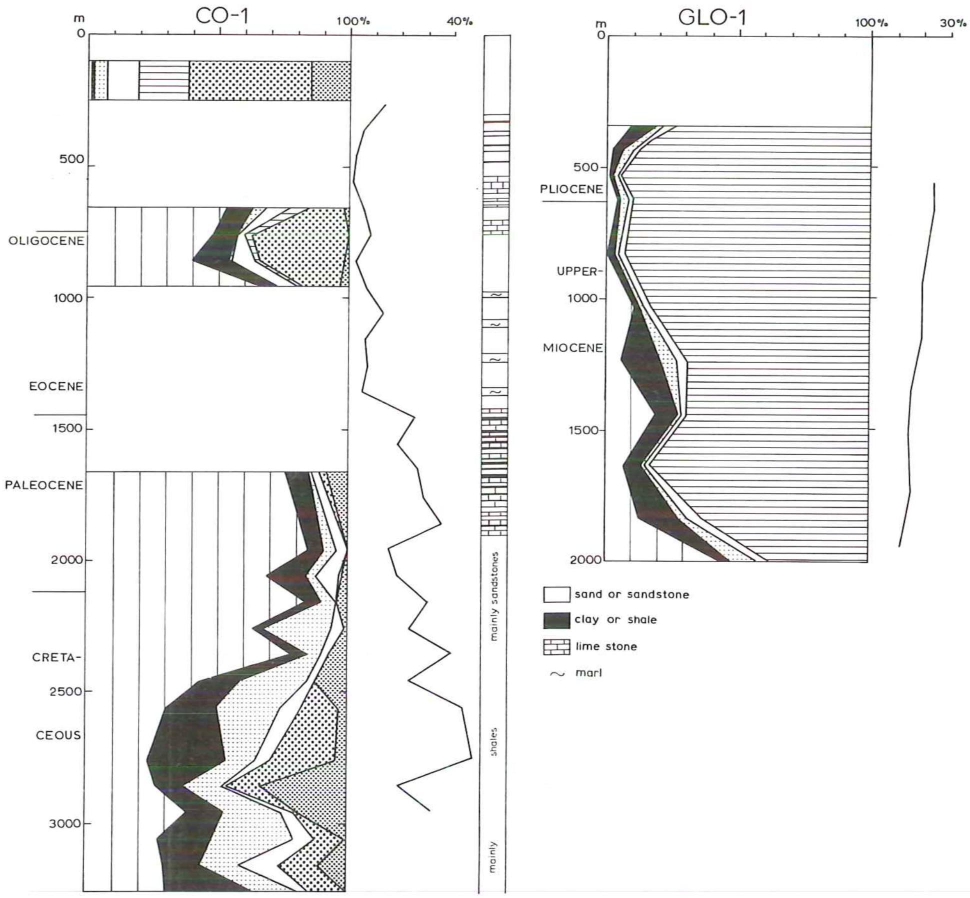


Fig. 13 Heavy mineral composition of sediments in drill holes CO-1 and GLO-1 on the continental shelf of Suriname

Summarizing it may be concluded that the heavy fractions in the sediments of the Cretaceous contain mainly zircon and several metamorphic minerals, including garnet. Monazite is also rather abundant. The light fractions contain relatively much feldspar.

2.4.3 The pre-bauxite Tertiary

The Tertiary of Suriname may be divided into sediments deposited before the bauxite formation and the sediments deposited after and, possibly, partly during the bauxite formation. In the southern part of the coastal area these sediments belong to the Onverdacht Formation (Paleocene-Eocene) and the Coesewijne Formation (Oligocene-Miocene-Pliocene) respectively.

The Onverdacht Formation in the Onverdacht-Lelydorp-Paranam area consists of coarse sands and kaolinitic clay (1.4.2). In the Moengo mining area, however, the formation also contains coarse gravel layers. O'Herne (1958) described a section in the Ricanau mine, comprising a coarse conglomerate at the base, followed by clayey sand, kaolin and bauxite. A different section, from the Begi Gado mine in the same area, is shown in figure 12. In this section not kaolin, but sand underlies the bauxite.

The Paleocene underlying the eastern part of the coastal plain consists of - partly calcareous - sands and clays with a few lignite intercalations. From the occurrence of the *Foraminifera*, the *Ostracods* and the *Bryozoa* in the deposits of drill hole T-28 a shallow marine environment with slightly reduced salinity has been concluded (Lagaay, 1969; Voorthuysen, 1969). Porrenga (1969) not only found this Paleocene transgressive phase, but also one in the Eocene, based on a study on paleosalinity by means of the boron content of the clay fraction. However, pollen from the same thin clay layers show high percentages of the *Palmae* group which seems to indicate a low relative sea level (Wijmstra, 1969). The Eocene in T-28 is sandy at the base, while the upper part consists of kaolin and kaolinitic sand, apparently indicating the weathering phase of the "bauxite interval". It should not be excluded that the kaolin was originally deposited as marine clay which was kaolinized during the long weathering phase. However, neither fossils nor pollen are present. The boron content is very low but this may also be due to the weathering after deposition (Porrenga, 1969). In many other drill holes in the coastal plain as well, the upper part of the sediments below the "bauxite hiatus" is deeply kaolinized (Wijmstra, 1971; Van Lissa, personal communication).

In drill hole CO-1 on the continental shelf the Paleocene consists of shales, limestones and sandstones with pyrite and lignite in the lower part, indicating a shallow marine environment. The lowermost Eocene contains calcareous algae which are overlain by continental sandy deposits (Wong, 1976).

In GLO-1 the Paleocene and Eocene show a positive sequence from shale to limestone (Belsky et al., 1972).

Regarding the description of the mineralogy of the drill holes in the coastal plain it should be noticed that the exact stratigraphy in these holes is known in only a few cases, viz. the holes which have been cored and studied palynologically in detail: C-1 (originally T-42, Wijmstra, 1971), C-12 (Amstelveen, 1969) and T-28 (Wijmstra, 1969). From the holes drilled by Shell only the exact position of the top of the Cretaceous and the MLM are known (MLM - Mid Lower Miocene; it is, however, probably the boundary between the Lower Miocene and the upper Middle Miocene which are separated by a hiatus, see 2.4.4), because of the presence of density shifts (see 1.4.2). The position of the bauxite hiatus is often difficult to determine. It can be done by comparison with adjacent holes with a known bauxite hiatus or with the aid of lithology.

The pre-bauxite Tertiary has been reached by most drill holes in the coastal plain (see encl. 3). WA-3 contains a relatively large amount of feldspar (up to 23%, but the heavy fraction is extremely poor and consists mainly of zircon and some monazite. BNS-1 has somewhat more staurolite and sillimanite than WA-3. The feldspar content has not been determined. WA-4 hardly differs from BNS-1. The feldspar content is moderate. TN-1 again has mainly zircon and some monazite, but a very low content of metamorphic minerals. The light fraction has no feldspar. CC-3 has a zircon-staurolite association and also contains no feldspar. In C-1 the pre-bauxite Tertiary consists of sandy kaolin. The association is very different from the nearby CC-3 since the staurolite is almost absent. The very impoverished association in a kaolin matrix indicates intense weathering in situ or deposition of highly weathered sediments derived from the hinterland. An association with much zircon and some staurolite is found in TA-2 while the lower parts of 7-70 and 8-70 give the same picture. It also occurs in a few other drill holes to the east, such as PB-3, T-28, TPS-1 (probably; the bauxite hiatus is not known, but since the hole is north of T-28, it may be below 250 m) and 4-71. 6-70 shows higher staurolite contents below the supposed depth of the bauxite hiatus (according to Dixon, 1971a). T-28 differs from the other holes by its' relatively high feldspar content.

The Paleocene of CO-1 on the continental shelf is richer in zircon than the Cretaceous and has less garnet and staurolite. The samples of the latest Paleocene and the Eocene did not contain any heavy fractions. The feldspar content of the Paleocene is high, but the Eocene shows low values.

The mineralogy of the Onverdacht Formation in the Onverdacht-Lelydorp-Paranam area has been discussed by Krook (1969a). The sands have an association of zircon and staurolite with lesser amounts of tourmaline, monazite, rutile and metamorphic minerals. The minerals show signs of extreme leaching. The light minerals do not contain any feldspar. Staurolite and quartz are heavily corroded while the ilmenite has been weathered to hydro-ilmenite and leucoxene. The deposits of the Onverdacht Formation in the Moengo mining area are intensely weathered as well. Table 13 shows some samples from the Ricanau mine (KK 32) and some from the Begi Gado mine (KK 458, 459 and 460, see also figure 12). Since the sediments contain mainly staurolite, they were obviously derived from the Armina Formation in the nearby hinterland. It is striking that not even a trace of sillimanite occurs, most probably due to weathering. The grain size of the sediments below the bauxite in the Begi Gado mine is reflected by an increasing content of zircon with decreasing grain size in gravel, sand and kaolin respectively.

Valeton et al. (1973) report, besides staurolite, the occurrence of epidote and clinozoisite in the sediments below the bauxite. This is highly remarkable since both minerals are relatively unstable and have never been found in pre-bauxite sediments by the present author. Indeed, clinozoisite is usually confined to the recent and subrecent coastal deposits. Ter Meulen (1948), who made a thorough study of the kaolin, also did not find epidote or clinozoisite.

In the Ricanau mine near Moengo black sand concentrates occur below the bauxite in which ilmenite is the main opaque mineral (KK 32). In the Begi Gado mine, however, hydro-ilmenite and leucoxene are predominant. Magnetite and chromite, both mentioned by Valeton et al. (1973), were not found.

Although Aleva (1965) extracted heavy minerals from the bauxite, no data were given as to their nature. They were found, however, to be much coarser than the heavy minerals in the underlying kaolin which may be an indication of the coarse nature of the original sediments.

Valeton et al. (1973) found that the bauxite of the Onverdacht mine was very rich in heavy minerals and suggested that this would also hold for the original sediment. This is interesting, especially if one considers that only the more stable minerals have been left. In an earlier paper Valeton (1971) studied the occurrence of fossil plant roots and burrows in the basal parts of the bauxite and in the underlying kaolin.She concluded that the sediments in concern were deposited in a mangrove environment or a swamp environment, either fresh or brackish. This near-coastal environment suggests that the relatively high content of heavy minerals was the result of concentration by waves on a beach. The black concentrates below the bauxite in the Ricanau mine may have a similar origin.

The present author studied heavy minerals from the bauxite in a few drill holes, but these did not differ from the sediments either older or younger than the bauxite (Aleva et al., 1969). He also studied a sample from the red mud lake of the Suriname Aluminum Company at Paranam. Since all heavy minerals of the bauxite, which is processed into alumina, eventually gets into the red mud, the heavy minerals give some idea of the mineral components which survived the process of bauxitization and the treatment with the caustic soda in the Bayer process. The heavy mineral sample was separated with a Frantz magnetic separator. It was striking that a great part of the zircon was more or less magnetic, a property not observed before in "normal" heavy mineral concentrates. The minerals encountered were, in decreasing order: ilmenite, hydro-ilmenite, leucoxene, hematite, limonite, zircon, staurolite, andalusite, rutile, kyanite, tourmaline, corundum, xenotime, garnet, pyrite, fibrolite, monazite and hornblende (the latter five in the merest traces only). The zircon content was about 0.18% by weight from the sand fraction (> 44 µm). The silt fraction probably contained considerably more, since much zircon could be observed in the silt washed through the sieve. The minerals have been derived from the bauxites from the Onverdacht-Lelydorp-Paranam area and from the Moengo area.

From the foregoing descriptions the conclusion may be drawn that the heavy fractions of the Paleocene and Eocene in all drill holes and in the bauxite mines show extremely poor associations which obviously are the result of long-time weathering. It is surprising that a few holes still have high feldspar contents. This suggests that the sediments originally were of subarkosic or even arkosic composition. This conclusion has been drawn before by the author, who used this as evidence for the origin of the bauxite from the weathering of the arkosic sands (Krook, 1969b).

2.4.4 The post-bauxite Tertiary

All post-bauxite Tertiary sediments underlying the coastal plain and those in the bauxite area belong to the Coesewijne Formation. In the coastal plain this formation starts with extensive sand deposits on top of the bauxite hiatus, the A-sands (see 1.4.2). According to Van der Hammen and Wijmstra (1964) these deposits are of a regressive character. They do not occur in the bauxite area (see figure 3). The A-sands are overlain by the Intermediate Clays, which, on the whole, are much more sandy in the eastern part than in the western part of the Guiana Basin. They also contain some lignite. In the Intermediate Clays two pollen zones can be distinguished, the E-zone and the F-zone. They have been described in detail by Wijmstra (1971). The E-zone consists of a lower, clayey part (E-1) and an upper, sandy part (E-2). The first is of a transgressive character, while the latter is clearly regressive. The overlying F-zone is more clayey again and shows at least three minor transgressions and regressions, but is on the whole transgressive. The age of both zones has not yet been established with certainty. The zones could be correlated with identical zones in drill hole SO-1 on the continental shelf (see figure 11) as described by Prestat et al. (1966). According to this correlation zone E was of lower Middle Aquitanian age, while the F-zone was Burdigalian. However, after correlation with certain foraminiferal zones Wijmstra (1971) concluded that the E-zone covered the Early Miocene and the F-zone the Middle Miocene.

In sections drawn from data of drill holes in the Young Coastal Plain by Dixon (1971a) several large sand bodies occur in the E-zone and the F-zone, possibly representing old river courses (proto-Suriname River?). Smaller and thinner sandbodies are probably fossil beaches. In C-1 fine as well as coarse beach sands could be recognized.

D'Audretsch (1953) described a zone of green, partly kaolinitic, clay at a depth of about 120-170 m which contained glauconite, some barite and several fossil marine faunal species. Van der Eyk (1957) thought that this green clay was a marine continuation of the deposit on which the bauxite was formed, but in the sections of Dixon (1971a) it occurs within the E-zone in clays above the A-sands. Apparently it marks a transgression.

The Late Miocene is missing in deposits underlying the coastal plain.

The Upper Sands of the Pliocene are not always clearly marked in the drill holes. In fact, the Pliocene may consist of clay for a considerable part (pollenzone G-1).

The Miocene and Pliocene deposits in the bauxite area have been described in 1.4.2. They comprise coarse sands and kaolinitic clays.

The lithology of the Oligocene, Miocene and Pliocene deposits underlying the continental shelf is very different from its southern counterparts (Wong, 1976).

In the Oligocene there is a strong influx of terrigenous sediments. CO-1 consists of medium to coarse sands with some layers of marl. SON-1 and MO-1 show sandy marl and some sand. In GLO-1 the Oligocene is relatively thin and consists of shale.

During the Early Miocene carbonate platform conditions existed on the continental shelf and limestone deposits were formed. The Langhian shows more terrigenous sedimentation: sand in CO-1 and sandy marl in SON-1 and MO-1. After this interruption limestone deposition continued until the Late Miocene, when terrigenous sedimentation started again.

The southern part of the Tertiary deposits is formed by the Upper Coesewijne Formation which crops out in the Savanna Belt. It consists of moderately to poorly sorted white sands and brown loamy sands.

The mineralogical composition of the deposits above the bauxite hiatus is usually markedly different from the composition of the older deposits as can be seen on the heavy mineral graphs of the drill holes in enclosure 3. The Coesewijne Formation of drill hole 5-72 has a zircon-sillimanite association with a minor content of other metamorphic minerals, monazite and garnet. WA-3 and BNS-1 have less sillimanite and more staurolite. In WA-4 there is a gradual decrease upward of staurolite and an increase of sillimanite. The feldspar content is zero to very low in 5-72, WA-3 and WA-4 and was not determined in BNS-1. TN-1 shows a very unusual association, viz. a high content of epidote and hornblende. This, together with some basaltic hornblende, clinozoisite, chlorite, chamosite (see also 2.4.5.4), biotite, muscovite and opal strongly resembles that of the recent marine deposits. The feldspar content is about 10%, which is relatively high compared to the other drill holes in the coastal plain. According to Van Lissa (personal communication) the sands of the Miocene, the Pliocene and the Quaternary of both TN-1 and SMS-1 (fig. 11, the latter hole has not been studied mineralogically) are exceptionally fine grained compared to the other drill holes. The fine grained sediments suggest a relatively deep marine environment of deposition which was little influenced by sediments transported along the coast. Since the sands both to the west and to the east were coarser grained the occurrence of an embayment might be presumed. It is hard to imagine, however, that an embayment could be maintained for millions of years in the same region. It should be added that in both holes the A-sands are lacking.

Sands of the Lower Coesewijne Formation, in most drill holes east of the Coppename River, have a relatively high staurolite content. Usually there is quite an abrupt change in the younger deposits from an association rich in staurolite to an association with a relatively small amount of this mineral. This change is only slight in T-28, but more pronounced in CC-3, C-1, TA-2, C-12, 7-70, 8-70, PB-3 and TPS-1. In a few holes it has been shown that the top of the high staurolite association coincides with the top of the Lower Coesewijne Formation while the Upper Coesewijne Formation cannot be distinguished mineralogically from the Pleistocene. These holes are C-1 (Voorthuysen and Wijmstra, 1966; Wijmstra 1971) and PB-3 (Amstelveen, 1971; pollen data from the adjacent hole PB-2). However, this is no general rule since in GH-1 the Pliocene has the same association as the Miocene.

The Calcutta holes C-1 and CC-3 differ from all other holes in their kyanite content. In C-1, which has been sampled in detail, the kyanite appears to occur only in the coarse sands and not in the fine sands.

In CO-1 on the continental shelf the two lower samples of the Oligocene at

1160 m and 1060 m depth contain only very few heavy minerals. The other Oligocene and Lower Miocene samples contain much zircon and staurolite and some tourmaline. The entire Oligocene and the Miocene have a low feldspar content.

The Late Miocene and the Pliocene deposits of GLO-1, which are slightly sandy clays, show a high content of epidote and hornblende, some zircon and tourmaline and little garnet and titanium minerals, rutile, anatase and sphene. The presence of some redbrown basaltic hornblende, clinozoisite and chlorite is striking. There is a gradual increase upward of the feldspar content which is higher than in any other post-bauxite deposits (fig. 13).

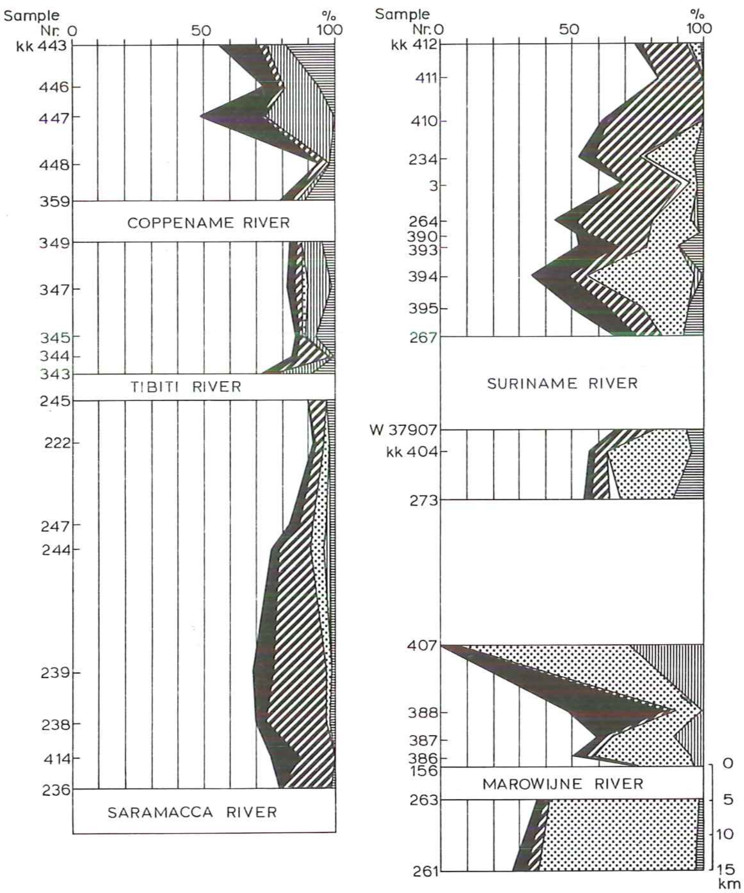


Fig. 14 Heavy mineral composition of sands of the Upper Coesewijne Formation

The Upper Coesewijne deposits of the Savanna Belt contain only stable minerals (tables 13 and 14). The light fractions consist only of quartz. For data on grain size, roundness, etching, weathering etc. see Krook and Mulders (1971). Most samples have been taken from the area just west of the Coppename to the Marowijne and a few in French Guiana. Figure 14 gives a schematic representation of the heavy minerals in these samples. West of the Coppename River the predominating zircon is accompanied by metamorphic minerals (mainly andalusite) and tourmaline. From just west of the Coppename to the Tibiti there is a decrease in the content of the metamorphic minerals and tourmaline. East of the Tibiti there is a general increase of rutile. This mineral is abundant up to the area east of Zanderij. From the Saramacca to the east the staurolite content increases. This mineral, with a few local interruptions, is the first or second abundant constituent in the eastern part of the Savanna Belt. It has been mainly derived from the Armina Formation (see 2.4.1.3). Tourmaline shows a few peaks, especially near Mongo Tapoe (KK 388) where it probably reflects the occurrence of pegmatite deposits in the hinterland (Van Eijk, 1958). The high andalusite content near the Patamacca River may indicate the nearby contact metamorphism of the granite and the metamorphic schists (KK 407).

In KK 465, just west of the Suriname River, a diamond with a diameter of about 100 µm has been found.

The opaque minerals of the Upper Coesewijne Formation are mainly ilmenite, hydro-ilmenite and leucoxene. The content of opaque minerals differs widely from one place to another. On average this content is high to the west of the Saramacca River and low to the east of it.

At several places in the Savanna Belt holes have been drilled for the prospection of bauxite (for a summary on bauxite exploration drilling see Van Lissa, 1975). From a few of them heavy minerals have been studied.

SL-12 (encl. 2, sheet 18b) is a hole in the Marataka area which has been sampled down to 70 m. The greater part of this section belongs to the Upper Coesewijne Formation. Zircon predominates, followed by sillimanite, variable tourmaline (1-16%) and accessory metamorphic minerals (andalusite, kyanite, staurolite and corundum), monazite, xenotime and rutile. There is a decrease of sillimanite with depth. The association resembles drill hole 5-72 near Nickerie (encl. 3) and the stable part of the Corantijn River (see fig. 16).

North of Bitagron seven holes were drilled and sampled (KK I-VII, encl. 2, sheet 20c). Three holes reached the bedrock at depths between 14.5 and 24 m. The composition of the sands resembles the association of the surface sands between the Coppename and the Tibiti, viz. mainly zircon, some metamorphic minerals (especially andalusite), more or less tourmaline, a few percent rutile and traces of monazite, xenotime and topaz.

Two holes have been drilled near Sabana on the Tibiti (encl. 2, sheet 20a).

One of them, KK-VIII, is shown in figure 15. The upper part of the sediments has a composition like the surface samples in the south, but there is a marked increase in staurolite below 12 m. This high staurolite content most probably points to a supply from the east by beachdrifting which would indicate a transgression in the lower part of the Upper Coesewijne Formation (Krook and Mulders, 1971). There are other indications of this transgression. The section of drill hole B-2 near Zanderij in figure 15 shows coarse sand with zircon near the surface and fine sandy clay with predominating staurolite at some depth. The coarse, zircon bearing, sand has apparently been derived from the

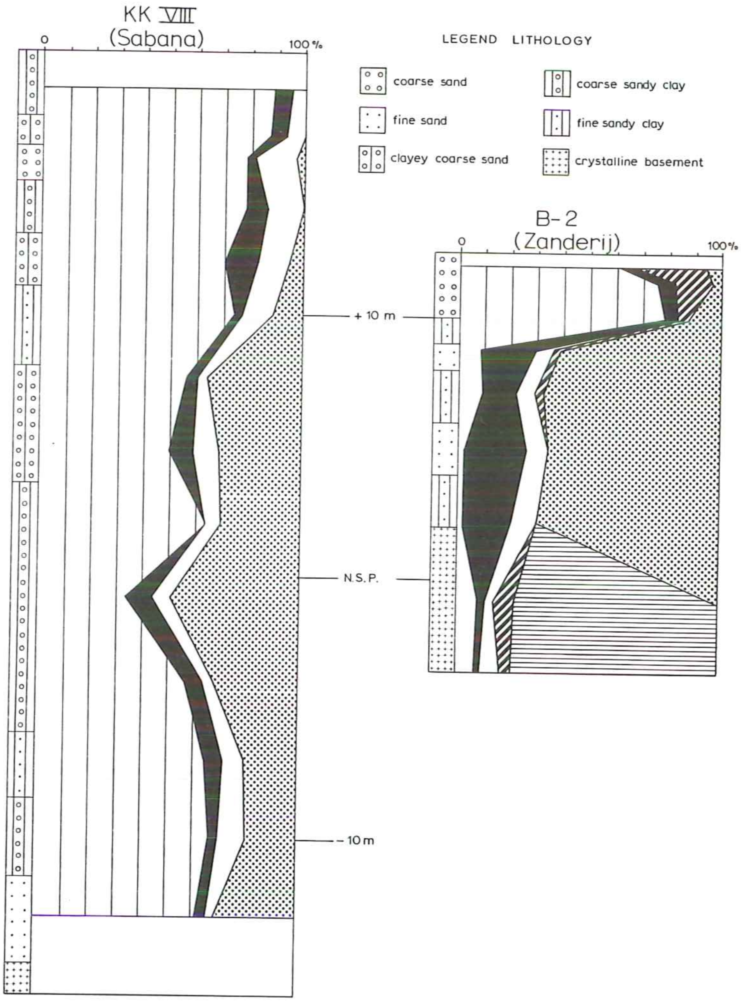


Fig. 15 Heavy mineral composition of sediments in two bore holes in the Upper Coesewijne Formation

hinterland while the fine sandy clay is of marine origin. The latter is confirmed by the occurrence of a foram, *Quinqueloculina* sp. (Van Hinten, personal communication).

In the Upper Coesewijne Formation encountered in the holes from Zanderij to Onverdacht, drilled on behalf of the Seventh Guiana Geological Conference in 1966, staurolite often dominates in the fine grained sediments, but it may also be abundant in coarse sands. These sands may either belong to coarse sandy ridges or to deposits from rivers draining the nearby Armina Formation. A present example of such a river is the Para Creek (see enclosure 2 and table 18, nrs. KK 380 and 381).

In some Upper Coesewijne and probably also Lower Coropina sands traces of virdine have been found. The viridine has been indicated in the section of enclosure 4 in Aleva et al. (1969).

In the sands of the Upper Coesewijne Formation in the Zanderij area rutile shows an increase in the upper few metres (fig. 15). Rutile is most probably derived from the Rosebel Formation just to the south (see 2.4.1.4). From this change in composition the conclusion is tentatively drawn that the deeper sands have a larger hinterland than the upper sands. The latter are of more local origin and were probably supplied by small braided rivers or even by ephemeral streams forming alluvial fans. This has already been suggested by Zonneveld (1955). The original opinion of Bakker (1954) that the sands were deposited in a coastal environment, is not in agreement with the facts now known.

Summarizing it may be stated that the Oligocene and Miocene sediments differ considerably from the older Tertiary deposits from a mineralogical point of view. The western part of the deposits underlying the coastal plain contains mainly zircon, some sillimanite and little staurolite, while in the eastern part staurolite usually predominates. TN-1 is exceptional in its high epidote-hornblende content. On the continental shelf the coarse sand of CO-1 is also rich in staurolite while GLO-1 has an epidote-hornblende association with a relatively high feldspar content. The sands of the Upper Coesewijne Formation in the Savanna Belt contain only very stable minerals, the composition of which reflects the lithology of the geological formations in the interior.

2.4.5 The Quaternary

The Quaternary of Suriname is known, because of its good accessibility, in much more detail than the Cretaceous or the Tertiary. An exception is, of course, the Lower Pleistocene, since this does not crop out and is only found in drill holes in the Young Coastal Plain. The Quaternary underlying the Young Coastal Plain consists of clay alternating with thick or thin beds and large lenses of sand. The pollen diagram of drill hole T-28 near Alliance (fig. 11) reflects a succession of transgressions and regressions, presumably correlating with interglacial and glacial stages (Wijmstra, 1969).

The Pleistocene in the Old Coastal Plain belongs to the Coropina Formation which has been discussed in some detail in 1.4.2. The Upper Coropina Formation is most probably of last interglacial age, while the Lower Coropina Formation was possibly deposited during an earlier interglacial (Brinkman and Pons, 1968). The term Coropina Formation is not used for the Pleistocene deposits encountered in the drill holes in the Young Coastal Plain since these are partly older and can hardly be correlated with the Coropina sediments exposed in the Old Coastal Plain by lack of data in the area between.

From the Quaternary found in the drill holes on the continental shelf only few data are known. The upper part of CO-1, consisting of coarse sand, is probably of Pleistocene age, but no lower boundary is known (Wong, personal communication. The upper part of SO-1 shows sands and clays (Belsky et al., 1966). In GLO-1 the Pleistocene consists of fine sandy clays of the same type as occur in the Upper Miocene and the Pliocene (Belsky et al., 1972).

The surface deposits of the continental shelf have been studied by Nota (1969, 1971), see 1.4.4. With the exception of a near coastal belt of silty clays of Holocene age, the shelf is covered with Pleistocene, more or less clayey sands, while remnants of reefs are found near the edge. Off the Marowijne a submarine delta occurs.

The sediments on the shelf off the Amazon River have been described by Tjoe Awie (1975) and Barreto et al. (1975). They consist of silty clays on the near coastal shallow parts and fine sands on the outer shelf.

The Quaternary also includes the river deposits, i.e. the terrace deposits of Pleistocene age, the subrecent and recent natural levees and the sands of the present river-beds.

The Demerara Formation of the Young Coastal Plain has been described in 1.4.2. Of most interest from a mineralogical point of view are the sandy ridges and the beaches.

Since the deposits of the Quaternary are of such a varied nature it would be confusing to describe them mineralogically in a chronological order. Therefore the description is more or less according to morphogenetical units. After the deposits underlying the Young Coastal Plain, the Coropina Formation of the Old Coastal Plain will be discussed, followed by the fluvial deposits, the sandy ridges, the beaches and the continental shelf.

2.4.5.1 The Quaternary underlying the Young Coastal Plain

The Pleistocene sediments in 5-72 and WA-3 differ little from the post-bauxite Tertiary. In BNS-1 there is an increase of staurolite and it also shows some epidote. In WA-4 the staurolite stops almost entirely while there is a large increase of sillimanite. TN-1 shows an increase of epidote and hornblende and a decrease of staurolite. The general decrease of staurolite and the increase of zircon probably at the beginning of the Pliocene has been described above (2.4.4). Several holes also show an increase of epidote and hornblende which - probably - starts in the Pliocene. The samples taken at 29 and 36 m from C-1 contain almost no epidote and hornblende. This is due to weathering of the top of the Pleistocene during the low sea-level stage of the last glacial. In the core of this drill hole a pronounced soil profile could be observed (Krook, 1969a).

The upper part of CO-1 on the continental shelf (103-250 m) is a coarse sand which contains a considerable amount of staurolite and sillimanite (fig. 13). The latter mineral is partly of the pleochroic type (see 2.3.2). This mineral and the coarse hypersthene are both typical of the Coppename River. The staurolite is of a more eastern origin (2.3.2, 2.4.1.3).

The Plio-Pleistocene part of GH-1 differs little from the Upper Miocene. The sediments contain zircon and metamorphic minerals of which staurolite is the most abundant. Most striking is andalusite which is probably of rather local provenance since it occurs also in the Upper Coesewijne Formation south of this drill hole and in sands supplied by the Coppename River (2.4.5.3).

From a few holes the Holocene has also been sampled. The Holocene part of 5-72 is entirely different from the Pleistocene part. It contains abundant staurolite and some epidote and hornblende, a composition similar to the fine sandy ridges of the Young Coastal Plain (2.4.5.4).

The topmost sample of WA-3 with 65% staurolite and 14% garnet resembles the coarse beach sands and the coarse sandy ridges of the Moleson and Comowine phases (2.4.5.4). It is the westernmost sample with this composition.

In the BNS-1 hole the upper sample is not significantly different from the ones just below although the sillimanite content is lower. Since it is a fine sand with 10% chlorite it is most probably a marine sand. It resembles the fine sandy ridges of tne Moleson-Comowine phases but it has a relatively high zircon content.

The Holocene of TN-1 does not differ from the Pleistocene. It contains mainly epidote and hornblende and little zircon and staurolite. The Holocene of C-1 contains also very little staurolite, but the zircon content is high.

2.4.5.2 The Old Coastal Plain

As is shown in table 14 the sands of the Offshore Bar Landscape west of the Suriname River have only stable minerals. No sands west of the Coppename have been sampled by the author. However, according to Zonneveld (1969a) they contain moderate percentages of sillimanite which apparently distinguishes them from the more eastern samples. The sands east of the Coppename (Kalebaskreek, KK 67 and 70) have about the same composition as the sands south of Paramaribo (KK 39 and 216) and show a staurolite-zircon association, accompanied by tourmaline, rutile, some metamorphic minerals and traces of anatase. West of the Suriname River the somewhat coarser sands have a higher staurolite percentage (KK 382 and 383). These differences are identical with the differences of the recent ridges west and east of the Suriname River respectively, as will be shown below.

The drill hole graphs representing the Upper Coropina in the Lelydorp area (Aleva et al., 1969) revealed the fact that, at about 6 m depth, these sediments contain unstable minerals such as epidote, hornblende and even garnet. These minerals apparently have been weathered in the upper zone only. Feldspar seems to be slightly more stable since this occurs from about 2.5 m down.

Table 14 shows the composition of some silty clays of the Old Sea Clay landscape which are far from uniform. Zircon usually predominates (MM 29, 35, 49), but staurolite may also reach high values (KK 42, 44). KK 117, south of Onverdacht, has a relatively high rutile content which may indicate a partly southern origin (Rosebel Formation, 2.4.1.4). Other Upper Coropina clays, which are found in the terrace deposits of the Coppename and the Saramacca will be discussed with these rivers separately.

2.4.5.3 The fluvial deposits

Corantijn River. Figure 16 shows a graph of the composition of the sands on the bottom of the Corantijn River, from the mouth to about 260 km upstream. There is a notable difference in composition between the upper part and the lower part of the river, the boundary lying somewhere between HI 76 and HI 77. The upper part shows an association of zircon, epidote-hornblende, sillimanite and garnet. The downstream part has less sillimanite and garnet and more zircon while staurolite also occurs. In figure 17 a relation is shown between the median grain size of the sands and the distance from the mouth of the river. For the lower 120 km the relation seems to be normal: decreasing grain size with increasing distance from the source. Further upstream, however, the opposite seems to occur and the grain size on the whole decreases in an upstream direction, with the exception of one sample, which is a fine gravel. The Coppename River shows the same phenomenon. No satisfactory explanation for this has been found. In the estuary of the Corantijn fine sandy clay occurs which is partly of marine origin.

As is usual in river sands there are notable differences in the heavy mineral

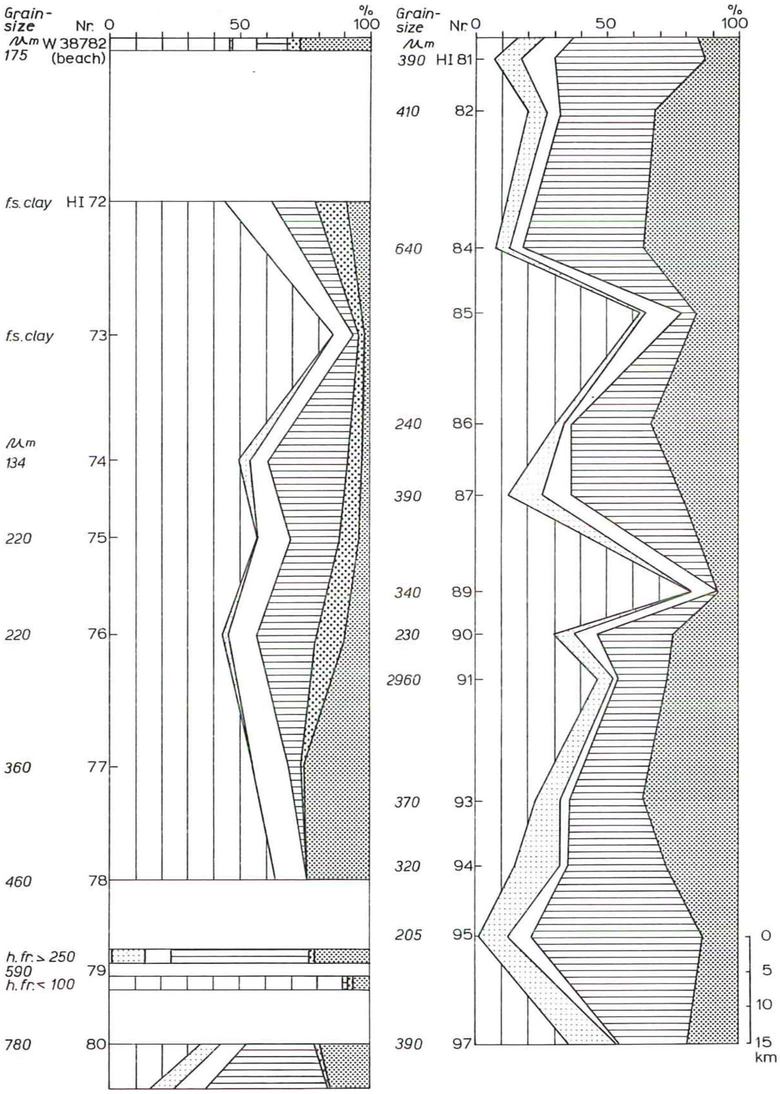


Fig. 16 Heavy mineral composition of sediments of the Corantijn River

composition between individual samples. Some deviations from the general picture may be due to local winnowing of the relatively light minerals which cause a concentration of the heaviest minerals, others are caused by the local supply of the highly stable sands of the Upper Coesewijne Formation. Examples are HI 78 with 64% zircon and 7% monazite and HI 89 with mainly zircon (see table 15).

HI 79 contains heavy minerals of two entirely different grain size classes, either very coarse (> 250 µm) or very fine (< 100 µm) which show a very different composition.

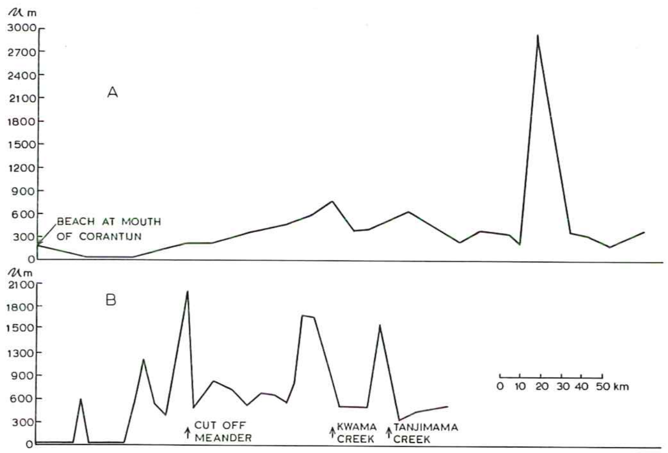


Fig. 17 Median of grain size of bottom sediments relative to their distance to the coast
A Corantijn River B Coppename River

West of Nieuw Nickerie some samples have been taken from a beach (W 38782) and a narrow ridge (W 38770). Both contain much sillimanite in contrast with the adjacent river bottom deposits. They resemble the upper Corantijn sands with some admixture of staurolite. The deposits were formed as sandy river banks near the mouth of the Corantijn during the Comowine phase apparently with exceptional strong floods of the river. Although the samples were taken at the surface (A-horizon), they contain some garnet and pyroxenes which mark them as relatively recent.

Kabalebo River. The sands of the Kabalebo River differ little from those of the Corantijn (table 15). Granitic and metamorphic rocks seem to be the source. The hypersthene has probably been derived from a dolerite dyke. KK 217, which is relatively rich in minerals, was taken from a pothole. The fact that potholes often have a rich variety of minerals, including several rather unstable ones, has also been found in samples of the Paloemeu River and the upper Tapanahony River.

Nickerie River. Although the lower part of the Nickerie River consists of fine to medium sandy clay, the high sillimanite content points to a supply mainly from the metamorphic rocks of the Bakhuis Mountains, see figure 18 and table 15. The staurolite is probably due to marine influence. This mineral occurs also in the fine sandy clay taken from the Marataka River (HI 71, table 15) just above the confluence with the Nickerie River.

Unfortunately there has been no opportunity to sample the middle course of the Nickerie. Near the Stondansie Falls a natural concentrate was found (KK 482, table 15). This contains sillimanite, zircon and kyanite as main constituents, while also a trace of cassiterite was found. The data from the Nickerie upstream from Stondansie are from Hermans (1961), who found some 7% topaz besides sillimanite, zircon and kyanite. This mineral, however, has not been found by the present author in any of the samples downstream.

It is remarkable that only three samples of the upper Nickerie contain some staurolite (GE 6, 28 and 32). Since this mineral apparently does not come from the upstream part of the river it may have been derived from the nearby Coesewijne Formation. In a later chapter the consequences of this will be discussed (see 4.5).

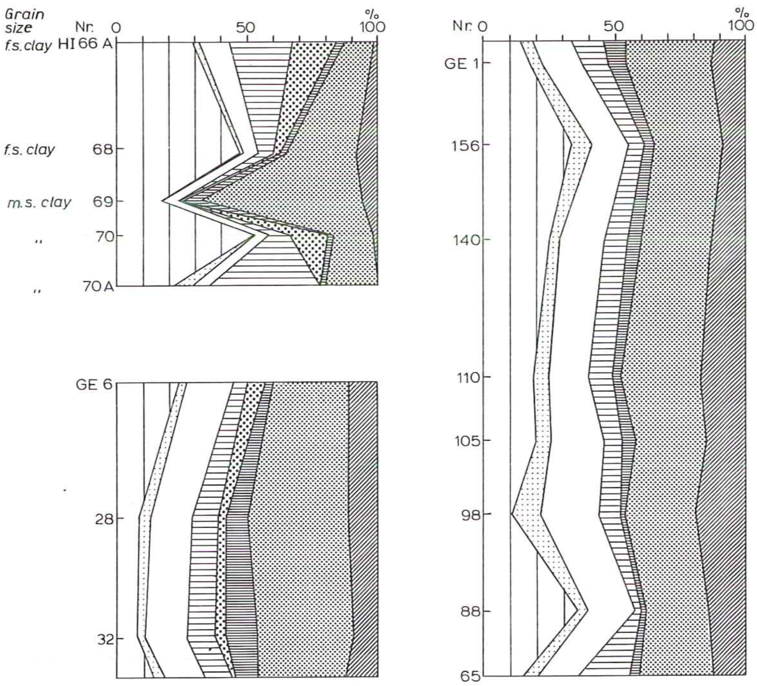


Fig. 18 Heavy mineral composition of sediments of the lower and upper Nickerie River

Fallawatra River. A sample from the Fallawatra River (GE 41, table 15) is extremely rich in metamorphic minerals, mainly sillimanite and kyanite.

Adampada Creek. A sample from the Adampada Creek (KK 379, table 15, exact location unknown) contains zircon, hypersthene and hornblende as main constituents. Almost no metamorphic minerals occur. The hypersthene has most probably been derived from the granulites of the Bakhuis Mountains. This is rather surprising since only the upper part of some tributaries of the Linker Adampada Creek reach the granulitic rocks.

Wayambo River. In the three samples of the Wayambo River two different compositions can be recognized. HI 3 with andalusite and sillimanite, resembles the Coppename sands, except for the kyanite and the high tourmaline content. The fine sand and fine sandy clay of HI 1 and HI 2A contain mainly zircon and less metamorphics. Almost no unstable minerals occur, which may indicate erosion of older, weathered sediments. The light fraction contains feldspar and the green, chamosite containing pellets which will be described in 2.4.5.4.

Coppename River. In the Coppename River there is a marked difference in composition between the fluviomarine deposits of the estuary and the coarse Coppename sands proper, see figure 19 and table 16. The fine sandy clay of the lower

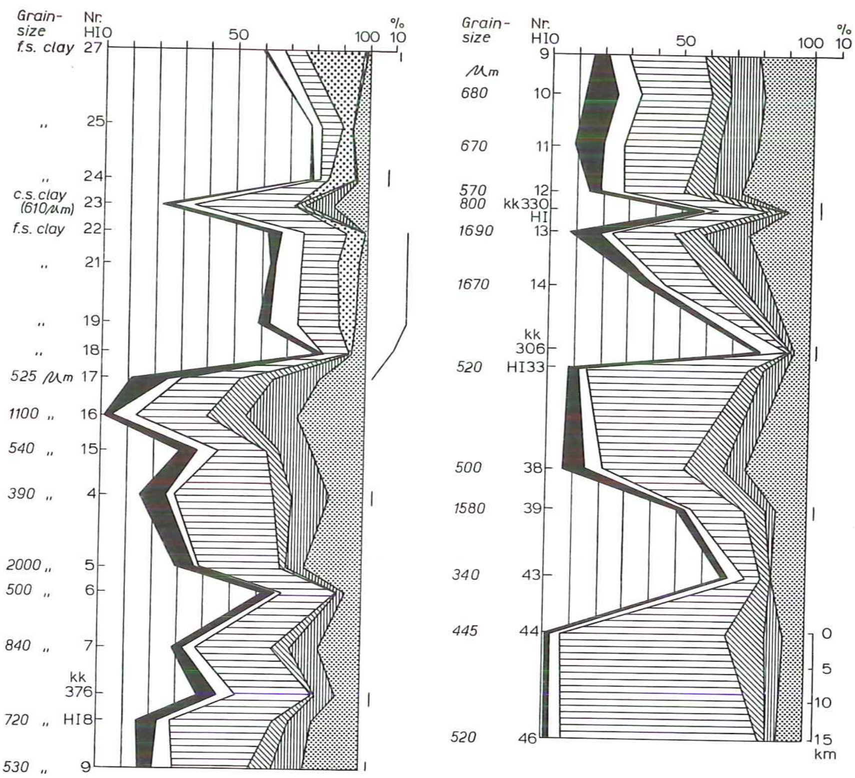


Fig. 19 Heavy mineral composition of sediments of the Coppename River

part of the Coppename shows a definite marine influence with some staurolite and only little sillimanite. The light fractions of these fine sands have relatively much feldspar and some other minerals, mostly highly weatherable: opal, biotite, muscovite, chlorite, chamosite pellets (see also 2.4.5.4, beaches), the blue phosphorous mineral vivianite and some diatoms. At one place coarse sandy clay was found which had the same composition as the Coppename sands upstream (HI 23). The occurrence of this coarse sand amidst the fluviomarine clayey deposits suggests that the latter deposits form a relatively thin veneer on top of the coarse fluvial sands.

A graph relating the medians of the grain sizes to the distance from the mouth has been shown in figure 17. Here, as well as in the Corantijn, the grain size seems to decrease in an upstream direction. Below the mouth of the Kwama Creek and the Tanjimama Creek very coarse sand occurs. Another coarse sample was taken just below a meander which was being cut off. The coarse material in both cases might partly be explained by a scouring effect, causing the winnowing of the finer parts due to the occasional relatively high current velocities. It may also partly be due to the supply of coarse sand by the creeks. However, the influence of the Kwama Creek and the Tanjimama Creek is not shown in the heavy mineral composition of the sands. Since there is a marked difference in composition between the Kwama Creek and the Coppename River it would be interesting to do some detailed sampling just below the mouth of the Kwama Creek at low water during the dry season in order to study the process of the mixing of sands of different origin.

The sand of the Coppename is coarser than that of the Corantijn. The Coppename shows zircon, metamorphic minerals (mainly sillimanite and andalusite), hornblende, some epidote and hypersthene. Part of the sillimanite is of the pleochroic variety. It has probably been derived from the granulites of the Falawatra Group in the Bakhuis Mountains. In the lower part of the river some may be added from rocks of the same Group occurring in this area (see 2.4.1.1).

KK 306 is a natural concentrate found on a sand bank during a stage of low water. As in most concentrates it shows much zircon and relatively much monazite (5% versus traces in most samples) and contains no hornblende and hypersthene of which the relatively large and flat grains are easily washed out. The concentration of the heaviest minerals was done by the action of wind driven waves. Although the waves in the upper part of the rivers are very low compared to the waves at the coast, they can be seen forming small concentrates where they touch the mega sand ripples when these emerge during the dry season.

On the Coppename natural levees are observed at two different levels, the higher ones about 2 m above the others. There is a notable difference in composition between the sediments in both levees. The higher and older, more intensely weathered levees contain less epidote and hornblende than the younger ones and no hypersthene (see table 16). Levees at two different levels have also been described by Bakker (1955) and De Boer (1972) on the Marowijne.

The occurrence of the terraces of the Coppename River has been mentioned in 1.4.3. At several places along the Coppename remnants of the Lower Terrace have been sampled, the upper sandy parts as well as the underlying white, kaolinitic silts, the Upper Coropina clays (see figure 5 and tables 16 and 17). Both, terrace deposits and clays, contain very few weatherable minerals. Their content of andalusite and sillimanite is usually somewhat lower than in the recent river sands. The Upper Coropina clays differ from the terrace deposits in their higher content of rutile and staurolite, both are probably mainly of marine origin. Their presence is not just due to the small grain size, since the natural levees - which are also fine grained - contain very little of both of these minerals. Andalusite and sillimanite, on the other hand, are derived from the interior and have been supplied by the Coppename. Some feldspar still occurs in most terrace sands and Upper Coropina clays.

Coesewijne River. A fine sandy clay of the lower Coesewijne River (HI 28, table 17) contains mainly zircon and staurolite. The light fraction has the typical composition of the marine sands and contains feldspar, chlorite, muscovite, biotite, opal and chamosite pellets (see 2.4.5.4., beaches).

Tibiti River. In the coarse to very coarse sands of the Tibiti River striking differences in composition are observed (see table 17). HI 30 has a high content of tourmaline, andalusite and sillimanite, unlike the other samples. HI 31 contains much staurolite but no epidote and little hornblende. The other samples contain either sillimanite or andalusite. The staurolite of the Tibiti may have two sources. It has been shown above (2.4.4) that the Upper Coesewijne Formation at Sabana on the Tibiti has a considerable percentage of staurolite below about 10 m depth. These sands are being eroded at present by the Tibiti. Near the upper Tibiti staurolite is very common in deposits of creeks draining an area of micaschists of the Paramaka Formation.

Kwama Creek. The sands of the Kwama Creek contain mainly zircon, hornblende and epidote and no metamorphics, typical of a river draining mainly granitic terrain. The natural levee sample (KK 294) has some thorite which has also been found in most samples of the small creeks in this area (Arjomandi et al., 1973). The zircon content is very high due to the small grain size and probably the weathering of unstable minerals.

Tanjimama Creek. Some influence of metamorphic rocks in this mainly granitic area is revealed by the occurrence of andalusite and sillimanite (table 17). Pits dug by Coleridge in the alluvial plain of the Tanjimama revealed the occurrence of some cassiterite. In samples of the creek-bed, however, this mineral has never been found.

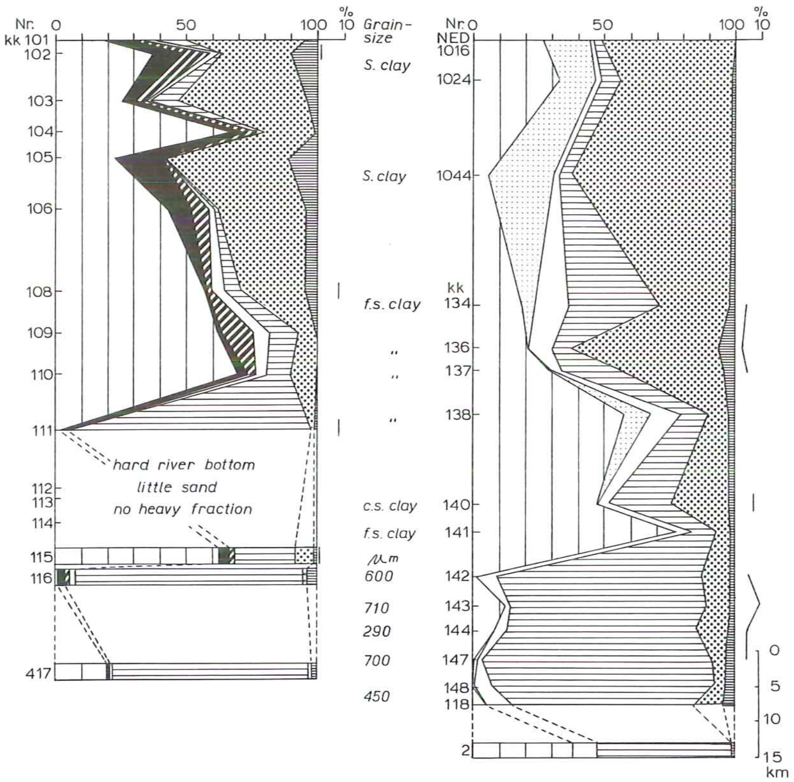


Fig. 20 Heavy mineral composition of sediments of the Saramacca River (left) and the Suriname River (right)

Saramacca River. This river has been sampled upstream from Uitkijk only. In the downstream part of the river marine fine sandy clay occurs as in all Surinam rivers. For about 75 km upstream from Uitkijk the deep (about 20 m) bottom of the river is hard and consists of sand cemented by iron oxides. This hard bottom, thought to have originated during the dry climatic conditions of the latest Pleistocene with a low sea-level (Krook, 1970a), carries only a thin veneer of sand. The main part of this sand has a considerable content of staurolite (fig. 20A and table 17) which is not found in the higher parts of the river. This sand may have come from the east by beachdrifting in a subrecent period when the mouth of the Saramacca was situated south of Uitkijk. On the other hand, the sands also contain a relatively large amount of rutile as do the sands of the Coesewijne Formation both east and west of the Saramacca River. The sand further upstream contains either much epidote and hornblende (KK 11, table 18) or mainly zircon, but only very few metamorphic minerals.

The depth of the river suddenly decreases from some 20 m to about 6 m between KK 115 and KK 116. This is the front of the present Saramacca sands approaching the coastal area.

Two samples of silty clay of the Upper Coropina (KK 107 and 413, table 18) which have been found on terrace remnants of the Saramacca, show a relatively high content of rutile and staurolite.

Para Creek. This creek contains mainly staurolite (KK 380 and 381, table 18) which has been derived from the Armina Formation in the south.

Suriname River. The heavy mineral composition of this river is shown in figure 20 and in table 18. At the bottom of the wide estuary the sandy clays contain much staurolite and garnet and resemble the coarse beach sands (see 2.4.5.4), but the relatively high zircon content points to a mixture with material from other sources. In the upstream direction this content increases while staurolite and garnet content decrease. Fine sandy clays cover the bottom until some km upstream from Paranam. Near Paranam the sand is rather coarse and contains a relatively large quantity of fine grains of corundum. This is alumina from the nearby alumina plant which was spilled into the water during loading on board freighters at Paranam. This corundum, of course, has not been included in the counting.

The sands of the Suriname River from KK 142 to 148 show only little differences in grain size (average of medians is 540 μm) and mineral composition. They have been studied in relation to grain size. This shows in general a strong increase of zircon and a decrease of epidote and hornblende with decreasing grain size but there are considerable differences between the samples as table 18 shows. The sands contain very much epidote and hornblende while staurolite has an average of 8%. KK 2, taken near Brokopondo, upstream from the Armina Formation, shows only traces of staurolite. During a diamond prospection in 1965, when the river was almost dry due to the construction of the dam near Afobaka, some gold was found, but no diamonds.

The clayey fine sand of a natural levee at Carolina (KK 463, sheet 14c,d) showed a much higher staurolite content than the nearby river bottom sands. It is probable that the sand is at least partly of marine origin. KK 281 is from another levee. It contains almost no staurolite since it is above tidal influence and upstream from the Armina Formation. Both natural levees contain a relatively large quantity of feldspar in the light fractions. This points to a recent deposit which is little weathered. Veen (1970) also described the presence of feldspar in the silt fractions of a natural levee near the citrus plantation Baboenhol (sheet 22a) on the Suriname River.

The Suriname River has three distinct terraces (1.4.3), parts of which are being utilized for the culture of citrus and oilpalms. In the samples of these loamy to sandy deposits staurolite occurs only downstream of the Armina Formation (tables 18 and 19). The deposits have been intensely weathered since they do not contain any unstable minerals, even in the light fractions. The rutile content is high in relation to that of the river sands. No explanation has been found for this.

Kleine Commewijne River, Tempati Creek and Penninica Creek. These streams contain predominantly staurolite (table 19: HI 99, 98 and 102, respectively), which is not surprising since they drain rocks of either the Armina Formation or Upper Coesewijne Formation deposits which are locally derived from the Armina Formation.

Marowijne River, Lawa River and Assici Creek. In figure 21 the composition of the Marowijne River and the Lawa River is shown. The sandbars in the mouth of the Marowijne (KK 485 and 486, table 19) have predominantly staurolite, little epidote and hornblende but some high values of andalusite and sillimanite and almost no zircon and garnet. This association shows little resemblance with the Marowijne sands (which have more zircon, epidote and hornblende and less staurolite, andalusite and sillimanite), but also with the coarse sandy beaches of Suriname and French Guiana (which contain more garnet and less andalusite and sillimanite). KK 487, 488 and 489 represent some fine sandy clays from the bottom of the river. They have less staurolite and considerably more zircon. The latter may be a function of grain size. However, one sample contains anatase and even brookite, which, although comparatively rare, are typical of fine sands of marine origin. The next sands upstream, from bars and the riverbed, again contain little zircon. Further upstream an association of staurolite, zircon, epidote and hornblende shows a mixture of detritals of the Armina Formation of other Formations of the Marowijne Group, granites and granodiorites. Just south of the Nassau Mountains (see figure 1) the sudden decrease of the staurolite content marks the southern border of the Armina Formation.

The first samples of the Lawa River show mainly epidote and hornblende, some zircon and a minor amount of metamorphic minerals, including some staurolite. The minerals are probably derived from the upstream area underlain by the Paramaka Formation.

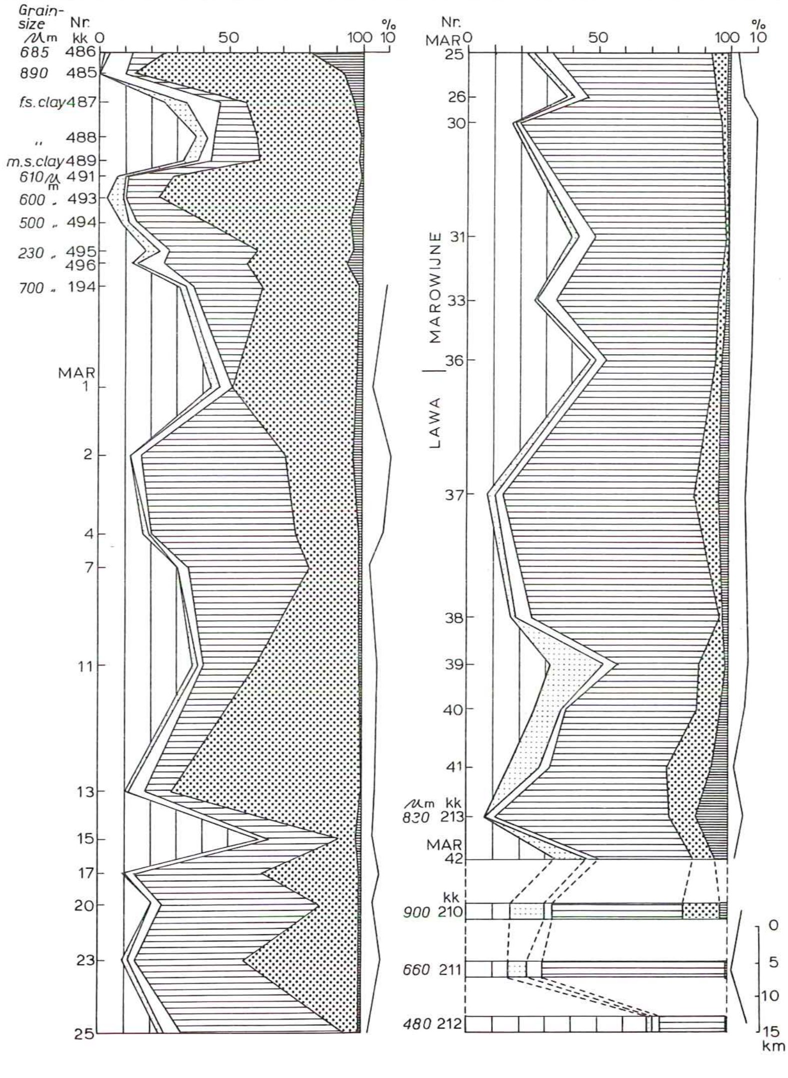


Fig. 21 Heavy mineral composition of sediments of the Marowijne River and the Lawa River

A typical granite association is found in sands of the Assici Creek: zircon, epidote and hornblende (table 19, KK 208 and 209). The low hornblende content of the natural levee may be due to weathering which apparently did not effect the epidote and the feldspar.

The Lower Terrace north of Albina reveals only stable minerals, mainly zircon and staurolite (table 19). Near the mouth of the Anjoemara Creek a sandy river bank and a spit occur which also show mainly stable minerals. This is mineralogical evidence that the sandy riverbanks (called "beaches" in Suriname) near Albina do not represent recent Marowijne sands but eroded terrace material.

On the higher parts of sandy riverbanks black concentrates of heavy minerals are often found. On the riverbank near the Anjoemara Creek black layers are formed temporarily. They consist mainly of ilmenite, followed by zircon and staurolite. One can observe that the concentration of the minerals is formed with the backwash of the waves. These waves are comparatively high for a river since the wind from the northeast has a fetch of about 6 km. The velocity of the water seems to be strong enough to transport the light minerals while the heavy minerals stay behind. This is illustrated by figure 22 which shows a section through some wave ripples cut off by the retreating water and covered by a thin layer of black sand.

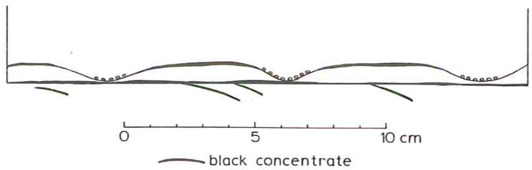


Fig. 22 Section through wave ripples showing heavy mineral concentrates

Along the Marowijne four kinds of beaches and beachlike sandy riverbanks can be recognized with regards to their origin:

1. Beaches of sand from French Guiana, mainly the Mana River, reworked by beachdrifting. They occur on the westbank of the Marowijne near its mouth. These beaches contain mainly staurolite and garnet. They will be discussed in the next paragraph (2.4.5.4).

2. Sandy riverbanks formed by erosion of the Lower Terrace, such as the ones occurring near Albina. They do not occur where the terrace is lacking, which is also an indication of their origin. Only stable heavy minerals occur in these deposits.

3. Sandy riverbanks of material which is locally derived from weathered rocks, partly supplied by colluvium, partly by river erosion. Several of these banks are found, often with a heavy fraction consisting mainly of staurolite (see table 12, MAR 3 and 24) derived from the Armina Formation.

4. Banks of river sand deposited during flood stage. These banks show sand of mixed origin, derived from the geological formations upstream.

De Boer (1972) used several of the author's data on the Marowijne River. He concluded that there is a close relationship between the mineralogical composition of the riversands and the lithology of the adjacent bedrock. Upstream from the estuary little sand would have been transported in recent times. He supports this statement with his figure 19, a graph which shows the mineral composition of the sands and the geological formations along the river. However, when the peaks of staurolite are left out, since these represent only pure Armina Formation colluvium of local origin (Levelt, personal communication), most samples show a mixture of staurolite on the one hand and zircon, epidote and hornblende on the other. This mixing can only have occurred during downstream movement. De Boer is probably right in stating that little transport has occurred recently, judging from the fact that in the estuary marine sandy clay has been deposited and little or no river sand. If the sand of the bars in the mouth of the Marowijne has been supplied by this river, it must have been a considerable time ago.

During the last few years gravel has been dredged from the Marowijne upstream from Albina. This gravel occurs below the sand on the riverbed. It is probably mainly of late Pleistocene age and was deposited in a relatively dry climate during part of the last glacial (Krook, 1968b, 1970a & b). The study of a natural concentrate of sand from the deeper parts of the gravel gave the following results:

abundant	:	ilmenite
much	:	staurolite and zircon
little	:	leucoxene, goethite, monazite, garnet
very little	:	andalusite, tourmaline, rutile
trace	:	kyanite, epidote, spinel, sillimanite, hornblende
few grains	:	xenotime, cassiterite, gold (very small and thin flakes)

The cassiterite was probably derived from the pegmatites of Jorka Creek (Montagne, 1964a). The occurrence of gold is not surprising since several areas near the Marowijne River were exploited as early as the last quarter of the 19th century. De Munck (1954) found indications of gold in the Marowijne gravels further upstream. An elaborate study of the occurrence of gold in Suriname has been given by Brinck (1956).

It has become clear from the foregoing that each river has its own heavy mineral composition. In some rivers this composition changes little from the most upstream places that have been sampled to the beginning of the estuarine part (Corantijn, Coppename). In other rivers the composition is strongly dependent on the presence or absence of certain geological formations (e.g. Armina Formation in the Suriname River and the Marowijne River). The near-coastal parts of the rivers usually have fluviomarine fine sandy clays which have associations that differ considerably from the proper riversands.

Apart from the differences mentioned above, the river sediments usually show considerable alternations of composition due to effects of scouring, concentration during low water stages, local supply by tributaries etc.

Although the content of the stable minerals (zircon, tourmaline, rutile and metamorphic minerals) is considerable, all rivers contain unstable minerals such as epidote and hornblende, garnet and even hypersthene. The feldspar contents of the coarse sands are low, mostly less than 10% and frequently even less than 5%. The fluviomarine fine sands not only have more feldspar (see figure 19, Coppename River), but they contain several other unstable minerals. Even higher feldspar contents are found in some natural levees. Contrary to the present riverbeds, the terraces contain only stable minerals.

2.4.5.4 The Young Coastal Plain

The composition of the sandy ridges has been discussed before by the author (Krook, 1969a). Two main associations were recognized, the SE-association (staurolite-epidote) and the S-association (staurolite mainly). The SE-association consists of staurolite, zircon, epidote and hornblende, tourmaline, metamorphic minerals, garnet, rutile and a few others. It is found in the *fine sandy ridges* occurring from the Suriname River to the west, even across the Corantijn River in Guyana (Bleackly, 1956a; Krook, 1969a). The S-association contains mainly staurolite, followed by zircon, tourmaline, some metamorphic minerals, garnet and very little epidote and hornblende. It occurs in medium to coarse sandy ridges from the Marowijne to the "Weg naar Zee" northwest of Paramaribo (see enclosure 2) while some small and narrow remnants occur further west to the Coppename River. These ridges will be referred to as *coarse sandy ridges*. A few of these ridges occur even north of Wageningen (see drill hole WA-3, 2.4.5.1).

All ridges belong to the Coronie Deposits of the Demerara Formation (see table 6, 1.4.2). Because of a difference in composition the ridges of the Wanica phase will be distinguished from the ridges of the combined Moleson and Comowine phases.

Figure 23A and tables 19 and 20 show the composition of the *fine sandy ridges of the Wanica phase* from the Maratakka area to the Suriname River. The Cupido Ridge near the Maratakka (sheet 10b) is the westernmost fine sandy ridge of the Wanica phase (W 38780-38781). It contains much zircon, some rutile, staurolite and other metamorphic minerals and only very little epidote. The high content of stable minerals may indicate that erosion products of the Old Coastal Plain supplied a large part of the detritals. However, it is more probable that the poor mineral composition is due to weathering since the sample has been taken from the surface, i.e. the A-horizon. Most other ridge samples were taken at a depth of 1 m. Part of the sillimanite in the Cupido Ridge and

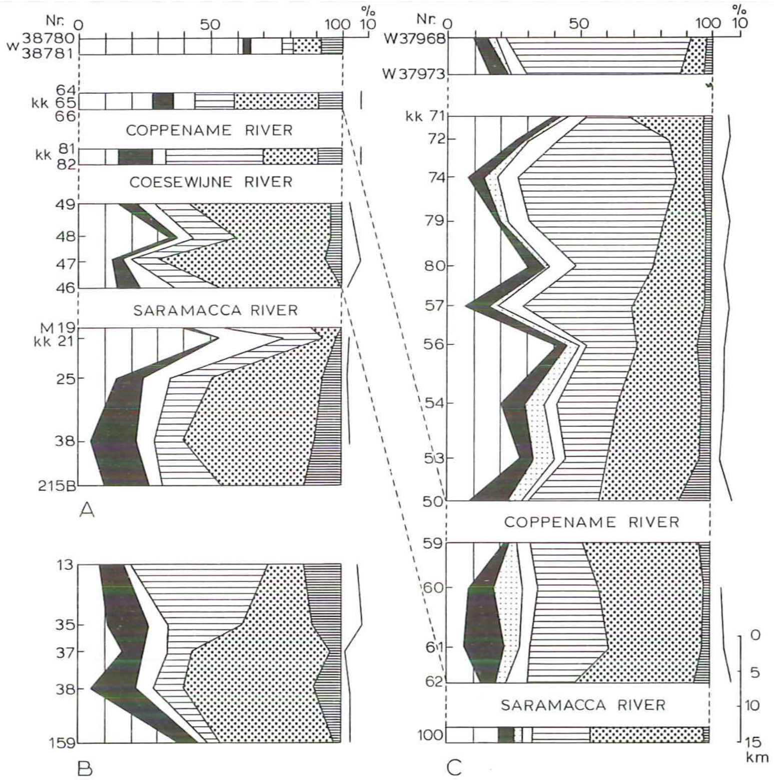


Fig. 23 Heavy mineral composition of the sands of the fine grained sandy ridges
A W-E section, Wanica phase
B N-S section, Wanica phase
C W-E section, Moleson and Comowine phases

in a ridge just west of the Coppename River (KK 64, 65 and 66) is of the pleochroic type (see 2.3.2 and 2.4.5.3), a variety which is also a characteristic constituent of the Coppename River.

From the Coppename River to the Suriname River staurolite, zircon, epidote and tourmaline are the main components. Other minerals are rutile, hornblende, little garnet and anatase and traces of a few others. Clinozoisite is quite common but this was counted as epidote. The light fractions contain 5% feldspar on the average.

Figure 23B shows the composition of the sands along a north-south section. There is a decrease of epidote and hornblende with increasing age. This decrease may have two causes. Firstly the material of the older ridges may have been derived partly from the eroded Upper Coropina sands of the Old Coastal Plain.

Secondly the impoverishment of the older ridges is due to prolonged weathering. The study of some soil profiles suggests the latter as the main cause. Table 20 shows the heavy mineral composition in two soil profiles. In the first profile (KK 23-26, 132 and 133) there is a distinct difference between the three soil horizons. The C-horizon contains much epidote and hornblende and furthermore has some biotite, garnet, sphene, apatite, chlorite, some pyroxenes and authigenic siderite. In the light fraction chamosite pellets occur (for a description of chamosite see below at the end of the section). The B-horizon contains considerably less epidote and hornblende, some apatite and chlorite, but none of the other minerals which are present in the C-horizon. In the A-horizon the epidote content is very low while hornblende is absent. The second profile (KK 215 A-F), although less deep, shows some similarities with the first one. Chamosite and garnet occur in the C-horizon but are absent in the oxidation zone (B-horizon). The A-zone has been leached so that epidote and hornblende have almost disappeared.

It was shown in both profiles that garnet is less stable than epidote and hornblende in the weathering process. In temperate regions, however, garnet is usually stable compared to epidote and hornblende. In podzol profiles the A-horizon often shows an enrichment of garnet due to the disappearance of epidote and hornblende (De Jong, 1957; Vink and Sevink, 1971).

Samples of the *coarse sandy ridges of the Wanica phase* were taken mainly between the Suriname River and the Perica River (encl. 2), while one sample is from the lower Marowijne area (KK 6). The composition of these samples is shown in figure 24A and table 20. The sands contain predominantly staurolite. Other minerals are zircon, tourmaline, metamorphic minerals, some epidote and even less hornblende, little rutile and traces of garnet. Only about 2% feldspar is found in the light fractions.

The composition of the *fine sandy ridges of the Moleson and Comowine phases* differs clearly from that of the older phase (fig. 23C and table 20). The content of epidote-hornblende and garnet is high in these young phases. West of the Coppename River there is a gradual increase of epidote and hornblende and a decrease of staurolite and garnet in a western direction. The ridges near Wageningen (W37968 and 37973) have only very little staurolite. The accessory minerals are about the same as in the Wanica phase. Sphene - although still quite rare - is of more frequent occurrence. The feldspar content is about 6%.

In the *coarse sandy ridges of the Moleson and Comowine phases* staurolite is the dominant mineral (fig. 24B, tables 20 and 21) with lower percentages of garnet, tourmaline, andalusite, sillimanite, zircon, epidote and hornblende.

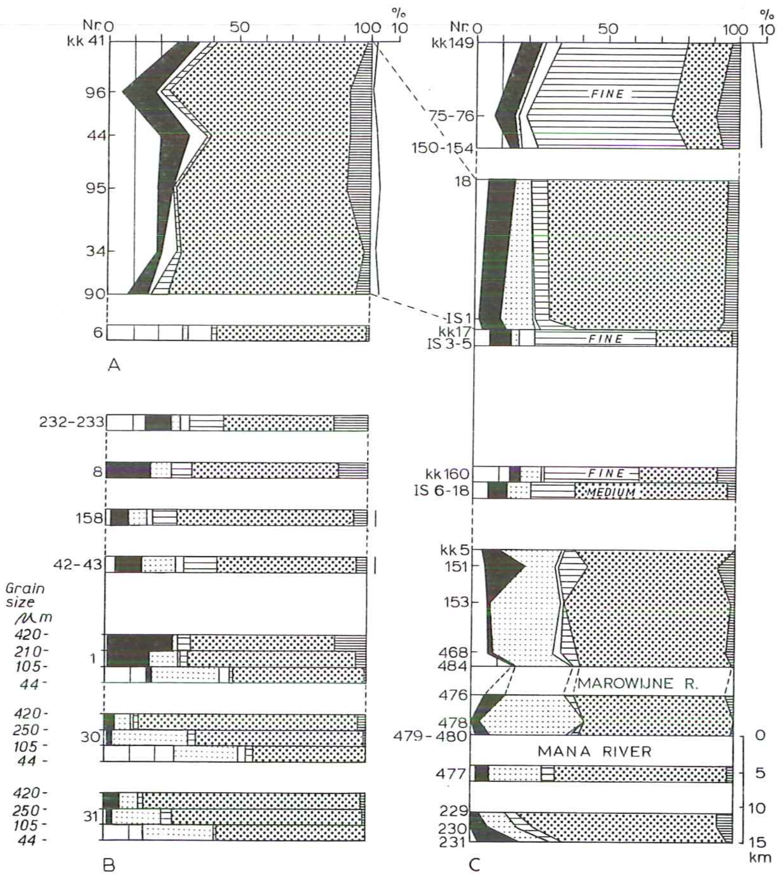


Fig. 24 Heavy mineral composition of the sands of the coarse grained sandy ridges and the beaches
A ridges, Wanica phase
B ridges, Moleson and Comowine phase
C beaches

Near the mouth of the Coppename River small remnants of these young ridges are found (KK 233, table 20 and fig. 24B). The sand contains slightly less staurolite than most coarse sandy ridges and is probably of mixed origin. Not only are the contents of zircon, hornblende and sillimanite relatively high, but the sillimanite is partly of the pleochroic "Coppename" type. Also, some hypersthene occurs, a mineral never found in the S-association but typical of the Coppename. The ridges may be compared with the subrecent sandy banks of the Corantijn (2.4.5.3). The latter, however, have an association which was mainly supplied by the Corantijn, whereas in the present case there is only a slight admixture of Coppename sand.

Samples from the young coarse sandy ridges NW and NE of Paramaribo (KK 8, 9, 10 and 1, fig. 24B and tables 20 and 21) are somewhat different from the samples taken west of Mattapicca (KK 30 and 31, fig. 24 and table 21). The "western" group contains more tourmaline, andalusite and sillimanite but less garnet than the "eastern" group. The samples from the ridges just east of the Suriname River (KK 158, 42 and 43, fig. 24) have about a mean composition. The higher content of tourmaline, andalusite and sillimanite of the "western" group cannot be explained by supply from the Suriname River, since these minerals occur only in minor quantities in both present and past sediments of this river. Possibly the Cottica has supplied these minerals, but there are no samples to prove this. However, it must be mentioned that in the Upper Coesewijne Formation south of Moengo the andalusite content is high while the same formation near Mongotapoe contains much tourmaline (see figure 14, KK 407 and 388 respectively). The lower garnet content in the western ridges is also found in the coarse sandy beaches.

The feldspar content of the coarse sands is about 2%.

The near absence of garnet in the ridges of the Wanica phase (both coarse and fine) as compared to the ridges of the Moleson and Comowine phases is probably due to weathering. Several samples from the coarse ridges of the Wanica phase were treated with a magnetic separator in order to concentrate the garnet that was still present. The grains were strongly corroded.

The influence of weathering may be shown even in ridges of Comowine age. Samples KK 9 and 10 (tables 20 and 21) have been taken from a soil profile in a coarse sandy ridge, from the A- and B-horizon respectively. The lowermost sample (KK 19) contains 56% biotite, but in the A-horizon not even a trace could be detected. Although biotite might not have been present here, the white sand seems to point to leaching processes.

A few samples of the S-association have been studied with respect to grain size. KK 1 (fig. 24B and table 21) shows a decreasing content of tourmaline, andalusite, sillimanite and hornblende with decreasing grain size. Zircon, garnet and monazite, on the other hand, increase with decreasing grain size. Staurolite is most abundant in the medium size group (105-210 µm), KK 30 shows roughly the same picture, but here staurolite is the most abundant mineral in the coarse fraction.

Selective action of the wind can be demonstrated by studying the samples KK 30 and 31. The first sample was taken from a sandy ridge at a depth of 50 cm and the latter from a little sand dune with a height of 60 cm on top of the ridge.

The mineral composition of both samples was studied and this revealed some interesting differences. The ridge sand was slightly coarser grained than the dune sand, with medians of 400 and 300 µm respectively. The total percentage of the heavy mineral content of the three grain size fractions was determined. This gave the following results:

grainsize fractions	total content of heavy minerals (%) ridge	dune	content h.m. ridge / content h.m. dune
250 - 420 µm	0.12	0.02	6.0
105 - 250 µm	0.96	0.24	4.2
44 - 105 µm	5.61	2.73	2.1

The content of heavy minerals is lower in the dune sand and there are considerable differences in both ridge and dune sand between the size fractions. The differences between the ridge sand and the dune sand are least in the fine fraction.

The influence of the wind action is also shown by selective transport of the minerals with respect to specific gravity and shape (fig. 24B and table 21). In the coarse fraction there is no notable influence since the staurolite is dominant. In the medium fraction garnet (almandine, sp. gr. 4.2) shows the highest percentage in the ridge sand (29 vs 19). Staurolite (sp. gr. 3.7) shows the reverse (64 vs 73). In the finest fraction the relations are more complicated since zircon enters as a third component of comparatively high quantity. The zircon content (sp. gr. 4.6) is lowest in the dune sand (15 vs 27). This consequently leads to a higher content of garnet and staurolite in the dune sand. The influence is greatest for staurolite (57 vs 42) and least for the heavier garnet (27 vs 23). Monazite (sp. gr. 5.1), although of minor occurrence, was only found in the ridge.

The differences in the opaque fractions are equally striking. In the coarse fraction the percentage is highest in the dune. Most opaque minerals in the dune sand, however, consist of relatively light, flat or oblong porous limonite grains. The oblong grains show a fine cellular plant texture. They were probably originally pyritized plant remains which were subsequently oxidized. In the ridge ilmenite is dominant in all fractions. The ilmenite in the dune sand, however, has more flat grains than in the ridge sand.

The influence of the wind could even be traced by the feldspar content. From the light fractions of both sands (< 250 µm) 1500 grains were counted. In the ridge the feldspar content was 0.8%, in the dune, however, this was 1.8%. Although the feldspar (sp. gr. of orthoclase and microcline is 2.55) is only slightly lighter than quartz (sp. gr. 2.66), the tabular shape may have been of influence.

Summarizing we may state that the selective action of the wind could be shown by the grain size, the content of heavy minerals and the distribution of grains with respect to specific gravity and shape.

The results that have been obtained seem rather obvious. With a low velocity of the wind only the lightest grains can be lifted and transported while the heavier grains stay behind. This phenomenon can be compared with the formation of the black concentrate by the backwash on a beach were the current is just able to remove the quartz grains but not the heavier minerals (see 2.4.5.3, Marowijne River, also fig. 22).

Eisma (1968) also found lower contents of heavy minerals in the dunes than in the beaches of the Dutch coast. Depuydt (1972), however, mentioned the opposite on the Belgian coast, viz. higher contents of heavy minerals in the dunes. The same tendency was found by Augustinus (1978) in his study on the Surinam coast. There must be an explanation for these contradictory findings. It seems possible that continued wind action in the dunes results in the formation of aeolian "lag deposits" which may eventually cause a relatively high heavy mineral content, such as this occurs in the water.

Coarse sandy beaches occur at several places at the northeast coast of Suriname, between the Marowijne and the Suriname River, on the west bank of the mouth of the Marowijne and on the coast of French Guiana. The medians of the grain sizes of 12 samples gave an average of 615 µm. The beaches show high values of staurolite, followed by garnet, tourmaline and zircon (fig. 24 and table 21). The zircon content is usually very low and may even be zero (KK 478). The sands contain only low percentages of epidote and hornblende and metamorphic minerals. The feldspar content of the sands is also low, averaging 3% from many samples (not in table). KK 153 is a "black sand", a natural concentrate which differs from the other sands by a lower content of the relatively light and easily transportable minerals and by the presence of some rare minerals such as spinel, monazite and xenotime.

KK 157 is a sand from tubes made by the larvae of some sort of caddis-fly. Apparently these larvae collected the smaller grains for building stones, since the zircon content is relatively high for the coarse beach sands.

The coarse staurolite bearing sands have been derived from the Armina Formation which crops out in large parts of NE Suriname and adjacent French Guiana. The highest garnet content occurs on the beaches of the southern bank of the Mana River (KK 476, 478-480). Extensive beach placer deposits, consisting mainly of ilmenite, staurolite and garnet, have been found here.

In the staurolite sands there is a general decrease of garnet in a western direction. More detailed studies revealed the fact that the garnet was found in all grain size fractions just west of the Marowijne mouth (KK 153) and only in the finest fraction in the sands NE of Paramaribo (IS 1). The same tendency has been observed in the coarse ridge sands (KK 1 and KK 30, fig. 24B and table 21).

The heavy mineral composition of the *medium sandy beaches* of Bigi Santi (Sheet 7) appeared to be different from the composition of the coarse sands on the one hand and the fine sands on the other. The average grain size is 240 µm. In the heavy fraction staurolite predominates, but the epidote-hornblende content is much higher than in the coarse beach sands (fig. 24B and table 21). The sand contains some biotite and traces of apatite.

Fine sandy beaches were sampled near Totness (sheet 3) and east of the mouth of the Suriname River (sheets 6 and 7). The medians of the grain size are usually below 100 µm. The sands have much epidote and hornblende (fig. 24C and table 21). Biotite, staurolite and garnet show a lower content near Totness than in the eastern sampling places. Biotite, apatite and several pyroxenes indicate that the sands are very immature, since these minerals are extremely weatherable.

The fine sands of beaches and the deeper part of the ridges (C-horizon) are usually green. This colour is caused by the presence of green pellets which also occur in the fine sandy clays of the estuaries of all rivers. The grains can be easily separated from the quartz and feldspar in the light fraction with a magnetic separator. They cannot be analysed by means of their optical properties since they show a fine aggregate polarization. Apparently the grains are aggregates of silt sized minerals. X-ray diffraction showed the following minerals: quartz, albite, muscovite, chlorite, hornblende and chamosite (Krook, 1970a). The grains are referred to as *chamosite* in this study. Many similar pellets were studied by Porrenga (1965, 1967) from several deltas in tropical regions but none of them were exactly the same as the ones described here. Hardjosoesastro (1970), however, made a thorough study of the same type of pellets occurring on the Surinam continental shelf and collected by Nota (1969). He distinguished several kinds of grains with respect to colour and shape. Furthermore he found that part of the grains had been formed from fillings of tests of small *Foraminifera* species, while other grains had originated from coprolites. He also mentioned that the grains had been formed in a reducing environment. They are unstable in oxidizing conditions. This is in accord with the fact that they are never found at the surface where they are altered into goethite. This process has also been described by Porrenga (1967).

The foregoing discussion on the composition of the sandy ridges and the beaches of the Young Coastal Plain can be summarized as follows:

There are two main associations, a staurolite association in the coarse sandy ridges and beaches and a staurolite-epidote association in the fine sandy ridges and beaches. Both associations show an impoverishment of the mineral content due to weathering. The highest stage of weathering is found in the upper part of the oldest ridges, but even in the recent ridges the weathering of chamosite and probably biotite can be observed. The deepest parts of the oldest ridges, however, still contain several highly unstable minerals.

In the composition of the sands a gradual change can be observed, viz. an increase of epidote and hornblende and a decrease of staurolite and garnet in a western direction. This means a lagging behind of the heavier components. Apparently this does not apply for zircon which has a higher specific gravity than garnet but does not decrease in content. Probably the small grain size of the zircon makes it easily transportable. In a detailed study on a beach sample (KK 150) most zircon was found in the fraction of 37-44 μm.

Augustinus (1978) found a decrease of the mean grain size and heavy mineral content along the coast from east to west which agrees well with the above mentioned observations. This decrease would be caused by the westward migrating mudflats which overtake the coarsest and heaviest grains most easily. As a result the finer and lighter ones would be able to migrate over larger distances. It seems probable, however, that the lagging behind of the large and heavy components would occur as well without the mudflats by the mechanism of swash and backwash.

2.4.5.5 The continental shelf of Suriname

Due to a lack of samples the author did not study heavy minerals of the Surinam continental shelf. However, some data have been given by Nota (1971) from medium to coarse sands which have been sampled from an old delta off the Marowijne, the top of which reaches to a depth of about 20 m. The heavy fractions consist mainly of staurolite (50-75%), followed by zircon (7-20%) and minor amounts of epidote, tourmaline, hornblende and andalusite. Garnet was not mentioned. The feldspar contents were low. The shape of the delta leaves no doubt as to the origin of the sands. However, none of the present Marowijne sands is exactly similar to the delta sands, which contain less unstable minerals. Vervoort (1971) mentioned the occurrence of fine green sand covering a great part of the Marowijne delta, but no samples were taken for mineralogical studies. This sand obviously contains chamosite pellets.

2.4.5.6 The recent and subrecent deposits of the Amazon River and the continental shelf of Northern Brazil and French Guiana

Several studies have appeared on the sediments of the coast of Brazil. Barreto et al. (1975) give several data on the heavy minerals of the North Brazilian continental margin (fig. 25). Off the mouth of the Amazon two suites occur: the "Amazon suite" with hornblende, enstatite, hypersthene and sillimanite and lesser amounts of augite, epidote and diopside and the "Pará-Maranhão" suite which contains mainly staurolite, tourmaline and zircon.

The present author studied a sample of a natural levee of the Amazon (KK 501, fig. 29) and some samples from deposits off the mouths of the Pará and the Amazon, the shelf north of the Amazon and the shelf of French Guiana (fig. 26). The results of the countings are given in figure 27 and in table 22.

The fine to medium grained sands (260-370 µm) off the Pará show staurolite, tourmaline and zircon mainly with some metamorphic minerals, epidote, garnet and rutile and very little hornblende. The opaque fraction is relatively large. This composition is well in accordance with the Pará-Maranhão suite of Barreto et al. (1975). The low content of weatherable minerals is in agreement with the nature of the sediments which are orthoquartzitic (fig. 25). Barreto et al. ascribe the mature character of the sediments to the extensive lateritic chemi-

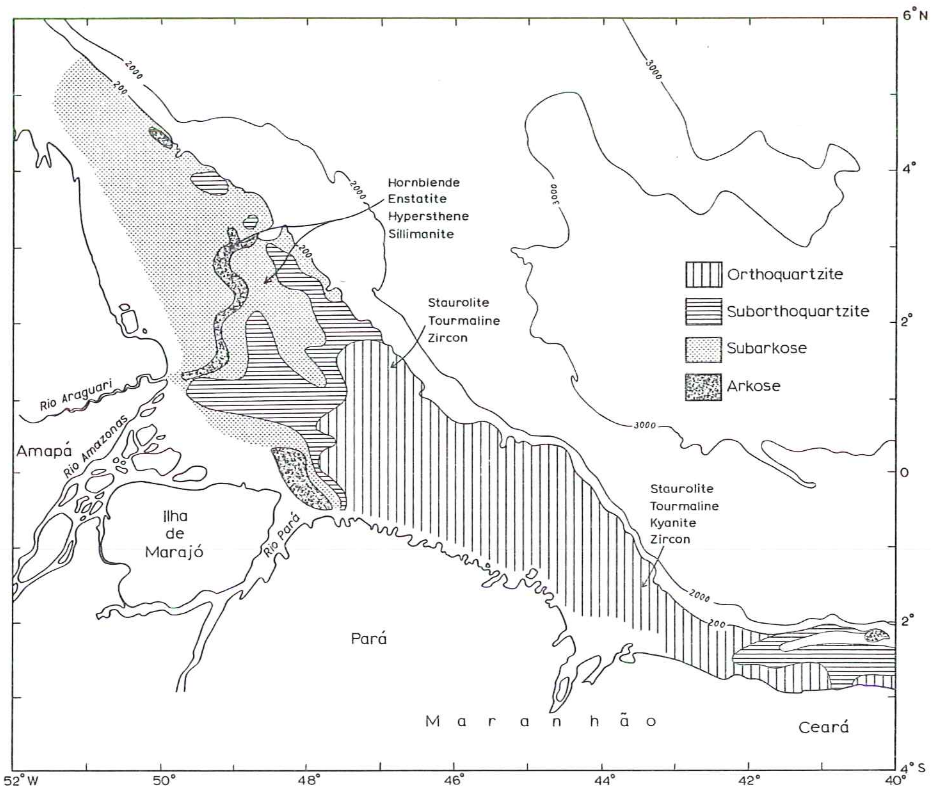


Fig. 25 Map showing composition of the sands and the heavy mineral suites on the shelf of Northern Brazil (after Barreto et al., 1975)

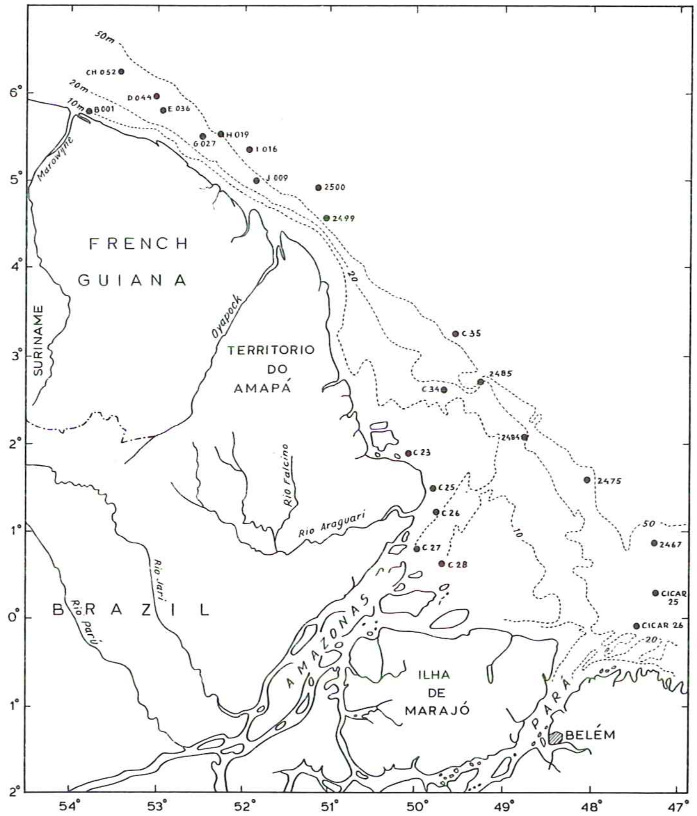
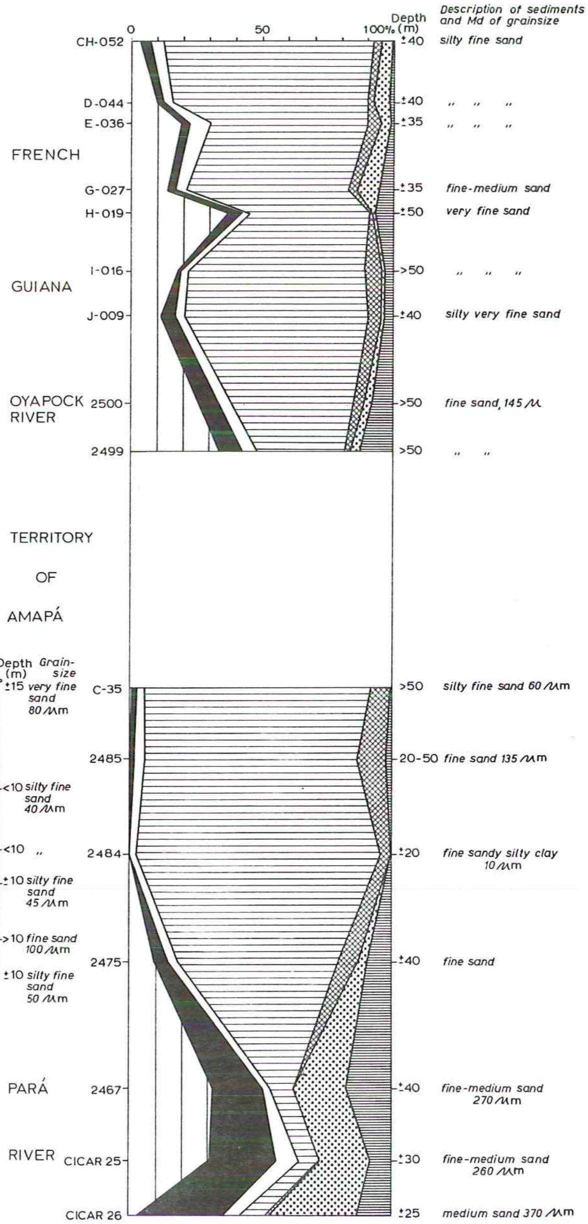


Fig. 26 Map showing sample localities on the shelf of Northern Brazil and French Guiana (partly after Tjoe Awie, 1975)

cal weathering of the tropical rainforests. However, since the sediments which occur on a considerable part of the continental shelf (fig. 25) may have been mainly derived from Cretaceous sedimentary strata, it seems that reworking might be a more important factor. The fact that the grains are relatively well rounded is highly indicative of reworking. Barreto et al. also suggest that some of the roundness of the grains might be inherited. Moreover, as is apparent from the composition of the sediments of the Surinam rivers, a humid tropical climate does not necessarily lead to stable associations. Also the Surinam sands are considerably less rounded than the sands off the Pará River.

The sediments off the mouth of the Amazon are either silty fine sands or silty clays. Their composition is entirely different from the one described above. They contain mainly epidote and hornblende, some hypersthene, augite, clinozoisite, chlorite, tourmaline and zircon and traces of metamorphic minerals and titanium minerals. Typical Amazon minerals are a redbrown basaltic hornblende, a euhedral hypersthene with faint but distinct pleochroism, clinozoisite and chlorite. The opaque fraction has a considerably lower content than the one of the Pará suite. The feldspar content has been determined in a few samples both by the staining method and by counting in an immersion fluid. The latter method proved to be the most reliable. The samples C-23 and C-27 have 23% and 20% of feldspar respectively. These sands could be characterized as an epidote-hornblende (EH)-association. Augustinus (1978) recognized an EH-association in some Surinam coastal sand samples. However, his "pure" EH sands differ considerably from the sands off the mouth of the Amazon, since the first contain more stable elements such as staurolite and tourmaline. The content of opaque minerals



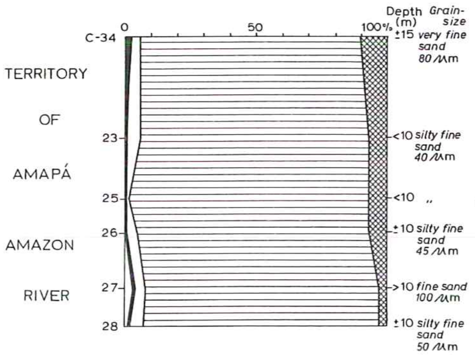


Fig. 27 Heavy mineral composition of sediments on the shelf of Northern Brazil and French Guiana

is also higher. The relation between both sands will be discussed in 4.7.

Sample 2475 shows a mixture of "Amazon" and "Para" sands, since it contains some zircon, tourmaline and metamorphic minerals belonging to the stable Pará suite. In this sample a grain of glaucophane occurs, a mineral that has never been found in any Surinam deposits.

KK 501 is a sample of a fine sandy clayey silt taken from a natural levee at the southern bank of the Amazon west of Santarém (see figure 29). It resembles the foregoing samples with the exception of a slightly higher content of zircon and staurolite. It contains 36% feldspar.

The association of the sample of the Amazon and those off the mouth of this river bear no resemblance at all to the Amazon heavy mineral suite of Barreto et al. (1975). Since there is no doubt about the origin of the sediments of the natural levee and those off the mouth, the heavy minerals of the so called Amazon suite on the shelf probably have another source. The nature of this source will be discussed in chapter 4.

Further north on the shelf there is a sudden change in composition of the heavy mineral fractions. The fine sandy sediments on the shelf of French Guiana still contain much epidote and hornblende, but they show an admixture of zircon, tourmaline, rutile and metamorphic minerals (especially staurolite and andalusite), typical Guiana Shield minerals. The content of opaque minerals is high. B 001 is a very coarse sand which has a high percentage of staurolite, tourmaline and garnet. It resembles the coarse sandy beaches of French Guiana and Suriname and is derived from the Armina Formation in NW French Guiana.

2.5 The occurrence of monazite and xenotime

In the course of time three detrital radio-active minerals have been found, exclusive of zircon, viz. monazite, xenotime and thorite. Monazite is by far the most important, but it is often accompanied by xenotime. Thorite is very rare and is not dealt with further here.

Monazite, $(Ce,La,Y,Th)PO_4$, is an economically important mineral, mainly because of its thorium content which may vary from almost zero to as much as 25%. It is an accessory mineral which is usually quite rare, except where it has been concentrated by chemical and mechanical agencies.

A Surinam monazite sample yielded 5-6% ThO_2, about the same as Brazilian placer monazite which has been reported to contain on the average 6% ThO_2 and 0.15 - 0.25% UO_2 (Bain, 1950). Overstreet (1967) gave an account on the occurrence of monazite in Suriname. He mentioned Middelberg (1908) as the first to recognize monazite in Suriname in gold placers overlying schists and gneisses and in the savannas (Upper Coesewijne Formation?). IJzerman (1931) found monazite in thin sections of biotite granites (Plate 33). This points to good observance since monazite is only rarely recognized by most petrographers.

The study of sediments in Suriname revealed the occurrence of some monazite in several rivers and creeks, e.g. Corantijn, Nickerie, Coppename, Tibiti, Saramacca, Marowijne, Tapanahony and Suriname River. Monazite has also often been found in relatively great amounts during alluvial prospection trips in the interior of the country due to the property that the mineral gives a very good recovery in the batea or goldpan because of its shape and relatively high specific gravity (Theobald, 1957; Krook, 1970b). It is always enriched where some kind of concentration occurs by waves or currents. Due to its chemical resistance and high specific gravity (5.1 - 5.4) it is a good placer mineral. However, it has a relatively low hardness (5) and rapidly decreases in size during transport.

Xenotime, YPO_4, is less common than monazite, but frequently connected with it.

The fact that monazite is far from rare on the Guiana Shield has been confirmed by Macambira (1975), who reported the occurrence of this mineral in more than 90% of the samples taken during alluvial prospection in Amapá, Brazil, mostly in areas underlain by gneisses and migmatites.

There are several places in northern Suriname where monazite has been found in weathered bedrock. High percentages occur in the heavy fraction of the bedrock encountered in the drill holes on the highway near Zanderij (Krook, 1969a; see also this study, figure 15, drill hole B-2). In some samples xenotime occurred as well, in one case even dominating the monazite. The nature of the bedrock is not known since drilling stopped before fresh bedrock was reached. In the Tibiti-Coppename area east of Bitagron monazite occurs in most creeks and weathered bedrock samples. This area is underlain by rocks of the charnockitic suite of the Falawatra Group (Arjomandi et al., 1973). This is in accordance with Olson and Overstreet (1964), who state that in metamorphic rocks the monazite content increases with the grade of metamorphism and is highest in the granulite facies. The drill hole KK-1 near Heidoti on the Coppename cut through weathered bedrock from 14.5 - 32.5 m which contained on the average 32% monazite and 68% zircon. Somewhat to the south the same composition was found in an outcrop of weathered bedrock (KK 424, table 12) at a roadcut near Bitagron. The monazite in this sample was strongly corroded, a rare phenomenon.

Southeast of the monazite bearing rocks of the Coppename-Tibiti area, near the upper part of the Mataway Creek (sheet 29d), xenotime was found, associated mostly with leucogranites.

A section in the Begi Gado mine southeast of Moengo has been discussed above (2.4.1.3, 2.4.1.5; also figure 12). In this section a weathered rock of granitic appearance containing 76% monazite (KK 455, table 13) is found in contact with a graphite bearing schist with 25% xenotime (KK 456, table 12). Another granite-like weathered rock near Albina showed 78% monazite (KK 457, table 13).

It is striking that many occurrences of monazite now known in the bedrock of Northern Suriname are found in an east-west belt (fig. 28), partly in metamorphic rocks of the Falawatra Group, partly in granitic rocks and partly in rocks of unknown nature. The metasediments of the Marowijne Group south of this belt do not contain monazite. A relatively large amount of monazite has also been found in the upper Tapanahony area and in the Coeroeni area (fig. 2). The first occurrence is related to granitic rocks, while the monazite in the latter area is apparently derived from the metamorphic rocks of the Coeroeni Group.

An example of monazite in weathered bedrock at greater depth is given by drill hole PB-1 (encl. 3) which shows an average of 14%.

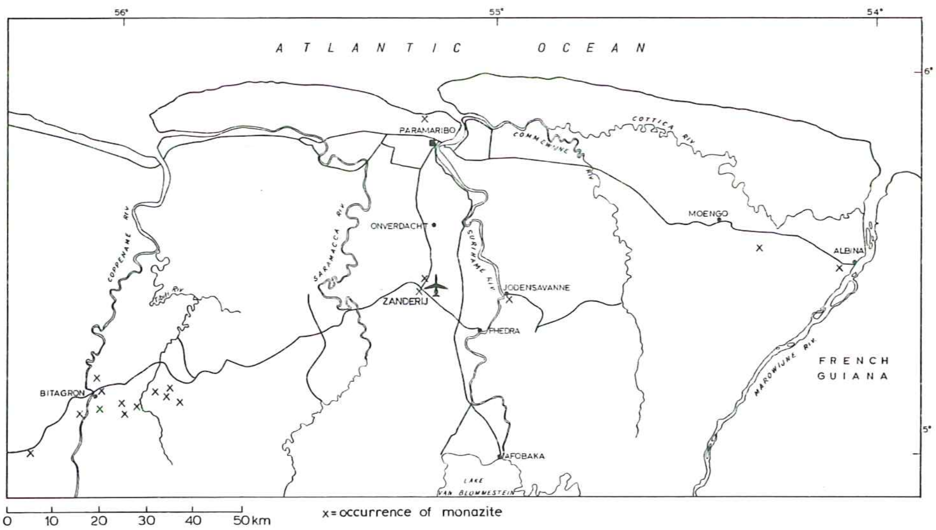


Fig. 28 Monazite occurrences in the weathered bedrock in part of Northern Suriname

According to Kroonenberg (personal communication) part of the east-west occurrence of monazite in Northern Suriname agrees rather well with a belt of biotite gneisses. A sample of a biotite gneiss from Jodensavanne on the Suriname River indeed yielded monazite as the main heavy mineral. Both the monazite and the - much less numerous - zircon were rounded, probably indicating a paragneiss. Several of IJzerman's (1931) biotite granites probably belong to these gneisses.

On the graphs representing the mineralogy of the deep drill holes (encl. 3) it can be observed that monazite is an important constituent of the sands encountered, especially in the western part of the coastal plain. Furthermore it is apparent that the content usually increases with depth. From this the conclusion may be drawn that in the past more monazite bearing rocks were exposed than at present. These rocks either disappeared by erosion or were covered by the sediments of the coastal area. Examples of the latter are the occurrences near Bitagron and Heidoti on the Coppename and the occurrence near Zanderij and Albina which are all covered by deposits of the Upper Coesewijne Formation. The rock containing monazite at the Begi Gado mine near Moengo is covered by the Onverdacht Formation.

3. THE STABILITY OF THE MINERALS

Much has been written on the stability of minerals and the factors governing their disintegration. The weathering of minerals has long been a subject of serious observation and study. Edelman and Doeglas (1932) described weathering phenomena on pyroxenes and amphiboles which showed "cockscomb" and "hacksaw" structures at the end of the crystals. In a later publication they also described weathering phenomena on minerals such as staurolite, kyanite, garnet, epidote and sphene (Edelman and Doeglas, 1934). Druif (1937), who studied the weathering of minerals in the volcanic soils of Deli in Sumatra, Indonesia, meticulously described the succession of weathering phenomena for many minerals. He introduced the term "roof tile structure" which so typically describes the surface weathering appearance of garnets.

The environment of weathering has been a subject of speculation for some time. Although the corrosion of mineral grains may already start in the magma, as Van Rummelen (1948) showed on augite crystals in recent andesites, this influence is apparently negligible. More important is the solution in the sedimentary rocks, the so called "intrastratal solution" (Pettijohn, 1941) which may explain the decrease of minerals with increasing depth and the weathering sensu stricto in the soil profile. The weathering during transport in the river is almost non-existent according to Van Andel (1952). Some minerals, however, may decrease considerably in size and quantity in a downstream direction by abrasion, as is the case in Suriname with monazite and xenotime which have a relatively low hardness.

It has long been recognized that not all minerals have the same susceptibility to weathering. Some minerals are very unstable while others survive several cycles of weathering, erosion and deposition.

The "stability series" of Goldich (1938) shows a decreasing tendency of stability with decreasing temperature of formation:

olivine — anorthite
augite
hornblende
biotite — albite
potash feldspar
muscovite
quartz

This series, strongly resembling Bowen's reaction series, shows only the most important rock forming minerals. Numerous other stability series have been proposed by several workers. Pettijohn's (1941) order of persistence was based on the comparison of the frequency of occurrence in recent sediments and the average frequency in non-recent sediments and reads as follows: anatase - muscovite - rutile - zircon - tourmaline - monazite - garnet - biotite - apatite - ilmenite - magnetite - staurolite - kyanite - epidote - hornblende - andalusite - topaz - sphene - zoisite - augite - sillimanite - hypersthene - diopside - actinolite - olivine. The first three minerals appear to be more abundant in ancient sediments than in modern sediments, probably due to authigenous formation.

According to Pettijohn (1956) studies on both weathering and intrastratal solution showed about the same order of persistence, with a few exceptions.

The following stability list was given by Pettijohn, Potter and Siever (1972):

ultrastable	:	rutile, zircon, tourmaline, anatase
stable	:	apatite, garnet (iron poor), staurolite, monazite, biotite, ilmenite, magnetite
moderately stable	:	epidote, kyanite, garnet (iron rich), sillimanite, sphene, zoisite
unstable	:	hornblende, actinolite, augite, diopside, hypersthene, andalusite
very unstable	:	olivine

In the course of time many workers have published studies on the weathering process. A few are briefly mentioned here. Loughnan (1962) found that the weathering of silicate minerals was a function of two variables, (1) the mobility of the essential cations and (2) the mineral structure. The factors influencing the mobility of the cations were the pH, the Eh, the leaching potential, time and fixation. A factor that should be added to the list, of course, is temperature. Some cations, e.g. Na^{+}, K^{+}, Ca^{++}, Mg^{++} and Si^{++++}, are readily soluble, others like Al^{+++} and Fe^{+++} are not soluble and form insoluble hydrated compounds creating secondary minerals. This behaviour can be understood with the ionic potential (Goldschmidt, 1937). The relation between mineral structure and weathering is less clear. There is no good correlation between the bounding energies and the weathering. It seems that the framework structure is a factor of importance.

Keller, Balgord and Reesman (1963) and Keller and Reesman (1963) approached the problem empirically by putting pulverized minerals into water (either distilled or with carbon dioxide) and studying the dissolution products. The solubility of minerals in distilled water was very low and did not show any similarity with the natural stability range. Muscovite appeared to be the most unstable mineral. The influence of carbon dioxide was clearly shown by the higher content of cations in the resulting solutions. The resulting solubility showed a much greater agreement with natural conditions than in the experiments with distilled water, with the exception of muscovite and labradorite. The carbon dioxide resulted in the complete absence of Fe in the solution because of the formation of secondary minerals such as siderite.

Nickel (1973) applied somewhat similar methods. However, he used coarser grains (20-35 microns) and determined the dissolution in water with different pH-values, viz 10.6, 5.6, 3.6 and 0.2. It was found that there is a great difference of solubility of the various elements. This incongruent solution causes (and is partly caused by) the formation of residual layers of Si, Al and Fe on the surface of the grains which hamper further dissolution to a certain degree. The most stable minerals like tourmaline and zircon had built up very thick residual layers, whereas on the unstable ones these were only very thin. The general conclusion was that most silicates are least resistant in strongly acid and strongly alkaline solutions and most resistant in approximately neutral solutions. Apatite was most resistant with pH = 10.6.

The resulting stability series for pH = 5.6 and pH = 10.6 are shown below.

pH = 5.6	pH = 10.6
zircon, rutile	zircon, rutile
	almandine, staurolite
muscovite	quartz
kyanite	hornblende
tourmaline, staurolite	apatite
quartz	muscovite
epidote, albite	kyanite
hornblende	tourmaline
almandine	albite
apatite	epidote

They agree rather well with the stability in weathering and intrastratal solution respectively. However, in the pH = 5.6 series tourmaline seems to be ranked too low and in the pH = 10.6 series hornblende has a much more stable position than actually encountered in intrastratal solution. The positions of almandine and apatite at pH = 10.6 are well in accord with their stability with respect to intrastratal solution as will be shown below.

The author obtained some practical knowledge on the subject of stability of minerals during his studies on heavy minerals from the interior of Suriname. It has been noted above that in flat areas with only small superficial creeks mainly stable minerals occur. Larger and deeper creeks and rivers usually still have many unstable minerals such as epidote, hornblende and even pyroxenes such as hypersthene (Arjomandi et al, 1973). Minerals like apatite and sphene, however, are very rare, even in granitic areas, while crushed unweathered granites contain a fair amount of both of them. Apatite was abundant in crushed samples of the Roraima sandstone, together with zircon, garnet and hematite. Other unstable minerals were lacking (see 2.4.1.6).

A good view of the stability of heavy minerals was also obtained by the study of the coastal plain. Although in the lower unweathered strata of the Pleistocene Coropina Formation epidote, hornblende and garnet were still present, they were absent in the upper part which has been submitted to subaerial weathering lasting all through the last glacial and the Holocene. Even in the Wanica phase ridges of the Young Coastal Plain it could be observed that the older ridges contain less epidote and much less hornblende than the younger ones, while the garnet was mostly found at depths where oxidation had never prevailed. The study of two soil profiles was shown to be particularly instructive (table 20). In the youngest stages (Moleson and Comowine phases) the weathering has not yet played an important role with respect to heavy minerals, with the possible exception of biotite. Unstable light minerals, however, such as chamosite and chlorite, have disappeared in the upper layers and probably helped to form the secundary iron oxides.

Under very long lasting and extreme weathering like kaolinization and bauxitization other, more stable minerals may also corrode and finally even disappear as illustrated in 2.4.3. Samples from the Onverdacht Formation below the bauxite in the Onverdacht-Lelydorp area showed severely corroded staurolite. It was at first difficult to decide whether this corrosion had occurred by subsurface weathering or intrastratal solution. Although it is recognized that there is no sharp boundary between the two, there was evidence that weathering was responsible for the corrosion judging from the fact that even quartz showed strongly etched surfaces, a phenomenon also observed in superficial sandy kaolins but never in samples from deep drill holes in the coastal plain, although the pH is usually higher at greater depth. By the extreme weathering conditions during bauxitization in the coastal plain quartz dissolved on a large scale from the original sandy sediment. It seems that temperature and "leaching potential" were important factors in the weathering of quartz under these conditions.

Sillimanite is another mineral that shows many signs of corrosion, even more than staurolite. Etching figures may appear on the surface of the sillimanite resembling deep gullies normal to the C-axis. When this solution proceeds, the grains break into several parts, especially during transport. The resulting parts are basal grains which show biaxial interference figures. It has already been mentioned in 2.4.3 that in the Onverdacht Formation of the Moengo area no sillimanite was found although it should have been present in this particular mineral association.

Corrosion of other metamorphic minerals in weathering profiles has been observed more rarely, but, of course, in the scope of the present study no systematic and painstaking observations have been done on minor superficial etching, a phenomenon which occurs in most minerals, even zircon.

An example of extremely severe weathering may be observed in the graph of drill hole C-1 (Encl. 3), where, in the kaolinized top of the Miocene, only the very stable zircon, rutile, monazite and corundum were found. Staurolite which almost certainly had been present as the predominating mineral, left only a mere trace. In the kaolin of the Paleocene and Oligocene of the same drill hole also only the most stable minerals occur.

With respect to intrastratal solution a few significant differences from the foregoing have been observed in the deep drill holes in the coastal plain. Amphiboles and epidote are usually only present in some upper Tertiary and Pleistocene sediments. In older deposits they are rare to absent with the exception of TN-1 and GLO-1. Garnet, on the other hand, found to be very unstable in the soil profile, can be encountered down to the lowest strata and is especially abundant in the Cretaceous of some drill holes. Apparently it is very stable under reducing conditions which prevail at all depths below the water table as can be inferred from the presence of siderite and pyrite in most drill holes samples (Krumbein and Garrels, 1952). It is striking that in the Early Miocene to Recent fine sands and fine sandy clays of TN-1 and in the very fine sandy clays of the Late Miocene and the Pliocene of GLO-1 the epidote and hornblende have hardly been weathered. This may be due to less water movement because of the small grainsize.

Gazzi (1965), who studied heavy minerals of the geosynclynal series in the northern Apenines, found a relative increase of garnet with depth due to the decrease of the more unstable minerals, followed by a decrease because of intrastratal solution. This decrease has not been found in Suriname. Apparently the conditions of the circulating waters in both cases are significantly different.

The occurrence of apatite in the Precambrian Roraima Formation has been mentioned above. Apparently this mineral is stable with respect to intrastratal solution. The fact that apatite does not occur in the bore holes in the Young Coastal Plain, contrary to garnet, may indicate that it had been weathered before the sediments were transported and deposited.

The speculative question now arises as to what the conditions were like when the Precambrian crystalline rocks were eroded and the erosion products deposited to form the Roraima Formation (1.4.1). In this formation the relatively good roundness of the light minerals (quartz and feldspar) and the heavy minerals (hematite, zircon, apatite and garnet) suggests wind action. This probably occurred in the source area since the sedimentary structures are indicative of a fluvial environment. Wind action during the Precambrian does not necessarily imply a dry climate, since desert conditions prevailed because there was no vegetation. Lack of organic acids may account for the abundance of apatite, which, under present weathering conditions, is highly unstable. If garnet and apatite were not weathered before erosion and deposition in the Precambrian, the same must have held for minerals such as epidote, amphiboles and pyroxenes. However, these minerals are entirely lacking, an indication of intrastratal solution which left the garnet and apatite almost unaltered.

Although quite rare, weathering phenomena like hacksaw terminations due to intrastratal solution were found on stable minerals such as andalusite, kyanite and even corundum in drill hole samples. The deep etching of sillimanite according to (001) as described above, was also observed. Often small, somewhat rounded grains resulted, showing a-centric pseudo uni-axial interference figures.

According to Van Andel (1952) the decrease of the number of mineral species with increasing depth could not be the result of intrastratal solution. He studied a great number of bore holes and found that the lower parts of the mineral zones were never accompanied by an increasing degree of etching. In the drill holes in the Surinam coastal plain, however, the absence of epidote and hornblende in garnet bearing sediments can only be explained by intrastratal solution, since by the weathering of the original crystalline rocks garnet would also have disappeared.

A mineral of some importance with respect to weathering is ilmenite. It is often found partly covered with whitish or yellowish leucoxene. After longterm severe weathering the bluish black colour of the ilmenite changes to brown due to oxidation of the ferrous iron. At the same time some H_2O enters the lattice. Flinter (1959a) speaks of hydro-ilmenite. X-ray diffraction patterns of hydro-ilmenite show rutile and goethite. After the ultimate leaching of the iron leucoxene is formed which is, in fact, crypto-crystalline rutile and anatase, Flinter's arizonite. Under extreme leaching conditions in an acid environment ilmenite grains may alter into brown spongelike aggregates which also show rutile and anatase by X-ray diffraction. In a sample (KK 419, table 13) from a natural water well of the transition from white Coesewijne sands to kaolinitic weathered schists all the ilmenite had been altered into these aggregates. This clearly shows the value of Loughnan's (1962) "leaching potential".

Intrastratal solution leads to the transformation of ilmenite to leucoxene as well. In the CO-1 drill hole the non-authigenic opaque minerals consist mainly of leucoxene. A different kind of weathering of ilmenite was observed in weathered bedrock samples from drill holes in the Onverdacht mining area

(Krook, 1969a). Authigenic pyrite was found combined with clusters of fine rutile needles, obviously of secondary origin. Apparently the ilmenite had been altered into rutile while the remaining iron was used in the formation of pyrite. The possibility of this type of weathering has also been described by Austin (1960) and Carrol (1960).

Magnetite, another opaque mineral, is usually regarded as stable. In tropical soils, however, it is far from stable. Although crushed fresh granites usually have a considerable content of magnetite, this mineral is quite rare in samples of creeks and rivers draining granite areas. The bulk of opaque minerals is usually ilmenite in these areas and in regions underlain by most types of igneous and metamorphic rocks. This is also the predominating mineral in either natural or artificial black sand concentrates.

As a result of the foregoing considerations the following stability table is proposed with respect to weathering conditions in humid tropical regions and to intrastratal solution.

ultrastable	rutile, zircon, tourmaline, anatase
very stable	corundum, monazite, xenotime, (garnet), (apatite), kyanite
stable	staurolite, andalusite, (corundum), sillimanite, ilmenite
moderately stable	epidote
rather unstable	hornblende, (biotite)
unstable	magnetite, garnet, augite, enstatite, hypersthene
very unstable	sphene, apatite, pyrite, biotite
extremely unstable	olivine (not detected in Surinam detritals)

Table 9 Stability series of heavy minerals in Suriname (minerals between brackets refer only to intrastratal solution)

From the point of view of soil fertility the heavy minerals are of little importance since the total content is usually very low, rarely exceeding 1-2% and often much less. Moreover, only a part of the unstable minerals has any value as a source of calcium (epidote, hornblende, augite, apatite), phosphorus (apatite) or potassium (biotite). Fertility caused by the weathering of minerals rather depends on the composition of the light fraction and the feldspar content especially determines its value (mainly potassium from orthoclase and microcline, rarely calcium from the scarce plagioclase).

The highest feldspar content occurs in the recent natural levees of the rivers (up to about 15%). The content is considerably less in the fine sandy ridges (5-6%), while the coarse sandy ridges have only about 2% feldspar.

The soils on older sediments such as the sands of the Offshore Bar Landscape of the Upper Coropina Formation contain no feldspar or only traces. The soils on the Upper Coesewijne Formation have no feldspar at all. Soils on the rocks of the crystalline basement are usually equally poor as far as mineral fertility is concerned.

4. PROVENANCE AND TRANSPORT OF THE SEDIMENTS

4.1 Introduction

In order to determine the direction of supply of older sediments in the coastal area their mineral composition is compared with the associations supplied by the present rivers. It should be remembered, of course, that the mineral associations of the older deposits are much impoverished due to the disappearance of unstable minerals such as pyroxene, amphiboles and epidote by intrastratal solution and weathering. This means that only the stable minerals in the present rivers must be regarded. Furthermore the distribution of geological formations may have differed considerably from the present situation. This is clear when one considers that since the Middle to Late Cretaceous the erosion has removed a probable thickness of about 600-700 m from the greater part of the country. Another important factor that should be taken into account is the fact that in the past formations were exposed at the northern part of the shield which have now been covered by younger deposits and no longer serve as a source from which sediments can be derived. This factor has already been discussed in 2.5 with respect to the occurrence of monazite.

In the following descriptions reference is made to the corresponding sections in chapter 2.

4.2 The Cretaceous

The Cretaceous in the drill holes in the western part of the coastal plain shows zircon, some peaks of garnet and a relatively high monazite content (encl. 3). TN-1 has much sillimanite which is less frequent in WA-3 and BNS-1. None of the present rivers show corresponding compositions. The Corantijn has more sillimanite, especially when only the stable minerals are taken into account. The high garnet and monazite contents cannot be explained with the present mineral supply. Garnet and sillimanite indicate a derivation from high grade metamorphic rocks such as occur in the Bakhuis Mountains and the Coeroeni area. During a prospection in the latter area sillimanite, garnet and monazite were found to be rather abundant. It is possible that the relatively low sillimanite content in the Cretaceous is due to intrastratal solution. The Cretaceous in WA-4 shows some more sillimanite and a little staurolite. In none of the Cretaceous deposits in the western part of the coastal plain are sediments rich in kyanite found, such as occur at present in the Nickerie River.

On the whole it is probable that the supply in the western part of the coastal plain during the Cretaceous was from southern to southwestern direction. This is in agreement with the continental facies. However, the exposed Precambrian formations were obviously of compositions which were considerably different from the present ones. The provenance of the staurolite in WA-4 and TN-1 should also be from the south. The present rivers in western Suriname supply only traces of this mineral, but staurolite bearing gneisses do occur in the Coeroeni area (Kroonenberg, 1976) albeit on a small scale.

Since the shales in CO-1 contain, besides garnet and sillimanite, a considerable amount of staurolite, an eastern influence during the transgressive phase is probable. The upper, sandy, part does not contain staurolite. This is in accord with the general regressive tendency as described by Belsky et al. (1972).

The sediments encountered in CC-3 are of totally different origin. They contain abundant staurolite and kyanite and a considerable amount of monazite. High contents of kyanite do not occur in any other drill holes. The only river supplying kyanite at present is the Nickerie. A kind of proto-Nickerie, flowing to the north-east is highly improbable, however, since then sillimanite would be dominating, which is not the case. Although staurolite is usually of eastern origin, there are reasons to doubt this provenance in the present case, since the high staurolite content also occurs in the Paleocene and Eocene deposits of this drill hole, in contrast with the more eastern holes. These considerations lead to the conclusion that there probably was a source somewhere in the south providing the kyanite and - at least part of - the staurolite. This kyanite-staurolite bearing formation has either disappeared by erosion or has been buried by more recent sediments. The kyanite is very coarse grained which may point to a nearby source. It should be mentioned that contamination from younger deposits may have influenced the composition of the sands of the Cretaceous and, possibly, the Paleocene and Eocene in this hole (see 2.2).

In PB-3 zircon predominates but staurolite occurs in reasonable amounts. This indicates a supply from both southern (granitic rocks) and eastern supply (staurolite schists).

In the Cretaceous of the Rose Hall test well in Guyana the following zones could be determined with respect to provenance of the sediments (Kugler et al., 1942):

Cenozoicum	0 - 2650':	granitic source and reworking of pre-existing material
Cretaceous	2650 - 4800':	reworking of pre-existing material
Cretaceous	4800 - 6300':	source material widespread, comprising Roraima and porphyries
Precambrian	6300 - 6450':	subsoil of granite apophyses and porphyry types

This means that during the whole of the Cretaceous the crystalline rocks of the Shield in Guyana were not exposed since they were entirely covered by the Roraima Formation. Only at the very beginning of the Tertiary the erosion has succeeded in removing large parts of the Roraima sandstones and exposing the underlying igneous and metamorphic rocks.

However, in the drill holes in Suriname no indications of a Roraima provenance could be detected. Characteristic minerals from the Roraima Formation of the Tafelberg are: zircon (frequently pink), hematite and apatite, all well rounded (see 1.4.1.6), but none of these have been found in large proportions in any of the samples. In the light fractions Roraima influence would be easiest to tell from the - often pinkish - rounded quartz grains. If the Roraima ever covered considerable parts of Suriname, it must have been removed long before the end of the Cretaceous. Possibly, however, the Roraima Formation in Suriname never covered a large area. This would be in agreement with the hypothesis of Kloosterman (1976) that the Roraima Formation on and around the Tafelberg is the crater filling of a large Precambrian caldera.

4.3 The Paleocene and the Eocene

This part of the Tertiary in general is characterized by its extreme poverty of minerals which seriously hampers the determination of the source of the sediments.

The sediments west of the Coppename show little change of direction of supply since the Cretaceous. The low garnet content of the Paleocene and the Eocene as compared to the Cretaceous is probably mainly a result of weathering and has little to do with a change in supply.

In CC-3 there is a strong decrease of kyanite. The staurolite supply is still considerable but the monazite shows a gradual decrease. Little can be said about the direction of supply in C-1 since the deposits consist of intensively weathered sandy kaolin.

It is striking that the pre-bauxite Tertiary deposits of the area east of Calcutta have a low staurolite content compared to the Early and Middle Miocene deposits. This cannot be entirely a result of weathering, since in that case T-28 would have no feldspar, a mineral which is much more subject to weathering than staurolite. Apparently the Armina Formation did not at that time play its later role as the main source of erosion products in the eastern part of the country. It is tentatively suggested that most detritals were derived from granitic rocks and from the biotite gneisses mentioned in 2.5. The possible importance of the latter has already been shown by its supply of monazite, a mineral of frequent occurrence in Cretaceous and Early Tertiary deposits.

Only little can be said about the sediment supply in CO-1, since the samples from the Eocene did not contain any heavy minerals. The heavy fractions of the

Paleocene consist mainly of zircon but as they contain more sillimanite than staurolite a mainly southern supply seems apparent.

The sediments from the Onverdacht mining area comprise kaolinitic clay and sand. Montagne (1964b) recognized two sequences from coarse sand to kaolinite clay. Ter Meulen (1948) found evidence for a marine provenance of the clays. It should be mentioned that the origin of the clays in the Paleocene and the Eocene was different from the one of post-bauxite times. The Amazon River, which now provides most of the clay, did not yet exist and the clay was probably supplied by rivers draining the Guiana Shield. From a heavy mineral point of view there is little difference between the sandy kaolin and the sand (Krook, 1969b). Both fine and coarse sands contain staurolite which may have been derived from the nearby hinterland as well as from the east by beachdrifting.

4.4 The Oligocene and the Miocene

The deposits just above the bauxite hiatus are generally of a sandy character and do not contain pollen: the A-sands, probably of Middle or Late Oligocene age. They are covered by the Intermediate Clays of the Early and Middle Miocene (pollen zones E and F).

In the Nickerie region the supply is still from the south. WA-3 has a garnet peak below the MLM (originally Mid Lower Miocene, probably early Middle Miocene, see 2.4.2) while both sillimanite and staurolite increase, the latter probably indicating a slight increase of eastern influence. The same tendency can be observed in BNS-1 and WA-4. The highly unusual composition of TN-1 has been mentioned in 2.4.4. The fine sands were possibly deposited in a relatively deep embayment. The small grain size probably prevented intense weathering during the later stages of regression and intrastratal solution.

The Calcutta holes show an increase of staurolite compared to the pre-bauxite deposits, rather clearly in CC-3 and very markedly in C-1. Some detailed work on the latter hole showed that the coarse sands contain staurolite and kyanite while the fine sands contain staurolite but little or no kyanite. The sand lenses in the Intermediate Clays are for the greater part fossil beaches, coarse sandy as well as fine. Since kyanite occurs in the A-sands and the coarse beach sands of C-1 and not in the drill holes further east, there probably was a river somewhat east of C-1 supplying this particular mineral plus staurolite. In CC-3 also some kyanite is present, although much less than in the Cretaceous.

A high staurolite content is found in all drill holes east of the Coppename. It points to beachdrifting which supplied sands derived from the Armina Formation. These sands hardly influenced the composition of the sediments to the west. Although the Miocene transgressions reached far to the south in the western part of the coastal plain and in adjacent Guyana (Van der Hammen, 1963; Wijmstra, 1971), the sand fractions of these deposits show mainly heavy minerals of local origin. GH-1 is the westernmost drill hole with a high staurolite content. It shows a mixed composition of locally derived minerals (sillimanite and andalusite, both also characteristic of the Coppename River) and the staurolite and garnet of eastern sources.

The Oligocene and the Miocene in CO-1 on the continental shelf have also a relatively high staurolite content (fig. 13). Wong (1976) assumed that the "barren" (from a paleontological point of view) sands which have little east-west extension (Elf Petroleum, personal communication to Wong) were a sort of channel fill formed in a type of Proto-Corantijn deltaic environment. However, the presence of staurolite and the absence of sillimanite indicates that the source of the sands must be sought further east. The sand may, however, have been reworked in the delta of a large river which itself apparently supplied very little material.

In drill hole CO-1 as well as in SON-1 and MO-1 on the continental shelf the terrigenous sediments of the earliest Miocene were replaced by carbonate platform deposits. Wong (1976) concludes that during the formation of this platform no terrigenous material reached the Guiana coast. However, large scale clay deposits do occur, the Intermediate Clays. Apparently a muddy near coastal shelf area and a clear sea with carbonate deposition on the seaward part could occur side by side. During the Langhian the carbonate shallow water facies was temporarily interrupted by terrigenous sedimentation which was explained by assuming increased erosion in the hinterland by Wong (1976). After the Langhian the carbonate deposition proceeded again until terrigenous sedimentation took over for good during the Late Miocene. The Langhian erosion phase probably corresponds with the so-called "Mid Lower Miocene" hiatus (Noorthoorn van de Kruijff, 1970; see also 1.4.2) and the hiatus between zones E and F which comprises the early Middle Miocene (Wijmstra, 1971; see also 1.4.2 and 2.4.4). A comparable erosion phase has also been described in Brazil where the basal Miocene has been eroded in most of the coastal basins. At the same time terrigenous supply occurred beyond the shelf (Kumar, 1978). Although in Brazil this is known as the "Early Miocene terrigenous phase", it is suggested here that it may well correspond to Wong's Langhian terrigenous phase.

The post-bauxite transgression in the present coastal plain started with the deposition of the A-sands after which there was a sudden supply of large quantities of clay, the Intermediate Clays. These clays have been found as far south as Sabana (Encl. 2, sheet 20a) and the Coesewijne Savanna (sheet 21a)(Reynolds

Suriname Mines, 1974). The question arises of where these clays have come from. At present the marine clays are mainly of Amazon origin (4.7). The Amazon as an eastward flowing river is a relatively recent phenomenon. Beurlen (1969) reasoned on tectonic grounds that the Amazon River system originated during the Miocene transgression. According to others, however, the Amazon is considerably younger. The greater part of the Amazon Basin is underlain by kaolin and quartz sand of the Alter do Chão Formation which has usually been assumed to be the same as the Barreiras Formation because of its close resemblance to this Late Tertiary Formation. The sandy kaolins are probably weathering products of clays and arkosic sands of terrestrial origin. In some parts of Amazonia extensive bauxite deposits were formed on the Alter do Chão (e.g. the Rio Trombetas deposits, see figure 29). The age of the Alter do Chão was assumed to be Miocene by Sombroek (1966), but Mousinho de Meis (1971), Dennen and Norton (1977) and many others even speak of Plio-Pleistocene. Beurlen (1970), however, argued that the formation was probably older than the Barreiras Formation, probably even older than the Miocene. On top of the Alter do Chão a uni-

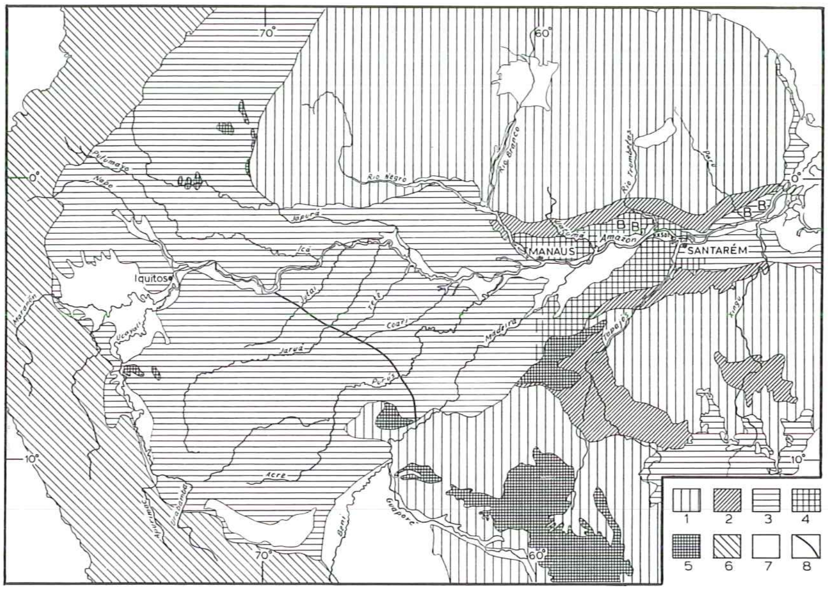


Fig. 29 Simplified geological map of the Amazon Basin (after Irion, 1976c with additional data from Daemon, 1974)

Legend: 1. Precambrian shields, 2. Palaeozoic, 3. Tertiary (undifferentiated), 4. Alter do Chão of Middle Amazon area (Upper Cretaceous), 5. Cretaceous, 6. Andes Mountains, 7. Quaternary, 8. Approximate boundary between Tertiary part of the Alter do Chão and lacustrine-marine Tertiary of the SW Amazon Lowland, B. bauxite deposits.

form, yellowish, very heavy kaolinitic or even gibbsitic clay occurs, the Belterra Clay which may reach a thickness of 20 m. This Belterra Clay has usually been regarded as a separate deposit, covering the lateritically or even bauxitically weathered Alter do Chão. Sombroek (1966) assumed that the Belterra Clay had been deposited in an inland sea during the Plio-Pleistocene. The Amazon proper originated at a later date. Klammer (1971), however, recognized the Belterra Clay as an extremely leached A-horizon which belongs to the same oil profile as the laterite or bauxite. The same opinion is held by Aleva (1977, personal written communication).

A most important contribution to the geology of the Amazon Basin has been given by Daemon (1974), who dated the Alter do Chão palynologically. He showed that this formation in the Middle Amazon area is of Late Cretaceous age, viz. Middle Albian, Cenomanian and Turonian and consists of continental deposits, fluvial and lacustrine, mainly formed in a dry tropical climate (fig. 29). This age is considerably older than has been assumed before and has serious consequences. The bauxite developed on top of the Alter do Chão (Dennen and Norton, 1977) may well be of the same age as the bauxite in the Guianas, viz. Eocene-Oligocene. The Amazon may also be much older than the Pliocene or Pleistocene as assumed by the authors mentioned above.

Another important fact, with respect to the Amazon, is the occurrence of a very large submarine fan bordering the continental shelf off the mouth of the Amazon, the Amazon Cone (Damuth and Kumar, 1975a), figure 30. During low sea-level stages the Amazon sediments were transported through a submarine canyon,

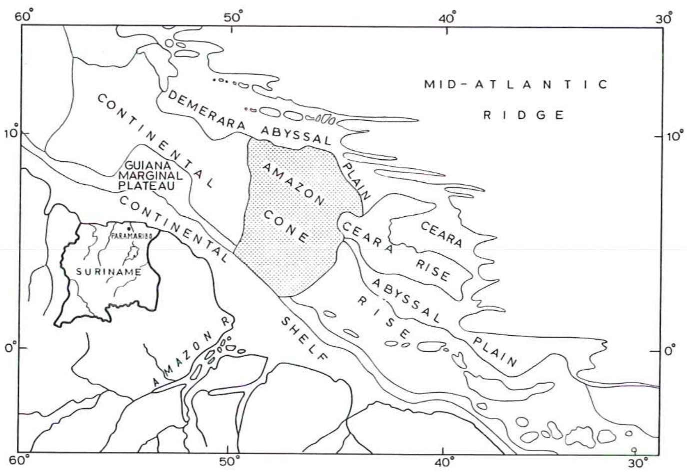


Fig. 30 Physiographic map of the Western Equatorial Atlantic (after Damuth and Kumar, 1975a)

the Amazon Canyon, after which they were deposited by turbidity currents and built up the Cone. During high sea-level stages, as at the present time, the sediments are deposited close to the mouth and subsequently partly resuspended by waves and currents and transported along the coast with the Guiana Current (Eisma and Van der Marel, 1971; Milliman et al., 1975).

By comparing the rate of sedimentation with the thickness of the Amazon Cone Damuth and Kumar (1975a) estimated the age of the cone at 8-15 million years which means that the cone started forming in the Middle to Late Miocene times. Kumar later (1978) gave a revised age of 22 m.y. or Early Miocene.

The sudden supply of mud at the Guiana coast in the Early Miocene (Intermediate Clays) might well be the announcement of the birth of the Amazon. During the high sea-level stage of the Early Miocene and the late Middle Miocene transgressions of the sediments of the Amazon should have been transported along the Guiana coast such as occurs at the present time. Is there any mineralogical evidence that the Intermediate Clays have been derived from the Amazon? In most drill holes in the coastal plain few unstable minerals occur in the Early and Middle Miocene deposits since they all have disappeared by weathering and intrastratal solution. There is one exception, however, viz. TN-1 which shows only very fine sands and sandy clays above the bauxite hiatus (Van Lissa, personal communication). It has been pointed out in 2.4.4 that these sediments have a high content of epidote and hornblende and furthermore some chlorite, basaltic hornblende and clinozoisite, typical Amazon derived minerals.

Observations in the area near the mouth of the Amazon are in agreement with the age of the Amazon which was mentioned above. During the Early Miocene deltaic and marine sediments were deposited in the Amapá Graben and the Mexiana Graben north of the Marajó Basin (Aguiar et al., 1969). The fine grained deltaic deposits containing lignite, wood and plant remains, fresh water fossils and even some bones are highly suggestive of the breakthrough of the Amazon.

During the Late Miocene a large regression occurred in South America and no deposits of this age are known in Suriname proper, although they do occur in the drill holes on the continental shelf. CO-1 contains mostly sands, probably of near coastal origin. In GLO-1, on the edge of the NE part of the Surinam shelf, about 1200 m of silty and sandy clays of Late Miocene age was found (fig. 9), mostly deposited in an upper slope environment (Belsky et al., 1972; Wong, 1976). This enormous sediment body could only have been supplied by a large river. Belsky et al. thought of the Marowijne or - more likely - the Amazon as the possible source. The study of this drill hole has shown that the sediments have partly the same mineral composition as the recent Amazon deposits, viz. mainly epidote and hornblende (fig. 13). The typical Amazon minerals such as basaltic hornblende and clinozoisite also occur. The near absence of the highly unstable pyroxenes, typical constituents of modern Amazon sediments (see table 22 and figure 27), must be ascribed to intrastratal solution. The question arises, however, of where the non-typical Amazon minerals such as zircon, tourmaline, garnet and rutile have been derived from. These minerals are characteristic of the Precambrian shield. They probably entered the Amazon sediment load by erosion during the deep incision of the Late Miocene, either directly from the shield or, more likely, from the Alter do Chão Formation. In this respect it may be mentioned that according to Beurlen (1970) a mineralogical study of a profile of the Alter do Chão on the lower Tapajós by Amaral (1954) showed mainly zircon and tourmaline and some staurolite, rutile and garnet. These are all stable minerals, except garnet. Even at the present time, a period of high sea-level, the Alter do Chão is eroded from steep local cliffs of terraces of the Amazon. This has been observed by the author during the flood stage in 1974, slightly west of the natural levee which has been sampled (KK 501, table 22; location west of Santarém, see figure 29). It probably explains the relatively high content of zircon, garnet and staurolite in this sample in relation to the deposits near the mouth of the Amazon.

The observations given above exclude the Marowijne as a source of the Miocene deposits encountered in GLO-1. Indeed, staurolite, the most typical mineral of the Marowijne, is almost entirely lacking.

It is interesting to note that the Amazon deposits are not at all confined to the Amazon Cone. The section through the Guiana Marginal Plateau (fig. 9) suggests that the whole upper part of this plateau consists of Amazon sediments. This means that the Guiana Current provides a very extensive area with a "blanket" of Amazon deposits. Both Belsky et al. (1972) and Wong (1976) mention the fine lamination in the deposits of GLO-1. This is an important observation. Damuth and Kumar (1975b) distinguish two modes of deposition on the continental rise of the western Atlantic: 1. deposition by contour currents, leading to finely laminated sediments and 2. deposition by turbidity currents. The first is restricted mainly to the western North Atlantic while the second is - with a few exceptions - confined to the western Equatorial Atlantic. One of the exceptions was observed in cores of drill holes from a small isolated part of the continental rise north-west of the Demerara Plateau (presently known as the Guiana Marginal Plateau). It now seems probable that the whole upper part of the Plateau, the "Amazon Blanket", consists mainly of contourites. Possibly these sediments are not confined to the Guiana Marginal Plateau and also cover parts of the surrounding continental slope and continental rise.

4.5 The Pliocene

After the deposition of the Lower and Middle Miocene a hiatus occurs, comprising the Late Miocene. During the Early Pliocene the sea-level rises and the coast moves far to the south. In the Savanna Belt the Upper Coesewijne Formation shows a transgressive phase at the base. This phase is characterized by sandy clay or even sand, locally with thin layers of lignite. Pliocene pollen, including *Rhizophora* has been found in drill holes south of Sabana and in the southern part of the Coesewijne Savanna (Reynolds Suriname Mines, 1974; pollen data from Wijmstra, internal report). The heavy fraction of the basal sandy clays and sands is relatively rich in staurolite (see figure 15), indicating a supply from the east by beachdrifting which is in accordance with the transgressive character. The possible occurrence of staurolite in the Coesewijne Formation near the Nickerie River (see 2.4.5.3, Nickerie River) might indicate that the Early Pliocene transgression even reached this area.

In drill hole T-28 in the Young Coastal Plain Wijmstra (1969) found two transgressive phases in the Pliocene. The lowest one probably correlates with the transgressive deposits in the Savanna Belt. Another drill hole, T-20, west of the first one, showed only one transgression, followed by a regression (Wijmstra, 1971).

In the northern part of the coastal plain the Pliocene sands seem to be mainly of a regressive character since they have a high zircon content and only small amounts of staurolite. In this respect they cannot be distinguished from the Pleistocene sands, but they differ considerably from the Miocene sediments. West of the Coppename there is little difference in mineralogical composition between the Miocene and the Pliocene since the staurolite rich sediments did not reach this area during the Miocene. The cause of the sudden change in heavy mineral composition in the middle and eastern part of the coastal plain will be discussed below (4.6).

It has already been shown (2.4.4) that the coarse sandy part of the Upper Coesewijne Formation consists of braided river deposits and probably alluvial fan deposits.

4.6 The Pleistocene

In the western part of the coastal plain (drill holes 5-72, WA-3 and BNS-1) there is little change in heavy mineral composition compared to the Miocene and the Pliocene. There is still some eastern influence in WA-3 and BNS-1 as shown by the occurrence of some staurolite. In WA-4 no more staurolite occurs and in TN-1 it decreased to a few percent. The fine sand in the latter hole with a very high content of Amazon derived minerals point to a direct supply by the Guiana Current and very little influence from sands drifting along the coast.

The great difference in composition between the Miocene on the one hand and the Pliocene and the Pleistocene on the other, calls for an explanation. It is recognized that sediments in the central part of the coastal plain which have a high staurolite content, have been derived from the Armina Formation in Eastern Suriname and were supplied by beachdrifting during the high sea-level stages. On the other hand, sediments rich in zircon have been supplied by rivers such as the Saramacca and the Suriname during the low sea-level stages. At these times beachdrifting occurred far north of the present coast. The Holocene transgression is apparent from the heavy mineral record: staurolite rich sands are found even in the western part of the Young Coastal Plain (figs. 23 and 24, see also drill hole graphs 5-72 and WA-3, Encl. 3). Since during the Pleistocene there have been transgressions as well as regressions it seems obvious that both would be reflected by the heavy mineral composition of the sediments. However, the sands are usually rich in zircon and contain only little staurolite. This means that the supply of the sediments from the interior, deposited during the regressive phases, usually predominates. The explanation may be that a considerable part of the sediments of the interglacial transgressive phases has been eroded by dissection during the subsequent regressions. This is also apparent from the lithology as is shown in the graphs of Enclosure 3, where the Holocene part usually consists of clay or sandy clay while the Pleistocene contains more sand. However, the fact remains that palynologically transgressive as well as regressive phases can be recognized in the drill hole sections (Wijmstra, 1969, 1971). Only very detailed sampling for mineralogical and palynological studies might throw some light upon this problem.

The sediments of the last interglacial, the Upper Coropina Formation, are divided into the fine sand of the Offshore Bar Landscape and the silty clays of the Old Sea Clay Landscape. The staurolite bearing marine silty clays have moved far up the rivers since they are found as far as Kaaimanston on the Coppename (MM-7, table 17) and west of the bridge across the Saramacca (KK 413, table 18). They were later covered by sandy, and locally even by coarse gravelly fluvial deposits (1.4.3). The fine sands of the Offshore Bar Landscape have been transported by beachdrifting and are of eastern origin. They have about the same association from Lelydorp to the Coppename River (Kalebaskreek) but contain slightly more sillimanite west of the Coppename (Zonneveld, 1969), showing some sediment supply from this river. The Upper Coropina sand consists of stable minerals only. However, in 2.4.5.2 it has been shown that at some depth the sand contains hornblende, epidote and garnet and thus closely resembles the fine sands of the Demerara Formation. It is assumed that they have the same origin.

With the lowering of the sea-level at the onset of the last glacial the sedimentation of clay went on for some time until the supply stopped for reasons that will be discussed in 4.8. On the newly formed coastal plain soil formation took place (Nota, 1969) under a poor grass savanna vegetation (Van der Hammen, 1963). During the low sea-level stage medium and coarse sand was deposited on the lower part of the shelf (Nota, 1957a, 1958b, 1969). It has been shown that this coarse sand was mainly supplied by rivers of Suriname and French Guiana (Krook, 1970a). The large sediment supply was mainly due to a more arid climate which favoured erosion (Damuth and Fairbridge, 1970; Krook, 1970a; Van der Hammen, 1972). The sands were transported to the west by beachdrifting. Staurolite bearing sands derived from the Marowijne and several French Guianese rivers have been found as far west as north of the Orinoco delta (Nota, 1958a,b; Krook, 1970a). This means that the process of beachdrifting was much more intensive during the last glacial than at present. Augustinus (1978) ascribes this to higher waves on the steeper shelf slope. However, it is suggested here that the increased action of sand transport along the coast has mainly been caused by the absence of mud. The cause of this absence will be discussed below (4.8). The clear sea water also allowed for the growth of a fringing coral reef along the coast (1.4.4).

4.7 The Holocene

According to Nota (1969) the Pleistocene medium to coarse sands were transported landward with the rising sea-level in early Holocene time and they covered the underlying weathered clays with a rather thin veneer. Some clay was deposited at a later date and mixed with the sands by burrowing organisms. The clay supply, however, was much less than at the present time and the fast sea-level rise during the Mara phase (10,000-6,000 y. B.P.) saw the formation of peat and clayey peat. At about 8,000 or 9,000 y. B.P. (1.4.4) there was a standstill during which the coarse sands of the delta of the Marowijne were deposited (Nota, 1971). At the same time fine, well sorted tidal flat deposits of local origin were laid down off the mouth of the Essequibo in Guyana (Nota, 1958a,b).

The sea-level reached its present position about 6,000 years B.P. and the accretion of the Young Coastal Plain started. All sediments came from the east. A rather high staurolite content in the fine sands was found as far as Nickerie in drill hole 5-72. Even the sandy ridges in NE Guyana contain a relatively large amount of staurolite (Bleackly, 1956a).

It has been shown in 2.4.5.4 that the composition of the coarse sandy ridges and the coarse sandy beaches does not differ basically, apart from the weathering of garnet. The sands probably have the same source. When the Surinam beaches are compared with the Marowijne sands and the beaches in French Guiana it is apparent that the coarse Surinam beach sands are identical with the sands on the southern bank of the Mana River (fig. 24). They differ considerably from the Marowijne sands (fig. 21) by their lower epidote and hornblende content and by their much higher garnet content. This means that the sands have been mainly supplied by the Mana and crossed the mouth of the Marowijne. A small part moved in a southern direction along the west bank of the Marowijne. The fact that so much garnet is present in these sands indicates erosion from relatively fresh outcrops of the Armina Formation. The low feldspar content is probably due to the fact that the feldspar of the staurolite schists is of a very unstable type, viz. oligoclase-andesine (IJzerman, 1931). It was shown that some sandbars occur in the Marowijne which have probably been derived from this river. On the other hand fine sandy clays occur in the estuary which are, at least partly, of marine origin. At present probably no Marowijne sand reaches the sea. Sand from the other rivers as well does not reach the coast in any appreciable quantities. On the contrary, fine sand as a constituent of marine clay moves far into the estuary part of the rivers. In the lower Corantijn allochthonous staurolite bearing sand is even found south of the marine clays (fig. 16). During the Moleson phase, however, the original wide estuary of the Corantijn was largely filled up (Pons, 1966) and extensive sandy river banks were formed (see Enclosure 1), apparently by sands supplied by the river. River banks of smaller dimensions were deposited in subrecent times (2.3.5.3, Corantijn River). Near the mouth of the Coppename River some river sand was mixed with larger masses of sand derived from the east (2.4.5.4). At the same time some coarse staurolite bearing sands entered the then N-S directed Saramacca estuary by tidal currents. A later supply of mud caused this river to deflect to the west and the sands were left as a witness of a former river mouth.

Before discussing the origin of the fine sands in beaches and ridges attention will first be paid to the provenance of the marine clays, since these form the bulk of the deposits of the coastal plain.

The first to mention the provenance of the mud on the coast of the Guianas was Lyell. In Principles of Geology, vol. 1 (1832) he wrote that these muds had been supplied by the Amazon River. Several later authors were of the same opinion (Reyne, 1961; Diephuis, 1961; Nedeco, 1968; Allersma, 1969; Eisma and Van der Marel, 1971). Bakker (1963a,b), however, pointed out that the Amazon could not possibly have provided all the mud since the clay minerals of the coastal plain of Suriname showed a composition of kaolinite, illite and montmorillonite whereas the Amazon would have transported only kaolinite. He suggested a supply of illite and montmorillonite from Africa, transported by marine currents.

Bakker's theory found little support. Papers of later dates all claimed the Amazon as the source of the marine clays deposited at the Guiana coast. This is not surprising since the muddy water can actually be followed from the mouth of the Amazon to the mouth of the Orinoco. Brinkman (1967) showed that the clays of the Young Coastal Plain in the Guianas and the Amazon River belonged to one clay mineral association consisting of about 40% kaolinite, 20% illite, 20% montmorillonite and 20% quartz. Surinam rivers supply mostly kaolinite and some quartz and the quantities are small compared to the clays provided by the marine currents. Eisma and Van der Marel (1971) obtained comparable results, but with lower kaolinite and higher montmorillonite contents.

It is probable that more than one weathering regime is responsible for the clay mineral composition. According to Gibbs (1967) the montmorillonite is mainly derived from the Andes, where it is a weathering product of "calcic rocks". Although in the tropical lowland almost only kaolinite is formed, the total supply by rivers draining this large area is small due to the low clay content of these rivers. Most kaolinite therefore is derived from the Andes and the Andes foreland because of the high erosion rate. The illite and chlorite of the Amazon are products of physical breakdown of primary mica and crystalline chlorite. Both minerals occur in all grainsize fractions. Chlorite is mainly derived from the Andes while most illite is supplied by the Rio Madeira.

The work of Irion (1976b), who studied the clay minerals of both soils and suspension material in rivers, provided a somewhat different picture. Table 10 shows the relative amounts of montmorillonite, illite, chlorite and kaolinite in soils and rivers. The present soils in the Andes have about equal amounts of all clay minerals. The rivers, however, contain mainly chlorite and illite. This means that both montmorillonite and kaolinite are weathering products of present soil formation, but that depth erosion provides mainly chlorite and illite. The part of the sediments derived from the Andes is relatively small. Much material is supplied by rivers draining the SW Amazon Lowland (Acre). This area is underlain by Tertiary lacustrine and marine sediments with intercalations of volcanic material. During a former (probably drier) weathering regime clays were formed consisting mainly of montmorillonite. In the actual soils illite and kaolinite occurs. These soils are rather thin because of the impermeability of the underlying montmorillonite clays. The large scale (rather deep) lateral erosion provides much of the old weathering suite and the resulting material in the rivers is very rich in montmorillonite.

	Soils				Rivers			
	M	I	C	K	M	I	C	K
Andes	x	x	x	x	(x)	xx	xxx	(x)
SW Amazon Lowland	(x)	xx		xx	xxx	x	(x)	x
Solimões					xxx	x	(x)	x
Beni-Madeira					x	xxx	x	x
Amazonas					xx	xx	x	x

Table 10 Schematic representation of the relative occurrence of clay minerals in soils and in suspension material of rivers in the Amazon Basin (according to Irion, 1976b)

(M = montmorillonite, I = illite, C = chlorite, K = kaolinite)

The same composition is found in the Solimões. The Madeira supplies mainly illite. As a result of the confluence of both rivers the Amazon shows about equal amounts of montmorillonite and illite and less chlorite and kaolinite.

Gibbs (1967, 1968) pointed to the fact that the suspension material of rivers coming from the Andes resulted from physical weathering. Garner (1959, 1968), however, held that the material from the Andes is mainly an erosion product of the large valley fills in the Eastern Peruvian Andes which were deposited during a former, drier, climatic phase. From the unstable nature of the minerals in the sediments derived from the Andes no conclusions can be drawn, since subrecent arid (and glacial) accumulates would supply the same immature associations as products of present physical weathering.

The provenance of the fine sands in beaches and ridges is probably related to the provenance of the clays. The origin of the fine sands has been a problem for a long time. Since most of the large ridge bundles are situated west of the past and present river mouths, the conclusion was generally drawn that the sand of the ridges had been supplied by these rivers (Geyskes, 1952; Brouwer, 1953; Zonneveld, 1954; Van der Eyk, 1957; Van der Voorde, 1957). Van der Eyk stated that the supply by local rivers had been proven mineralogically. However, no river-bed samples had ever been studied. Krook (1969a) showed that all ridges were of about the same association which was quite different from the compositions of most of the rivers. He also found some similarity with the then known data of the Suriname River (Krook, 1969a, written in 1966), but at a later date (Krook, 1968) he suggested that the sands had been provided with the marine clays which had been supplied by the Amazon River. In 1968 Augustinus (personal communication) found pockets and thin layers of fine, green, chamosite bearing sand in the coastal clay deposits. Similar sands had been found by Nota (1958a) in nearshore deposits of Guyana. Since these could be proved to be derived from the 12 fathom tidal flat off the Essequibo mouth, the same mode of origin was proposed for the fine sands of Suriname (Krook, 1970a). Fine green "glauconite" sands were indeed found on the surface of the Marowijne delta (Vervoort, 1971). Unfortunately, however, no samples were collected for mineralogical investigations needed to compare them with the fine coastal sands and to find a clue to their provenance.

Only recently the author obtained several samples from the Amazon mouth area, the Brazilian shelf off the Amazon and the Pará River, and the shelf of French Guiana. The results of the analyses are shown in figure 27 and have been discussed in 2.4.5.6.

The origin of the fine coastal sands is now assumed to be as follows: Part of the fine sands is derived from the Amazon drainage area and is transported, mainly in suspension, with the silty clays. The sediments are deposited near the mouth of the Amazon, after which a part is resuspended by waves and currents and transported along the coast of the Guianas with the Guiana Current (Milliman et al., 1975; Eisma and Van der Marel, 1971). Along the coast of French Guiana fine sand is taken up from the shelf. This sand was probably deposited during the early stages of the Holocene, but it also contains authigenic chamosite pellets, characteristic constituents of the fine coastal sands.

Eisma (1967) has shown that even at a depth of 35 m the bottom currents are strong enough to transport fine sand. These currents are about parallel to the coast but have a landward component. Some sand may also be added by abrasion of promontories of Precambrian rocks and by the present supply of local rivers. In this way a mixture is formed of the Amazon minerals (mainly epidote and hornblende) and typical shield minerals such as zircon, tourmaline, rutile, some metamorphic minerals and - near the western part of French Guiana - staurolite and garnet. The medium sandy beaches which form a separate sedimentary unit with respect to grain size and mineral composition, are probably also a mixture of shield minerals and Amazon minerals, albeit that the latter are coarser than the average Amazon mineral grains.

The low feldspar content (about 6%) in the fine sand of the ridges indicates that in the mixture of shelf sand and Amazon derived sand the first predominates. The high content of unstable heavy minerals from the Amazon in the mixture is not surprising, since immature sands usually have a higher total content of heavy minerals than mature sands.

The mud containing the fine sand forms large banks on the coast from which, during erosion phases, beaches are formed (Diephuis, 1966; Pons, 1966). The process of the formation of beaches and ridges is discussed in great detail by Augustinus (1978).

Since the concentration of beaches and ridges west of the past and present river mouths cannot be ascribed to local sediment supply, there must be another explanation for their formation. It is obvious that the direction of the wind plays an important role. West of the rivermouths the NE trade wind is about perpendicular to the coast which results in a strong wave action and, hence, a thorough separation of the sands from the mud. Beaches are formed and the clay is washed out and transported further in suspension.

4.8 Sediment supply of the Amazon River during the last glacial and the Holocene

There is now considerable evidence that during a part of the last glacial period the climate in tropical South America was more arid than at present (Van der Hammen, 1963, 1972, 1974; Mousinho de Meis, 1971; Wijmstra, 1971; Wijmstra and Van der Hammen, 1966) and a savanna and savanna woodland vegetation most probably had a greater extension. The climate and the resulting vegetation should greatly have favoured erosion (Krook, 1968b, 1970a,b). Coarse terrigenous sediments reached the coast apparently by means of braided rivers. They were deposited near the present shelf edge and transported to the west by beachdrifting. Probably at the same time fringing reefs occurred along the coast (Nota, 1958a,b; 1969), an indication of little clay supply. The absence of mud induced the present author to assume that the Amazon supplied less clay during the last glacial because of less chemical weathering and clay formation and less rainfall in the catchment area of the Amazon (Krook, 1968; 1970a). This reasoning, however, is not in agreement with the facts now known. According to Milliman et al. (1975) deposition of mud off the mouth of the Amazon and the subsequent resuspension and transport with the Guiana Current, as can be observed today, also occurred during the last interglacial. With the lowering of sea-level during the glacial this process went on and by the slow prograding of the coast a "mud wedge" was formed until the sea regressed to about 60 to 80 m below the present sea-level. At this depth the sediments were transported into the deep sea by way of the Amazon Canyon and smaller channels and the mud wedge stopped forming (Milliman et al., 1975). The Amazon Submarine Canyon extends from at least 50 m depth on the continental shelf down to approximately 1500 m. The sediments which were channelled through this and other canyons were deposited by turbidity currents on the huge deep sea fan which extends from the edge of the shelf down to the Demerara Abyssal Plain, the Amazon Cone (4.4 and fig. 30). Cores in the fan deposits show late "Wisconsin" (last glacial) grey clay with interbedded silt and sand covered by Holocene pelagic foraminiferal marl and ooze. This means that the Amazon Cone received terrigenous sediments only during the low sea-level stages (Damuth and Kumar, 1975).

During the last glacial extensive arkosic sands were deposited on the continental rise off NE South America, the Amazon Cone and the Demerara Abyssal Plain (Damuth and Fairbridge, 1970). Most of the deposits are within reach of the turbidity currents coming down from the shelf off the Amazon River. Damuth and Fairbridge ascribed the arkosic character to the relatively arid climate during the last glacial which would have caused large scale erosion of unweathered rocks of the Precambrian shield. Although at present the Amazon supplies sediments mainly derived from the Andes and the SW Amazon Lowlands, this would have been different during the low sea-level stages. The fact that the erosion increased due to a change of climate has been mentioned above (1.5, 4.6). However, the relict Pleistocene sands on the Surinam continental shelf are poor in feldspar (Nota, personal communication) and the provenance of the arkosic sands must be looked for elsewhere.

Irion (1976a) has shown that during the low sea-level stage of the last glacial the Amazon carved out a deep and wide valley in the deposits of the Alter do Chão (fig. 31). He states that the arkosic sands deposited off the Amazon mouth are erosion products of the unweathered Alter do Chão. If this were so, Amazon sediments deposited during older periods of low sea-level, would also consist mainly of erosion products of the Alter do Chão. However, it has been shown above (2.4.4, 4.4) that the Late Miocene and the Pliocene sediments of GLO-1 have a heavy mineral composition which is a mixture of minerals derived from the Andes and minerals derived from the Alter do Chão (fig. 31). It is rather improbable that the Alter do Chão supplied more feldspar than the Andes Mountains, since the feldspar content seems to increase with a decreasing content of heavy minerals from the Alter do Chão. It is also clear that the feldspar content is not as high as in the arkosic sands described by Damuth and Fairbridge (1970) off the coast of Northern Brazil, which attain average values of nearly 40%. Modern sediments off the mouth of the Amazon have about 20% feldspar while the content of a sample from a natural levee of this river was 36% (2.4.5.6, table 22). All this shows that the problem of the provenance of the arkosic sands has not yet been solved. It is proposed that heavy mineral studies be carried out on all sediments concerned.

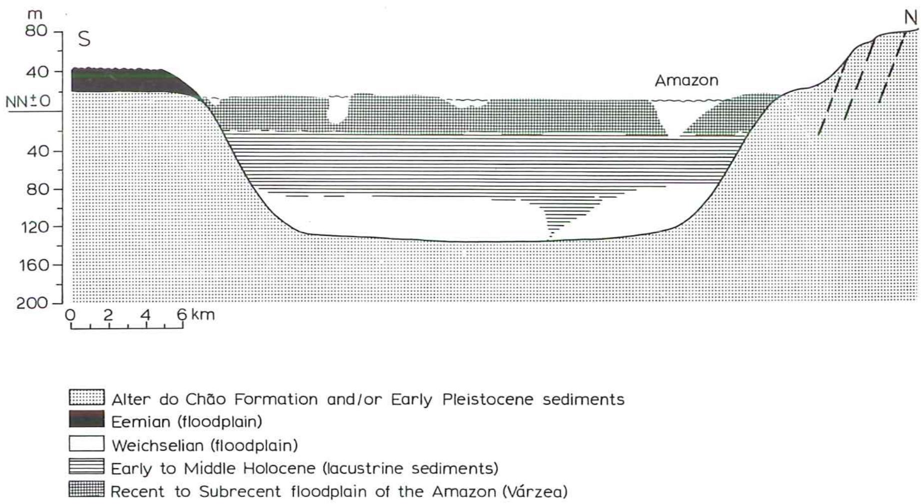


Fig. 31 Section through the valley of the Amazon, east of Manaus (after Irion, 1976a)

Milliman et al. (1975) found a band of arkosic sand across the shelf north of the Amazon mouth (fig. 25). This band contains more than 25% heavy minerals which belong to the highly unstable "Amazon Suite". It is unlikely, however, that these sands have been supplied by the Amazon since the association of heavy minerals is entirely different from the recent Amazon deposits. Enstatite, hypersthene and sillimanite seem to be derived from ultrabasic rocks, granulites and sillimanite gneisses, characteristic of the Precambrian Shield. However, these rocks are far from common and occur only locally on the shield. This means that the minerals have a rather restricted hinterland. Granulites occur in Amapá, where they are exposed in the valley of the Rio Falcino, a tributary of the Rio Araguari which discharges into the Atlantic Ocean exactly in line with the arkosic belt (fig. 26). The granulites contain hypersthene and diopside while a nearby gneiss contains hornblende (Scarpelli, 1969). Sillimanite is quite common in lesser quantities and is found in quartzites, schists, migmatites and granulites, all of which occur in the drainage basin of the Rio Falcino and the Rio Amapari, also a tributary of the Rio Araguari (Macambira, 1975). Enstatite was not mentioned by either author but since ultrabasic rocks are found in the south of Amapá their occurrence is quite probable. The minerals of the "Amazon Suite" must have been eroded somewhere from fresh, unaltered rocks. This is highly remarkable, even if it had taken place in semi-arid conditions during part of the last glacial. If so much pyroxene occurs, of course, the high feldspar content is hardly surprising.

It has been mentioned above that the Amazon River scoured out a large valley during the low sea-level stage of the last glacial. Toward the end of the Pleistocene and during the early Holocene the sea-level rose with a speed attaining 1 cm/year (Fairbridge, 1961). Obviously the sedimentation could not keep place with this fast rise and a large ria-lake originated with a surface of sbout 32,000 km^2 in the early Holocene, increasing to a maximum of some 80,000 km^2 at later times and even extending across the border of Brazil to Iquitos (Irion, 1976a, 1976c). With the decreasing rate of sea-level rising the lake began to fill up, but it was not until about 6,000 years B.P. that the present floodplain (várzea) was formed with numerous natural levees and várzea lakes - backswamps on Amazon scale (for descriptions on the present Amazon area see Sioli, 1975a, 1975b). The lake deposits are finer grained than the present floodplain deposits (fig. 31) and only the finest suspended matter was transported to the Atlantic Ocean (Irion, 1976a). This may have caused the very high montmorillonite content on the middle and outer shelf off the Amazon described by Barreto et al. (1975), since montmorillonite is the finest of the common clay minerals and probably stays the longest time in suspension. The fact that most of the Amazon sediments were deposited in the drowned valley of the Amazon may also explain why the sea water off the Guiana coast was still relatively clear when the water had already risen to about 20 m below the present sea-level, allowing for the growth of isolated coral reefs (Nota, 1969). It also accounts for the relatively poor content of clay in the early Holocene Mara deposits (1.4.2).

The following summary of the history of the last interglacial-glacial-Holocene cycle is probably valid for most earlier cycles: the Amazon sediment load reached the mouth of this river and part of it was subsequently transported by coastal currents. This process went on during the glacial induced regression until at a certain level the sediments crossed the shelf through the Amazon Canyon and moved down the slope by turbidity currents to build up the Amazon Cone further. Because the Amazon formed a deep and wide valley in the Alter do Chão Formation, the resulting sediments were a mixture of erosion products from this Formation and the detritals derived from the Andes. During the subsequent fast sea-level rise the Amazon valley became an extensive lake and only little clay in suspension reached the ocean. Probably during this rise much coarse immature sand, supplied by the Rio Araguari, was deposited on the continental shelf. When the sea had about attained its present level, the drowned valley of the Amazon was filled up, a floodplain was formed and the sediments again reached the ocean.

5. SEDIMENTARY HISTORY OF THE COASTAL AREA

As Wong (1976) stated, the history of the Guiana Basin probably began in Late Jurassic-Early Cretaceous time with the separation of America and Africa. This was accompanied by steep faulting in the coastal areas which went on to the Early Tertiary. The faulting resulted in the formation of the Guiana Basin in the north, several grabens and horsts in the area off the mouth of the Amazon River (Aguiar et al., 1969; De Boer et al., 1965; Van der Hammen, 1969) and the Takutu Graben in Guyana (Van der Hammen and Burger, 1966; McConnell et al., 1969). The steep slopes on the NE and E sides of the Guiana Marginal Plateau may also date from this time. Collette et al. (1971) already pointed to the fact that the depth contours to the SE form fairly straight lines. It is significant that these are in direct line with faults in the Amapá Graben (Aguiar et al., 1969). The basins and grabens received a large supply of terrigenous sediments. The coarse sedimentation did not only effect the coastal areas. In the Middle Amazon Basin the Alter do Chão was deposited, consisting of clays, silts and arkosic sands, derived from the Brazilian Shield and the Guiana Shield. Palynological studies by Daemon (1974) have shown that the fluvial and lacustrine sediments are of Late Albian, Cenomanian and Turonian age and were deposited in a dry tropical to subtropical environment. The Amazon River did not at that time exist and the South American continent drained to the west into the Pacific Ocean.

In the present coastal plain of Suriname only sediments of a Late Cretaceous age overly the Precambrian basement. They consist of coarse continental deposits. On the outer shelf (site GLO-1) a marine platform sedimentation prevailed from Early Albian to the Paleocene (Belsky et al., 1972). In the Bacia de Marajó near the mouth of the Amazon continental deposits of Early and Late Cretaceous age were covered by marine Maastrichtian sediments. After this marine invasion Tertiary continental sediments were deposited up to the Early Miocene (Aguiar et al., 1969).

At the Cretaceous-Paleocene transition the Guiana coastal area, and most probably the greater part of the shield, underwent a considerable uplift. This was followed by a phase of intense erosion which removed the uppermost 150 m of the Maastrichtian deposits (1.4.2), while on the shield the formation of the Early Tertiary Surface started which went on to the Late Eocene (1.6).

During the Paleocene and the Eocene there were two transgressive phases. Their influence is found as far south as the Onverdacht mining area where clays were deposited in a brackish environment (2.4.3; 4.3). Coarse sands, probably arkosic, laid down on top of the clays, marked a period of increased erosion. The sea gradually withdrew from the coastal plain. During the following regression intense weathering lead to deep kaolinization in the northern part of the coastal plain while in the southern part bauxite was formed on the coarse sands. The shape of the bauxite bodies suggests that a drainage system developed already before the bauxite formation (Aleva, 1965; Aleva et al., 1969). It is remarkable that locally, below the bauxite, lignites were found which were hardly leached and contained well conserved pollen (Wijmstra, 1971). Bauxite formation was not confined to the coastal plain. It occurred also on the Precambrian Shield, on those parts of the Early Tertiary Surface where basic rocks prevailed.

The age of the bauxitization of the Alter do Chão Formation in the Middle Amazon Area (Rio Trombetas deposits) is probably the same as the age of the bauxite formation on the Guiana Shield and in the Guiana coastal plain (4.4), viz. Late Eocene - Early Oligocene. In the Amazon area the bauxite formation also started after the dissection of the landscape had begun (Dennen and Norton, 1977).

During the Paleocene the Surinam coast had a WNW-ESE direction, even during the transgressions, when at site CO-1 a lagoonal environment prevailed (Wong, 1976). After the limestone of the Paleocene coarse, barren sands of eastern origin were deposited from the Eocene to the Early Miocene (4.4).

After the formation of the bauxite in the Suriname coastal plain the erosion proceeded and the steep cliffs of the bauxite remnants created a sort of mesa landscape. The sea transgressed again and sands - presently known as the A-Sands - were deposited along the coast which was situated somewhere halfway between the present coast and the bauxite deposits (see figure 3). The sands probably included former erosion products which moved landward with the transgression. They were transported along the coast by beachdrifting. The exact age of the transgression is not known. According to Hallam (1963) the Middle Oligocene was transgressive in the Caribbean while the Late Oligocene showed a regression. No traces of a regression, however, have been found so far. The transgression proceeded during the Early Miocene and clays were deposited on top of the A-Sands, the Intermediate Clays. At the same time marine and deltaic sediments were deposited in the Amapá Graben and the Mexiana Graben north of the Marajó Basin in Brazil. The fine grained deltaic deposits containing lignite and scattered wood and other plant fragments, fresh water fossils and even some bones, probably show the breakthrough of the Amazon River (4.4). There is evidence that the Intermediate Clays were also derived from the Amazon. The clays, containing sand lenses, partly beach sands, transgressed far to the south and even covered the bauxite. The situation in the coastal plain was more or less like the present one. On the northern part of the shelf, however, the conditions were different from the present ones and limestone was deposited in a carbonate platform environment (2.4.4; 4.4).

During the Early Miocene transgression a great change occurred in the vegetation of the area. The post-bauxite vegetation was different from the pre-bauxite one. For the first time modern mangrove elements *(Rhizophora)* appeared at the coast (Wijmstra, 1971). Other floral elements in these areas are the grasses which appeared mainly during regressive phases from the Early Miocene to the Present.

During the Aquitanian the climate was more humid than the present one. In the Burdigalian it changed to a climate with more pronounced dry and humid seasons (1.4.2; 1.5, table 7). The sea started to regress, probably aided by an uplift of the area. This was followed by a stage of denudation during the Langhian (2.4.4) which removed about 60 m from the coastal deposits including the Early Miocene sediments covering the bauxite. This severe denudation explains the fact that the Early Miocene sediments (E-pollen zone) are only found in some deep depressions in the basement underlying the northern part of the Savanna Belt. During the denudation the carbonate deposition on the shelf was replaced by terrigenous sedimentation: sand at site CO-1 and silty marl and some sand at MO-1 and SON-1 (2.4.4). Large scale erosion of the Lower Miocene deposits also occurred in the coastal area of Brazil (4.4).

After the Langhian there was another transgression which reached as far as south of Sabana on the Tibiti. The sedimentation was resumed in the coastal plain (F-zone) while limestone was again deposited on the shelf.

Mineralogically beachdrifting can be shown by the occurrence of staurolite in Oligocene (?) and Miocene deposits. In the western part of the coastal plain this influence is negligible and the sands are of more local origin.

The sediments in TN-1 are entirely different from the deposits in the other drill holes. The sands are finer grained and the composition shows a considerable mixture of Amazon derived minerals, such as epidote, green hornblende and - in lesser quantities - basaltic hornblende, clinozoisite and chlorite. These fine grained sediments have probably been deposited in a lagoon or an embayment.

The Late Miocene showed a large regression and no deposits were laid down in the present coastal plain area, while on the shelf terrigenous sedimentation increased again. Judging from the coarse sand at CO-1 this site was still situated close to the shore and the coastline probably still had a WNW-ESE direction. This opposed Wong's opinion that the coast had already obtained its present position in the Early Miocene (Wong, 1976). This assumption was based on the similar carbonate deposition at the different sites on the shelf.

During the Late Miocene the sediments supplied by the Amazon were no longer deposited near its mouth but were transported down the continental slope by turbidity currents. They built up a very extensive submarine fan, the "Amazon Cone" (4.4). Part of the sediments were transported by marine currents in a NW and W direction along the continental slope where they were eventually deposited. In later stages of low sea-level occurring during the Pliocene and the Pleistocene this process was repeated and resulted in the formation of an "Amazon Blanket" which is nearly 2000 m thick on the present outer shelf of Suriname (site GLO-1). It probably thins out to the north and might cover the greater part of the Guiana Marginal Plateau and the continental slope and rise. This illustrates the origin of the asymmetrical shape of the plateau, viz. a steep east flank and a gently shelving slope to the west. It confirms the suggestion of the influence of the south-easterly current by Collette et al. (1971). The middle shelf area was probably hardly influenced by the Amazon sediments. Only CO-1, however, has been studied mineralogically. The small samples of relatively coarse sand contained very few heavy minerals in the deposits of relevant age. The coarse grainsize and the paucity of heavy minerals are in great contrast with Amazon deposits which are fine grained and have a high heavy mineral content. SON-1 and MO-1 both show marl in the Upper Miocene which may have some Amazon derived clay, but due to lack of data this can neither be proved nor disproved.

The Early and Middle Miocene deposits in the coastal plain are covered by Pliocene sediments. The base of the Pliocene Upper Coesewijne Formation in the northern part of the Savanna Belt consists locally of fine to coarse sandy marine clays or coastal sands, indicating a transgression. This transgression reached as far south as the preceding one during the Middle Miocene. Mineralogically the effect of beachdrifting can be shown. This transgression was followed by a major regression during which coarse sandy sediments of continental origin were deposited. The sands and clayey (kaolinitic) sands are erosion products of the hinterland. They are generally considered to be the correlative deposits of the Pliocene Late Tertiary II Level which was formed after an uplift of the shield (1.6). On closer observation, however, it appears that matters are more complicated. Parts of the Late Tertiary II Surface are covered with a lateritic duricrust. This crust originally had a much wider extension but most of it has been removed by erosion during the Pliocene and the Quaternary. In several parts of the Savanna Belt laterite capped hills which are erosion remnants of the Late Tertiary II Surface, are surrounded by the white sands of the Upper Coesewijne Formation. The same has been described by Bleackly (1956b) in Guyana. In some places large areas of the kaolinitically or lateritically weathered surfaces have been buried by the white sands. The formation of erosion terraces in the Upper Coesewijne Formation along the Coppename River removed the white sands locally from the weathered surfaces (Krook and Mulders, 1971, fig. 4).

From the above mentioned observations and the fact that at the base of the Upper Coesewijne Formation marine transgressive sediments occur (see 4.5), the following succession of events may be suggested: after the formation of the Late Tertiary II Surface, essentially a pediplain, a change of climate to more humid conditions caused large scale laterite formation and, in places, deep kaolinitic weathering, depending on the source rock. The crust was largely eroded, after which the sea transgressed far inland. During the subsequent regression another erosive phase provided much terrigenous material which was transported by braided rivers and - at a later date, with a desiccation of the climate - probably by ephemeral streams. The coarse, poorly sorted sands and clayey sands were deposited in a zone which is now known as the Savanna Belt. The decrease in the distance of the source of the sediments is reflected in the nature of the heavy minerals which, at several localities, are of a more local provenance in the upper few metres than at greater depth (2.4.4).

At some places in the Savanna Belt, especially near the large rivers, a basal gravel occurs varying in thickness from some cm to several m. This gravel locally seems to contain exploitable amounts of alluvial gold derived from quartz veins connected with granite intrusions (1.7.3).

The deposits of the Upper Coesewijne Formation are extremely weathered and contain only stable minerals. No feldspar occurs in the light fraction while the heavy fraction contains zircon, tourmaline, rutile, metamorphic minerals, some monazite, spinel etc. Moreover the clay fraction contains only kaolinite (Levelt and Quakernaat, 1968). The sediments were probably already in a relatively weathered state when they were eroded from the deep regolith on the crystalline rocks.

The Quaternary saw a succession of transgressional and regressional phases and an alternation of climates varying from very humid to semi-arid. The original picture of pluvials corresponding with interglacials and interpluvials with glacials must be abandoned. According to Van der Hammen (1974) the major part of the last glacial in the Northern Andes had a climate with a higher effective precipitation than the Holocene. During the periods of maximum extension of glaciation, however, the climate was much drier. Less is known about the tropical lowland, but during part of the last glacial the climate was considerably drier than the present one. During these dry stages the tropical rainforest locally made way for savannas in at least several parts of South America. The forest remained intact in "forest islands". In these "refuges" as they are called by biologists, populations of species of vertebrates and invertebrates belonging to the forest biotope seemed to have been isolated from each other for thousands of years. This phenomenon was repeated several times during the Quaternary and apparently resulted in a large scale "speciation" (Haffer, 1969; Vuilleumier, 1971; Müller, 1973; Vanzolini, 1973). During the humid periods xerophytic floral elements could survive in the refuges formed by the bare rocks of the inselbergs in granitic terrains and on "savanna islands" in the forest. This also happens at the present time (Schulz, personal communication).

During the Quaternary the Upper Coesewijne Formation underwent considerable change. Terraces were formed at several levels, while river captures eliminated several consequent rivers of lesser size. The dry stages of the Pleistocene should have had a significant influence on the sandy deposits. The occurrence of climatologically induced savanna vegetation on the sandy soil should have lead to large scale podzolization which may be the explanation of the origin of the extremely bleached "white sands". These are mainly found in the higher interfluvial areas of the Savanna Belt while the more loamy "brown sands" occur near the creeks and the rivers. There is no doubt that the natural pattern of the white and brown sands has been greatly influenced by the annual burnings which have been practised by the Amerindians for centuries. More details on the Upper Coesewijne Formation are given by Krook and Mulders (1971).

Along the rivers the erosional and depositional processes during the pluvials and those during the interpluvials differed widely. De Boer (1972) studied the morphology of the valley of the Marowijne and found that during the dry stages pedimentation and the formation of coarse grained alluvial fans occurred. During the subsequent humid stages the pediments and alluvial fans were covered by fine grained terrace sediments. Gradually the river incised after which the same succession occurred at a lower level.

Recently studies on the morphology and soils of parts of the drainage areas of other rivers (Suriname, Saramacca, Coppename) have been carried out by graduates of the Institute of Earth Sciences of the Free University at Amsterdam and the results are now being evaluated. Several surfaces and summit levels have been found, but the origin of these morphological features is still incompletely understood. Terrace deposits are common in some areas whereas in others they are comparatively rare.

Bigarella et al. (1965) dated the formation of pediments during the glacials and the incision during the interglacials in Brazil. The formation of fine grained terrace deposits was not mentioned and apparently is of minor importance.

The author studied the deposits of some creeks coming from the Fatoe Swietie Hills in SE Suriname (fig. 1), an area where gold has been exploited since the last quarter of the nineteenth century (Krook, 1968b, 1970b). The base of these deposits usually consists of coarse gravel and even boulders while the upper part comprises mainly kaolinitic clay. The gravels were found to contain a high content of heavy minerals, including gold. The overlying fine grained deposits were almost sterile with respect to the gold. The conclusion was drawn that the mineral rich gravels on the bedrock are the result of favourable climatic conditions in the past. Indeed, many alluvial placer deposits in present-day humid tropical areas seem to have been climatically controlled.

In the coastal plain of the Guianas deposition of clay and some sand occurred during the high sea-level stages while erosion prevailed during the regressions. The probable succession which can be deduced from the events during the last interglacial transgression, the subsequent regression and the Holocene transgression, will be discussed below.

The sediments of the present Old Coastal Plain were deposited during several stages of high sea-level in the Pleistocene. In the southern part deeply weathered clay of the Lower Coropina Formation is exposed but its boundaries have not been mapped. On aerial photographs the Lower Coropina Formation cannot be distinguished from the Upper Coropina Formation. The age of the latter is unknown but it was probably deposited during one of the older interglacials. The clays were deeply and intensely weathered during one of the following low sea-level stages (1.4.2). They are overlain by the Upper Coropina sediments laid down in the coastal plain during the last interglacial. Their depositional history is rather well known. During the transgression the dark Onoribo clays were deposited, rich in organic matter and pyrite, a typical rising sea-level facies. When the sea-level had reached its maximum elevation and remained more or less constant, the sediments of the Santigron phase were deposited, showing offshore bars near the coast and more or less extensive flats of marine silty clays at the landward side. The offshore bars consist of well sorted fine sand in the central part of the coastal area while in the eastern part they are coarser grained.

At the beginning of the regression of the last glacial Amazon sedimentation went on as before. The mud wedge off the mouth of the river gradually moved seaward and a great part was still transported along the coast to the Guianas. When the sea had attained a level of about 70 m below the present one, however, the sediment load went down the Amazon Canyon and was deposited on the Amazon Cone and in the adjacent basins (4.8). As during the other low sea-level stages a part of the sediments remained in suspension, drifted in a northwestern direction and came to rest on the continental slope and the Guiana Marginal Plateau.

During the period of low sea-level the Amazon River, which had a very low gradient, scoured out a deep and wide valley in partly unweathered deposits of the Alter do Chão Formation. This probably added some feldspar rich sands to the Andean Amazon sediment load. The resulting sediments, deposited off the mouth of the Amazon, are of arkosic composition. However, no heavy minerals of the sediments of the last glacial have been studied due to the lack of samples and more definite conclusions can only be drawn after such a study.

During the low sea-level weathering and soil formation occurred on the coastal plain and a redbrown soil with iron concretions was formed on the recently deposited clays of the shelf. In the coastal area incision of the rivers took place and the tributaries showed a high degree of headward erosion. The deposits of the Upper Coropina Formation were severely eroded, partly under relatively dry conditions, and erosion remnants remained, varying from some tens of metres to several kilometres in width.

Toward the end of the Pleistocene the sea started to rise with a speed averaging about 1 cm/year. This rise, however, was far from uniform. This may be concluded from the occurrence of remnants of coral reefs at certain depth, of submarine terraces and a drowned delta (1.4.4). Two radio-carbon datings from reef like material occurring at a depth of about 80 m on the western Guiana shelf show ages of 11,560 and 17,550 years respectively (Nota, 1955a,b). However, the nature of the material and its relation to the sea-level are too uncertain to use for drawing a sea-level curve. Furthermore nothing is known about the ages of the submarine terraces.

When the sea-level was from about 60 to about 90 m lower than at present and the climate probably drier, relatively large scale erosion took place on the shield and the rivers supplied coarse sand to the coast. Since the sediments were mainly derived from the erosion of a thick regolith cover, the sands were rather mature and contained only little feldspar. On the coast they drifted westward under the influence of the trade winds. Since the water was relatively clear due to the lack of Amazon mud, corals built colonies and formed a fringing reef along the coast.

During the transgression the supply of sediments by the Amazon could not keep pace with the fast rise and the Amazon valley drowned and became an extensive ria-lake. Since most of the sediments were deposited in this lake, only a fraction - obviously very fine - of the supply reached the ocean.

Northeast of the Amazon mouth arkosic sands were deposited with a highly immature heavy mineral association, viz. hornblende, enstatite, hypersthene and sillimanite, indicating derivation from ultrabasic and high grade metamorphic rocks. An ancient bed of the river which supplied the arkosic sand starts just off the Rio Araguari. Since granulite and sillimanite gneisses occur in the drainage basin of this river and ultrabasic rocks occur just south of it, a rather local provenance of the arkosic sands may be assumed. The cause of the erosion of a relatively large area of unweathered bedrock, however, is not known.

Since most of the sediments of the Amazon were deposited in the drowned valley during the fast rise of the sea-level, the Guiana shelf also received very little clay supply. A part of the old coastal sand and newly supplied sand moved landward with the transgression and formed a thin blanket on top of the weathered clays deposited during the preceding drop of the sea-level (4.7). A fossil coral reef found at a depth of 26 m also points to relatively clear water. However, the conditions for coral growth obviously were not optimal since the fringing reef, formed during the low sea-level, could not keep pace with the fast rising ocean and consequently no barrier reef was formed.

Stages of relatively slow rising of the sea or even standstills also caused the formation of submarine terraces (1.4.4). During a standstill at about 22 m below the present sea-level a tidal flat was formed off the Essequibo River in Guyana. The age of this standstill was estimated at about 8000 y. B.P. by Nota (1957a,b) and at about 9000 y. B.P. by Van der Hammen (1963). The first would be in agreement with a standstill or even a temporary lowering of the sea-level to about -20 m found by Fairbridge (1961) and Mörner (1969). The Marowijne River formed a large delta at about the same time (Nota, 1971). The great sediment supply of the Marowijne was not equalled by the other Surinam rivers. This explains why the western half of the Surinam shelf has an erosive character, while the eastern part is predominantly depositional.

During the later stages of the sea-level rise the Mara Deposits, comprising peat and pyrite clay, were formed in the Young Coastal Plain.

When the sea-level attained its present level about 6000 years B.P. the large drowned valley of the Amazon was filled up and the present Amazon riverplain started to form. Consequently more sediments reached the sea and a new mud wedge was formed at the mouth of the river (4.8). This again lead to increased sediment supply to the Guiana coastal plain. A different kind of facies was now laid down with clays poor in pyrite. These Coronie Deposits can be divided into three phases, the Wanica phase (6000-3000 y. B.P.), the Moleson phase (2500-1300 y. B.P.) and the Comowine phase (about 1000 B.P. to present). This division is mainly based on the character of the morphology and the soil formation (1.4.2). The depositional phases are separated by erosional phases, possibly during intervals of slightly lower sea-level. However, there has been no evidence of any considerable emersions as found by Fairbridge (1976) on the coast of Brazil (Roeleveld, personal communication).

At the beginning of the Wanica phase all the rivers still debouched directly into the Atlantic Ocean. The large sediment supply from the east, however, gradually forced the smaller rivers to deflect to the west and flow parallel to the coast. The probable order of deflection, as deduced from the Geomorphological Soil Map of Northern Suriname (Pons et al., 1972), is: Wanica phase: Cottica and Perica, Coesewijne; Moleson phase: Maratakka and Nickerie, Nanni Creek; Comowine phase: Commewijne, Saramacca.

During the Moleson phase the Corantijn River had a very wide estuary. Apparently the river supplied a relatively large amount of sand which was deposited as sandy river banks marking the stages of the filling up of the estuary (4.7).

Every river has its own mineral association, reflecting the lithology of the hinterland (2.4.5.3). Besides zircon, epidote and hornblende, metamorphic minerals occur. The rivers in Western Suriname supply sands with relatively high contents of sillimanite, derived from the gneisses of the Coeroeni area and the Bakhuis Mountains. In Eastern Suriname staurolite prevails. In the estuaries fine sandy clays occur which are mainly of marine origin. Besides a high content of zircon they have some staurolite, indicating a supply from the east. The Saramacca riverbed upstream from Uitkijk has a thin cover of sands containing much staurolite, on an old iron crusted surface. The sand was supplied by coastal and tidal currents when the mouth of the river was still near Uitkijk. The proper Saramacca sands have a different composition and show mainly zircon, epidote and hornblende, minerals of granitic origin.

The deposits forming the coastal plain consist mainly of clay while the sandy ridges or cheniers mark the old coastlines. The fine grained ridges from the Suriname River to the west all have the same association (2.4.5.4). The sands are a mixture of Amazon derived sand containing mainly epidote and hornblende, and old continental shelf deposits of Precambrian Shield origin which contain zircon, staurolite, tourmaline, garnet and rutile (4.7). The medium to coarse sandy ridges in the eastern part of the coastal plain are rich in staurolite.

The present Surinam coast shows an alternation of erosive parts and accretionary parts. Accretion may be by mud in the form of mudflats or by sand in the form of beaches (Augustinus, 1978). The fine sandy beaches, which occur mainly on the western part of the coast, have the same provenance as the fine sandy ridges. The coarse sandy beaches, on the eastern part of the coast, have probably been mainly derived from the Mana River, since they show the same mineral composition of staurolite and garnet. The Marowijne apparently supplied only very small amounts of sediments after the deposition of its large delta at about 8000 y. B.P.

The effect of weathering in the Young Coastal Plain is shown by the lack of garnet in the sands of the Wanica phase, while the A-horizons of soil profiles have almost no epidote and hornblende left (2.4.5.4).

During the Holocene the climate in South America was far from stable. In Suriname so far there have been no indications of dry intervals, but they have been found in other parts of South America. Van der Hammen and Gonzales (1960) showed a succession of dry-wet-dry-wet intervals during the Holocene in the Andes in Colombia from pollen of the Sabana de Bogotá. This succession seems to correspond with the European Boreal-Atlantic-Subboreal-Subatlantic. There are some lowland data from Colombia and Guyana. Pollen from the Llanos Orientales in Colombia show dry intervals from 5000-3800 y. B.P. and from 2400-2000 y. B.P. In the Rupununi Savannas of Guyana several dry stages with extended savanna vegetation in the Holocene could be shown (Wijmstra and Van der Hammen, 1966). Bigarella et al. (1969) noted that the last fluctuation toward dryness in Eastern and Central Brazil ended about 2400 y. B.P. This statement was based on the data of the last extensive solifluction and landslide movements. According to Meggers (1975) the most recent episode of forest fragmentation in Brazil due to drier climatic conditions was from about 3500-2000 years ago and had serious consequences on the diversification of the Amerindians of Arawakan and Tupí stocks.

As far as we know there seems to be no relationship between climatic stages and sediment supply on the coast of Suriname. However, there might be a connection between a relatively dry Boreal and the formation of the Marowijne delta due to increased erosion and sediment supply. Without any direct climatic indications from Holocene deposits in this area, however, this reasoning is highly speculative.

6. SOME REMARKS ON DENUDATION SURFACES AND THEIR CORRELATE DEPOSITS

The oldest denudation surface that has been distinguished in several parts of the world is the Gondwana Surface of Mid-Jurassic to Early Cretaceous age (King, 1967). Remnants of this surface also occur on the South American continent (King, 1967; Mabesoone et al., 1977). The surface has been best preserved at the base of the Early Cretaceous deposits as a regional erosional unconformity (Mabesoone et al., 1977). It is tentatively suggested here that his surface also occurs at the base of the sediments forming the Guiana continental shelf and the Guiana Marginal Plateau. The deepest drill hole at the edge of the shelf (GLO-1) only got as far as the Albian (fig. 9) but since a total thickness of about 10 km has been presumed (Collette, personal communication), the presence of the whole sequence of the Lower Cretaceous and possibly some Upper Jurassic may be expected on top of the Precambrian Shield. Shallow water sandstone of Late Jurassic age has actually been dredged from the steep northern slope of the Guiana Marginal Plateau (Fox & Heezen, 1970).

On the Guiana Shield in Guyana the Gondwana Surface may be present with a few remnants of some 900 m high (Mc Connell, 1966; Berrangé, 1975). According to the latter author some summits in the central part of Suriname, including the Tafelberg, may also belong to this surface. King (1962, 1967) dated the surface as probable Gondwana, but in a report on Suriname he described the Tafelberg as a part of a domed surface of the Early Tertiary Surface (King et al., 1964).

Below the northern part of the coastal plain of Suriname only the latest Cretaceous (Maastrichtian) occurs. The surface on which the Late Cretaceous sediments have been deposited may be considered as a Post Gondwana Surface. It will be shown below that probably two more Post Gondwana denudation surfaces have existed in the coastal area.

The data of King et al., (1964) have been discussed in 1.6. They are listed below, together with data from several authors on Brazil, Guyana and French Guiana. Although there is a general agreement on the elevation of most of the surfaces, some are considerably divergent, such as the Oronoque Surface and the Kuyuwini Surface which seem much too low compared with Suriname and French Guiana. Also Choubert's 3e Pénéplain does not have a corresponding surface in the other countries.

Usually absolute elevations are given instead of elevations in relation to present water courses. Furthermore, although both absolute and relative elevation decrease from south to north, this is never shown. In this way it is difficult to correlate the surfaces. This may serve to illustrate that the study of the geomorphology of northern South America is still in its infancy and can

Suriname	Brazil		Guyana		French Guiana	Age
King et al.1964	Bigarella & Andrade,1964	King,1967	McConnell,1966	Berrangé,1975	Choubert,1957	
		Gondwana		Kanuku (900 m)		Jurassic or older
			older bevels			
		Post Gondwana				
E.T.S.	Pd-3	Sul-Americana	Kopinang (630-690 m)	Oronoque (270-300 m)	1e Pénéplain (525-550 m)	Lower Tertiary
L.T.-I	Pd-2	Early Velhas	Kaieteur (390-450 m)	Kuyiwini (225-255 m)	2e Pénéplain (300-370 m)	Oligo-Miocene
					3e Péneplain (210-260 m)	
L.T.-II	Pd-1	Late Velhas	Rupununi (100-150 m)	Rupununi (100-165 m)	4e Pénéplain (150-170 m)	Pliocene
Quaternary Fluvial Cycle	P-2 P-1	Paraguaçu	Mazaruni	Mazaruni		Quaternary

only proceed by a close cooperation of the countries involved.

A few general remarks may be added on correlative deposits of erosion surfaces.

Correlate deposits in basins bordering active tectonic areas are usually thought to reflect the relief of the areas which supplied them. Steep slopes provide coarse sediments whereas flat areas supply only fine deposits. Bakker (1957b) has shown that this is not valid for the humid tropics, at least not for relatively stable areas. It is still true for fast rising mountain ranges, like parts of the Andes and the Central Mountain Range of New-Guinea. Due to intense weathering the humid tropics supply only very little coarse material, even if steep slopes occur. Instead of tectonic activity and relief the nature of the sediments often reflects the climate of the area of provenance. Not only the grain size of the sediments, but also the degree of maturity and the total mass of the sediments are of importance.

During a period with a humid climate a deep regolith is formed, under a tropical rain forest. Some sand and clay are supplied by creeks and rivers which show linear erosion. Little lateral erosion occurs due to the protective cover of the forest. The floodplain deposits consist of fine sandy clays mainly (De Boer, 1972). The total mass of sediments reaching the coast is small. This picture just about reflects the present situation.

During a period with a drier climate the forest might be partly replaced by dry savannas. Mainly lateral erosion occurs by sheet floods which form pediments. The coarse sediments are poorly sorted. The total mass of sediments is very large. If conditions are very dry the erosion products may not reach the coast but may be deposited by short braided rivers or by ephemeral streams as a sort of piedmont deposit. This is probably the way in which part of the Upper

Coesewijne deposits of the Savanna Belt have been formed.

Semi-arid erosion products may be mineralogically immature when the climate has been dry for a long time and the rocks are hardly chemically weathered. Examples are the arkosic Cretaceous deposits, both in the Guiana Basin and in the Middle Amazon Basin, and the arkosic sands of the Eocene which probably were largely the source rock of the bauxite. However, erosion in a semi-arid climate may also occur on deeply weathered rocks. In this case the resulting sediments are rather mature as relics of an earlier humid phase of weathering. The A-sands and the Upper Coesewijne sands are examples of the latter.

A tentative approach toward the main erosion surfaces and their correlate deposits in Suriname is given below.

Gondwana Surface. Although very speculative it is tempting to start at the base. The correlative deposits of the Gondwana Surface - which itself is almost entirely absent on land, but a part of which is tentatively supposed to underly the continental shelf and the Guiana Marginal Plateau - might eventually be found in the Proto-Atlantic Ocean north of Suriname, in some grabens (e.g. the Takutu Graben in Guyana) and, possibly, even in the Andes geosyncline.

Post Gondwana Surfaces. One of the Post Gondwana Surfaces occurs below the Nickerie Formation (Maastrichtian) in the coastal plain. Its correlate deposits form the Lower and most of the Upper Cretaceous which are found below the continental shelf and the Guiana Marginal Plateau. Figure 32A shows the hypothetical continuation of this surface, labeled C-1.

The correlate deposits of the second Post Gondwana Surface (C-2) are the arkosic sediments of the Maastrichtian. The "red beds" at the base of the Maastrichtian (2.4.2) are probably the erosion products of the lateritically weathered C-1 surface. It is not known if weathering occurred at the top of the Maastrichtian sediments, since the upper part, about 150 m, was removed during the next stage of denudation (1.4.2; 5) and probably redeposited further north on the shelf where sedimentation went on without interruption. A rather irregular surface was formed, C-3.

Early Tertiary Surface. On the seaward side of C-3 the Paleocene and Eocene sediments of the Onverdacht Formation were deposited during the formation of the Early Tertiary Surface. A few stages can be distinguished in the sedimentation of the Onverdacht Formation. The first stage is a transgression during the Paleocene with the deposition of - locally calcareous - clays in the present coastal area, followed by a regression. The Eocene also saw a transgression, less extensive than the former, again followed by a regression. In the Onverdacht bauxite area two sequences from coarse sand to kaolin could be detected

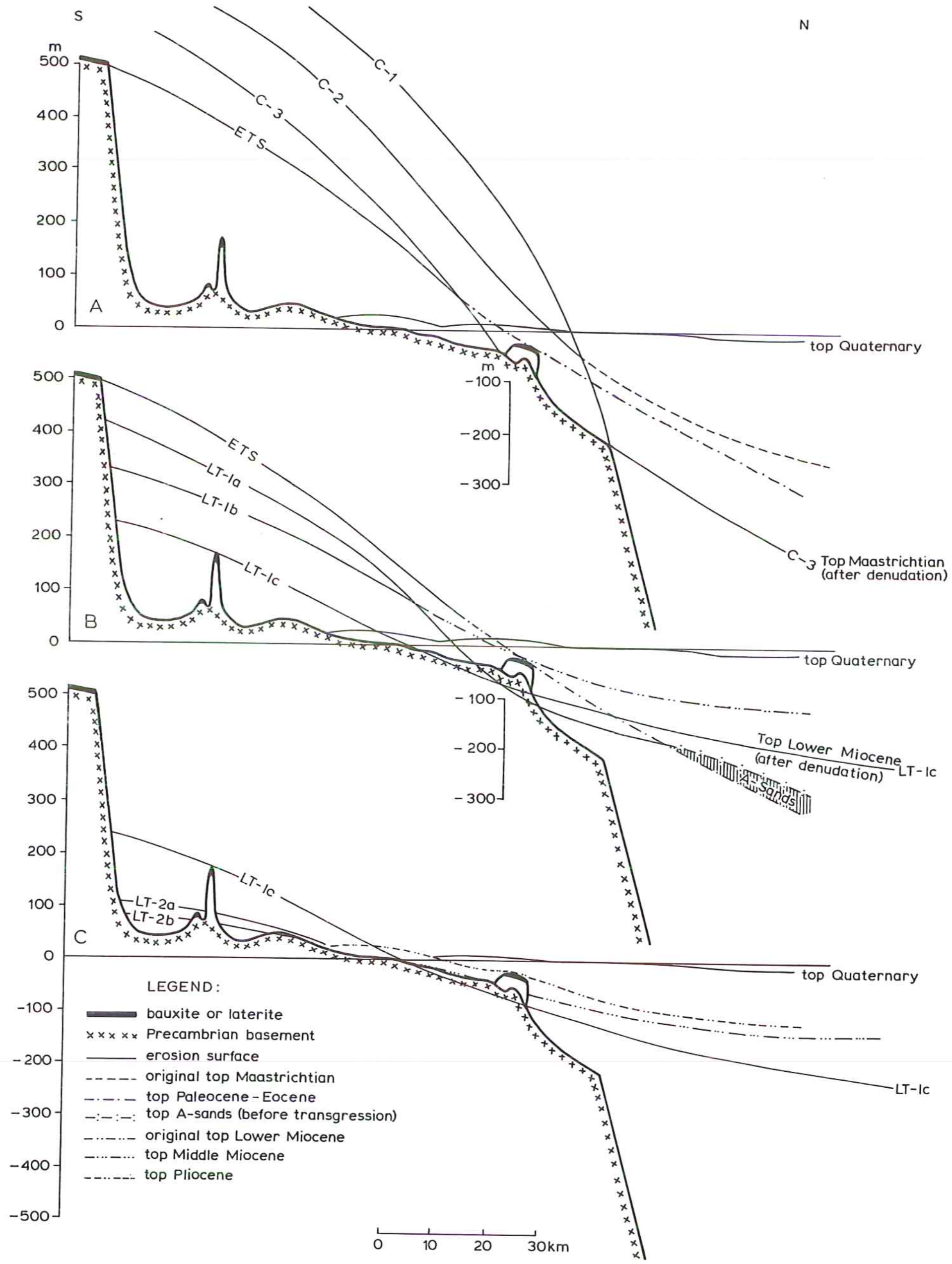


Fig. 32 Hypothetical development of erosion surfaces in Northern Suriname

(1.4.2), possibly corresponding with the regressions and the transgressions. A following sequence was terminated by bauxitization after deposition of coarse, presumably arkosic, sands. These coarse sands were the last correlate deposits of the Early Tertiary Surface. Bauxitization and lateritization now occurred on both the Early Tertiary Surface and the landward part of its correlate deposits. At the same time fluvial erosion started to form a drainage system. The contradictory situation now arose in which the new denudation cycle started to break down the erosion surface of the preceding cycle while contemporaneously a duricrust was formed to protect the same surface.

With the erosion of the Early Tertiary Surface the formation of inselbergs started in granite areas, especially in southern Suriname, where most inselbergs attain about the elevation of this surface (Zonneveld, 1969b).

Late Tertiary-I Surface. The Late Tertiary-I Surface was probably formed in several stages (fig. 32B). The first stage, LT-1a, started during the bauxitization, as has been shown above, and went on for some time after. Its correlate sediments are the A-sands, deposited in a coastal environment during a low sea-level stage. With the subsequent transgression they moved landward and were transported to the west by beachdrifting (4.4). This probably occurred in Late Oligocene times. During the Early Miocene the climate was hot and humid and the erosion was probably of the linear type (stage LT-1b), supplying some fine and coarse sand of the same composition as the A-sands. The sands formed beaches on a coast mainly made up by mud derived from the Amazon, a situation which is similar to the present one. With a change of climate to more arid conditions the vegetation apparently changed locally from a rain forest to grassy savannas and the increased erosion caused the supply and deposition of coarse sands (table 5). These sands covered even a part of the bauxite deposits. A large regression followed and the subsequent denudation was probably the main stage (LT-1c) in the formation of the Late Tertiary I Surface. In the coastal area it removed the upper part of the Lower Miocene. The denudation was reflected by terrigenous sedimentation during the Langhian which interrupted the deposition of carbonates on the continental shelf.

Late Tertiary-II Surface. After the Langhian the climate was again hot and humid and the sea transgressed. The marine clays and some sand were deposited as far south as Republiek. By the end of the Middle Miocene the sea regressed again. There was a large scale denudation of the shield and the main stage of the Late Tertiary-II Surface was formed, LT-2a (fig. 32C). This surface consists of a system of wide pediments connected with the main rivers. It was intensively weathered and locally laterite was formed. Subsequently the laterite crusts were eroded and only a few remnants were left. The correlate deposits of the surface and the products formed by its dissection were deposited on the outer parts of the continental shelf during the Late Miocene. In the present coastal plain the Late Miocene is represented only by a hiatus.

The Early Pliocene saw a transgression and the sea advanced as far as Zanderij and Sabana. Then the sea regressed again and a new stage of erosion started. The climate gradually grew more arid and coarse erosion products were deposited by short braided rivers and by ephemeral streams forming alluvial fans which built the coarse sandy to loamy Upper Coesewijne Formation.

The Quaternary Cycles. During the Quaternary the Late Tertiary-II Surface was attacked again and again. Most denudation probably occurred during the relatively dry stages corresponding mainly with parts of the glacial stages at higher latitudes.

In the foregoing reflections on denudation levels it has been assumed that the main surfaces consist of several substages. Up to now little research has been done on these substages. However, Mulders (1976) made a map study of the sheets nrs. 38, 39, 47 and 48 and found several distinct levels at various heights. It should be stressed that the substages not necessarily have to be represented by more or less flat surfaces since during some of them depth erosion may have prevailed. Both climate and degree of uplift played a role in this respect.

In the study of planation surfaces and their correlate deposits it should be realized that the latter may often be dated, whereas the age of a planation surface cannot be determined directly. It is suggested that the use of palaeomagnetic dating of weathering profiles be considered. This method has already been successfully applied in Australia (Idnurm and Senior, 1978) and might be useful in the study of laterites and bauxites on erosion surfaces in the Guianas.

SUMMARY

Chapter 1 shows some geological aspects of Suriname. The country is a part of the Guiana Shield which is covered to the north by sediments of the Guiana Basin with ages from Late Cretaceous to Recent. The Cretaceous occurs at some depth and is not exposed. The southern part of the sedimentary deposits consists of Pliocene continental sands of the Savanna Belt. There are a few outcrops of Paleocene and Eocene deposits which are capped by bauxite. To the north the Old Coastal Plain and the Young Coastal Plain occur, the sediments of which were deposited during the late Pleistocene and the Holocene respectively. The exposed formations and their morphology have been mainly described by soil scientists. The deeper strata were studied by means of holes drilled for ground water and, at a later stage, for the exploration of oil. Detailed studies were carried out in and around the bauxite deposits. The stratigraphy of the sedimentary deposits is based mainly on palynological studies.

Short descriptions have been given on the occurrence of river terraces, the continental shelf and the Guiana Marginal Plateau. Some attention is paid to relative sea-level movements and climatic changes in the past, while the connection between cyclic development of landforms and the contemporaneous sedimentation in the coastal plain is also discussed.

Bauxite is the most important natural resource. Others, only part of which are exploited, are: kaolin, gold, sand, gravel, shells and clay. Ground water is obtained from bore holes from aquifers which are replenished in the Savanna Belt. Drilling in the coastal plain showed some oil in the Tertiary sands. Several oil exploration holes have also been drilled on the continental shelf.

Chapter 2 discusses the heavy minerals of the sand fractions of weathered bedrock and sediments. Some attention is also paid to the light minerals, since the feldspar content may give information on the state of weathering. A description of the detrital minerals in Suriname is followed by a systematic treatment of the weathered bedrock and the sediments from Cretaceous to Recent.

Crystalline rocks are usually deeply weathered and the sediments derived from them contain mainly stable minerals such as zircon, tourmaline, rutile and the metamorphic minerals. A different sort of weathering occurs on the bare rock surfaces of inselbergs and of large boulders in rivers which emerge during the dry season. These weathering products have a relatively high content of unstable minerals.

The Cretaceous comprises mainly continental sub-arkosic to arkosic sediments. They contain zircon, some metamorphic minerals and monazite, while locally garnet is abundant. The Paleocene and Eocene deposits show very poor mineral associations, apparently mainly due to extreme weathering conditions during the pe-

riod of bauxite formation. In a few drill holes, however, a moderate feldspar content is found.

In Oligocene and Miocene deposits in drill holes east of the Coppename a high staurolite content occurs while zircon predominates to the west. Almost no weatherable minerals occur. An exception is found in the fine grained sediments in two drill holes, one of which is situated at the edge of the shelf. They have a high content of epidote and hornblende and a relatively high percentage of feldspar.

The deposits of Pliocene and Pleistocene age encountered in the drill holes usually differ from the older sediments by their lower staurolite content. The deeply weathered Pliocene deposits of the Savanna Belt show great differences in composition from west to east. The sediments of the coastal plain are much more homogeneous. The differences in composition between the Old Coastal Plain and the Young Coastal Plain can be explained by post depositional weathering. In the Young Coastal Plain fine grained and coarse grained beaches and cheniers or ridges occur. The fine sands contain mainly zircon, staurolite, epidote and hornblende while in the coarse sands staurolite predominates. The beaches and younger ridges contain garnet. In the older ridges this has been weathered.

Besides zircon and metamorphic minerals the rivers contain a fair amount of epidote, hornblende and locally garnet and hypersthene. In the terrace deposits only stable minerals occur. The content of unstable minerals in the natural levees depends on the age of these deposits.

Recent sediments of the Amazon River contain mainly epidote and hornblende. The fine grained sands of the shelf of French Guiana have a similar composition but they contain some more stable elements.

Some attention has been paid to the occurrence of monazite and xenotime. In the coastal deposits the monazite content increases with increasing depth. Monazite is mainly derived from granulitic rocks, biotite gneisses and, to a minor degree, granitoid rocks. Part of these rocks are now covered by Tertiary deposits. The present rivers supply very little monazite.

In chapter 3 the stability of the minerals is discussed. There are considerable differences in persistence. For some minerals the stability toward weathering sensu stricto differs from the stability with respect to intrastratal solution. The relative stability is shown in a table.

Chapter 4 discusses the provenance of the sediments. This greatly depends on the facies of the sediments concerned. The mineralogy of continental deposits generally shows a relationship with the geology of the hinterland. In older deposits such as the Cretaceous some associations occur which cannot be explained with the formations now exposed. The continental Pliocene deposits in the Savanna Belt, however, are a reflection of the geology of the hinterland. Coastal deposits often contain minerals derived from eastern sources. They are usually connected with marine clays, as can be observed in the Miocene sediments which are partly characterized by high staurolite contents derived from Eastern Suriname and French Guiana. The large clay supply which started in the Early Miocene probably shows the breakthrough of the Amazon.

The Pleistocene saw an alternation of transgressions and regressions. The latter left more traces from a mineralogical point of view, probably partly due to erosion of the transgressive deposits during the subsequent regressions. The fine grained sands of beaches and ridges in the Young Coastal Plain are a mixture of Amazon sands and shelf sands. The coarse grained sands have been derived mainly from some rivers in French Guiana. The present Surinam rivers do not supply sand.

The deposition of sediments supplied by the Amazon is closely related with the sea-level. At a high sea-level the sediments are deposited off the mouth after which a part is resuspended and transported to the Guiana coast. During low sea-level stages the sediments cross the shelf and are deposited by turbidity currents on a large submarine fan, the Amazon Cone. A part of the sediments, however, seems to remain in suspension to be deposited in the form of contourites on the Guiana Marginal Plateau and presumably also on parts of the continental slope and the continental rise. This means that the Amazon deposits are much more widespread than so far assumed.

On the continental shelf NE of the mouth of the Amazon an ancient river bed occurs which contains arkosic sands with a very high content of heavy minerals comprising hornblende, enstatite, hypersthene and sillimanite. On mineralogical grounds the original idea of an Amazon origin cannot be maintained. The sands are probably erosion products from gneisses, granulites and ultrabasic rocks in Amapá, supplied by the Rio Araguari during a low sea-level stage.

Chapter 5 describes the sedimentary history in relation to climate, weathering, erosion, relative sea-level movements etc. The fast sedimentation of relatively unweathered sands in the Late Cretaceous is probably a result of large scale faulting and graben formation which is partly connected with continental drift. At the transition from Cretaceous to Paleocene part of the recent sediments was eroded. During late Eocene - early Oligocene times intense weathering occurred and locally bauxite was formed in the shield and in the coastal plain. During and after the bauxitization large quantities of sand were supplied as a result of a new erosion phase. The Miocene is characterized by extensive transgressions as well as regressions. The Early and Middle Miocene transgressions supplied large quantities of mud. At the same time, however, carbonate deposition occurred on the continental shelf. During a regression in the early Middle Miocene large scale denudation of the coastal sediments took place. In the Late Miocene the sea withdrew far to the north only to return in early Pliocene times. During the subsequent regression continental deposits were laid down in the present Savanna Belt.

At the time of the transgressions the climate was usually humid while more arid conditions prevailed during the regressions.

During the Quaternary pediments and alluvial fans as well as fine grained terrace deposits were formed along the rivers in the interior. This points to an alternation of dry and humid climatic phases. This is also evident from palynological studies. Dry stages probably occurred during the coldest phases of the glacials at higher latitudes.

At the time of the low sea-level stand in the last glacial the rivers of the Guiana Shield supplied coarse sands which drifted along the coast far to the west. The sea-water was clear due to the transport of the Amazon mud across the shelf and this allowed the growth of a fringing reef. In the late Pleistocene and the early Holocene the Amazon deposited its sediment load in the large drowned valley formed by the fast sea-level rise. Consequently only little clay in suspension reached the ocean. About 6000 y. B.P. the valley was filled up and large quantities of Amazon mud were transported to the Guiana coast. This started the fast growth of the Young Coastal Plain.

A few dry stages have been shown to occur during the Holocene on the South American continent. It is not known what their influence was on the sedimentation in the coastal plain of the Guianas.

Chapter 6 gives a new approach of the formation of denudation surfaces and their correlate deposits in Northern Suriname. This shows a more complicated picture than the original one. There are indications that the extensive Late Tertiary II Surface was formed during the Late Miocene. This implies that the continental Pliocene sediments are not the correlate deposits of this surface but rather erosion products formed by its destruction.

SAMENVATTING

Hoofdstuk 1 toont enige geologische aspekten van het te behandelen gebied. Suriname is een deel van het Guyana Schild dat in het noorden wordt bedekt door sedimenten van het Guyana Bekken met een ouderdom van Krijt tot Recent. Het Krijt komt op betrekkelijk grote diepte voor en is nergens ontsloten. Het zuidelijk deel van de sedimentaire afzettingen bestaat uit Pliocene continentale zanden van de zogenoemde Savannegordel. Op enkele plaatsen komen Paleocene en Eocene afzettingen voor, bedekt met bauxiet. Naar het noorden treffen we achtereenvolgens de Oude en de Jonge Kustvlakte aan, waarvan de sedimenten zijn afgezet in respectievelijk het Laat Pleistoceen en het Holoceen. De dagzomende formaties en de daarop voorkomende landschappen zijn vooral beschreven door bodemkundigen. De diepere formaties werden bestudeerd aan de hand van boringen ten behoeve van de drinkwatervoorziening en, in een later stadium, voor de exploratie van aardolie. Gedetailleerd onderzoek werd verricht in en nabij de bauxietafzettingen. De stratigrafie van de sedimentaire afzettingen berust op palynologisch onderzoek.

Korte beschrijvingen worden gewijd aan rivierterrassen, de continentale shelf en het Guyana Randplateau. Verder wordt een overzicht gegeven van de zeespiegelbewegingen en klimaatswisselingen in het verleden, terwijl ook het verband tussen de cyclische ontwikkeling van landvormen in het binnenland en de sedimentatie in het kustgebied wordt besproken. Van de delfstoffen in Noord Suriname neemt bauxiet de belangrijkste plaats in. Andere delfstoffen, al of niet geëxploiteerd, zijn: kaolien, goud, zand, grind, schelpen en klei. Drinkwater wordt door middel van boringen gewonnen uit aquifers die gevoed worden vanuit de Savannegordel. Onderzoek naar aardolie heeft kleine hoeveelheden hiervan aangetoond in Tertiaire zanden onder de kustvlakte. Grote mogelijkheden liggen op de continentale shelf, waar reeds verscheidene boringen zijn verricht.

Hoofdstuk 2 behandelt de mineralogie van de zandfraktie van verweerde bedrock en sedimenten. De nadruk valt hierbij op de zware mineralen. De samenstelling van de lichte fraktie is over het algemeen weinig typerend voor de herkomst van het materiaal, maar het veldspaatgehalte kan informatie geven over de mate van verwering. Na een beschrijving van de detritale mineralen die in Suriname zijn aangetroffen volgt een bespreking van de verweerde kristallijne gesteenten en de sedimenten van Krijt tot Recent. De kristallijne gesteenten zijn meestal diep verweerd en de erosieprodukten bevatten voornamelijk stabiele mineralen als zirkoon, toermalijn, rutiel en metamorfe mineralen. Uitzonderingen komen voor bij verwering onder een aride micro-klimaat op inselbergen en op ontsluitingen van gesteenten in rivieren die in de droge tijd boven water komen. Deze verweringsprodukten bevatten relatief veel onstabiele mineralen. Het Krijt bestaat grotendeels uit continentale afzettingen met een samenstelling variërend van sub-arkose tot arkose. Behalve zeer veel zirkoon bevatten ze metamorfe mineralen en monaziet. Plaatselijk komt veel granaat voor. De Paleocene en Eocene afzettingen zijn over het algemeen uiterst mineraalarm, deels ten gevolge van de intense verwering ten tijde van de bauxietvorming. In enkele boringen wordt echter nog een matig veldspaatgehalte aangetroffen. In Oligocene en Miocene afzettingen komt ten oosten van de Coppename zeer veel stauroliet voor. Ten westen van de Coppename overheerst zirkoon. Ook deze afzettingen bevatten grotendeels stabiele mineralen. Een uitzondering vormen de zeer fijnkorrelige sedimenten van een tweetal boringen, waarvan één op de rand van de shelf, die veel epidoot en hoornblende bevatten en een relatief hoog veldspaatgehalte. De Plio-Pleistocene afzettingen in de boringen in de kustvlakte verschillen sterk van de Miocene sedimenten en bevatten minder stauroliet. De intens verweerde continentale Pliocene afzettingen van de Savannegordel vertonen grote verschillen in samenstelling van west naar oost. In tegenstelling hiermee zijn de afzettingen van zowel de Oude als de Jonge Kustvlakte zeer homogeen. De verschillen tussen de Oude en de Jonge Kustvlakte blijken geheel een gevolg te zijn van post-depositionele verwering. In de Jonge Kustvlakte komen zowel fijn- als grofkorrelige fossiele strandwallen voor, zogenoemde "ritsen". De fijne zanden bevatten zirkoon, staurolite, epidoot en hoornblende, terwijl de grove zanden vooral door stauroliet gekenmerkt worden. In de jongere ritsen komt granaat voor; in de oudere ritsen is deze door verwering grotendeels verdwenen. De huidige stranden komen mineralogisch overeen met de ritsen. De rivieren bevatten naast zirkoon en metamorfe mineralen vrij veel epidoot en hoornblende, terwijl plaatselijk granaat en hypersteen voorkomen. De fijnzandige kleien in de estuaria hebben een geheel andere samenstelling. In de rivierterrassen worden uitsluitend stabiele mineralen aangetroffen, terwijl het gehalte aan verweerbare mineralen in de oeverwallen afhankelijk is van de ouderdom van deze afzettingen. Recente afzettingen van de Amazone hebben een zeer hoog gehalte aan epidoot en hoornblende. De fijne zanden op de shelf van Frans Guyana komen hier enigszins mee overeen, maar hebben een hoger gehalte aan stabiele mineralen.

Een aparte bespreking wordt gewijd aan het voorkomen van monaziet en xenotiem. Het monazietgehalte stijgt met toenemende diepte in de sedimenten van de kustvlakte. Monaziet is vooral afkomstig uit gesteenten van de granulietfacies en biotietgneissen en in mindere mate van granieten. Een deel van deze gesteenten is thans bedekt door Tertiaire sedimenten. De huidige rivieren leveren zeer weinig monaziet.

In hoofdstuk 3 wordt de stabiliteit van de mineralen besproken. Er blijken zeer grote verschillen in resistentie te bestaan. Enkele mineralen, zoals granaat, zijn onstabiel ten opzichte van verwering in de bodem, maar stabiel ten opzichte van oplossing in sedimenten op grote diepte.

Hoofdstuk 4 behandelt de herkomst van de sedimenten aan de hand van de mineraalinhoud. De herkomst toont een duidelijke samenhang met de facies. Continentale afzettingen vertonen over het algemeen een beeld dat samenhangt met de geologie van het achterland. In oudere continentale afzettingen zoals die van het Krijt komen echter plaatselijk associaties voor die niet te verklaren zijn aan de hand van formaties die thans dagzomen. De continentale Pliocene sedimenten in de Savannegordel daarentegen zijn een duidelijke afspiegeling van de geologie van het Precambrische Schild. Kustafzettingen bevatten dikwijls mineralen die afkomstig zijn van oostelijk gelegen gebieden. Ze komen over het algemeen voor in samenhang met mariene kleien. Voorbeelden zijn de Oligocene en Miocene sedimenten, gekenmerkt door het voorkomen van stauroliet, afkomstig van Oost Suriname en Frans Guyana. De grote kleiaanvoer vanaf het Vroeg Mioceen is waarschijnlijk een gevolg van het ontstaan van de Amazone.

Hoewel er tijdens het Pleistoceen zowel transgressies als regressies voorkwamen overheersen over het algemeen de sedimenten die tijdens de regressies zijn aangevoerd. De fijne zanden van stranden en ritsen in de huidige kustvlakte zijn een mengsel van Amazone zanden en van shelfzanden, terwijl de grofkorrelige zanden hoofdzakelijk afkomstig zijn van enkele rivieren in Frans Guyana. De Surinaamse rivieren leveren thans vrijwel geen zandige sedimenten.

De afzetting van de door de Amazone aangevoerde sedimenten hangt nauw samen met de zeespiegelstand. Indien deze hoog is worden de sedimenten afgezet bij de monding, waarna een deel opnieuw wordt opgenomen en verder getransporteerd naar de kust van de Guyana's. Tijdens lage zeespiegelstanden wordt het materiaal over de continentale shelf vervoerd en door troebelingsstromen afgezet op een submariene puinwaaier, de zogenoemde "Amazon Cone". Een deel van het materiaal blijkt echter nog in suspensie getransporteerd te worden en wordt in de vorm van "contourieten" afgezet op het Guyana Randplateau en mogelijk ook op delen van de continentale helling en daaronder. De afzettingen van de Amazone zijn dus veel meer wijd verspreid dan tot nu toe werd aangenomen.

Op de shelf ten N.O. van de Amazonemonding komt een oude rivierloop voor die arkosezanden bevat met een zeer hoog gehalte aan zware mineralen, bestaande uit hoornblende, enstatiet, hyperstheen en sillimaniet. Deze zanden zijn waarschijnlijk afbraakprodukten van gneissen, granulieten en ultrabasische gesteenten in Amapá en zijn tijdens een lage zeespiegel aangevoerd door de Rio Araguari.

In hoofdstuk 5 wordt een beeld gegeven van de sedimentatiegeschiedenis in samenhang met klimaat, verwering, erosie, relatieve zeespiegelbewegingen enz. De snelle sedimentatie van weinig verweerde zanden in het Krijt hangt waarschijnlijk samen met breukvorming die deels een gevolg is van de continentale drift. Tijdens de overgang Krijt-Paleoceen viel een groot deel van de sedimenten aan denudatie ten prooi. In het laat Eoceen - vroeg Oligoceen kwam plaatselijk bauxietvorming voor op het schild en in de kustvlakte. Gedurende en na de bauxitisatie vond een grote aanvoer van zanden plaats ten gevolge van een nieuwe erosiefase. Het Mioceen wordt zowel door uitgebreide transgressies als door regressies gekenmerkt. De Vroeg en Midden Miocene transgressies voerden grote hoeveelheden slib aan. Tegelijkertijd vond kalkafzetting plaats op de continentale shelf. Tijdens een regressie in het vroeg Midden Mioceen kwam grootscheepse denudatie voor van de kustafzettingen. In het Laat Mioceen trok de zee zich ver naar het noorden terug. Het Plioceen begon met een transgressie. Ten tijde van de hierop volgende regressie werden continentale zanden afgezet in de huidige Savannegordel.

Transgressies gingen over het algemeen gepaard met een humide klimaat, terwijl tijdens regressies vaak meer aride condities voorkwamen, hetgeen de erosie bevorderde.

Gedurende het Kwartair werden langs de rivieren naast pedimenten en puinkegels ook fijnkorrelige terrasafzettingen gevormd, hetgeen wijst op het voorkomen van zowel droge als vochtige perioden. Dit wordt bevestigd door pollenonderzoek.

Tijdens de lage zeespiegelstand in het laatste glaciaal voerden de rivieren van het Guyanaschild grove zanden aan die langs de kust werden getransporteerd tot ten noorden van de Orinocodelta. Tegelijkertijd groeiden koraalriffen langs de kust, hetgeen mogelijk was door de geringe kleiaanvoer. Dit laatste was een gevolg van het feit dat de Amazonesedimenten werden afgezet in de diepzee. In het laat Pleistoceen en het vroeg Holoceen vond de sedimentatie van de Amazone plaats in het grote verdronken dal ontstaan door de snelle zeespiegelstijging. Hierdoor bereikte slechts weinig suspensiemateriaal de zee. Ongeveer 6000 jaar geleden was het dal opgevuld en de grote hoeveelheden slib die nu aangevoerd werden begonnen aan de snelle opbouw van de Jonge Kustvlakte van de Guyana's.

In Zuid Amerika zijn ook droge stadia in het Holoceen aangetoond. Het is nog niet bekend welke invloed deze hebben gehad op de sedimentatie.

In hoofdstuk 6 wordt aan de hand van de recente gegevens van het kustgebied een nieuwe benadering gegeven van de ontwikkeling van denudatievlakken en hun correlate afzettingen. Dit laat een meer gedetailleerd beeld zien dan het oude.

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SAMPLE NUMBER	SAMPLE LOCATION (MAP-SHEET)	DEPTH (m)	LIGHT FRACTION		HEAVY FRACTION																												REMARKS
					OPAQUE		TRANSPARENT																										
			fsp (%)	OTHER MINERALS (apart from quartz)	(%)	MINERALS	Siderite	Biotite	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Sphene	Staurolite	Kyanite	Andalusite	Sillimanite	Corundum	Epidote	Hornblende	Augite	Enstatite	Hypersthene	Topaz	Spinel	Apatite	Monazite	Xenotime	Others (%)	Others (min)	
KK 437	28-b		0		28	il, li			3	6							10	13	65										2	1	x	du	
444	28-b		0		64	li, il			81	x						x		x	18										1				
445	28-b		0		43	li, il, le			4	75		3					6	3	7								x	1	1	x	x	du	
361	20-c		0		93	il, li, le				99									x										1				
423	20-c		0		89	il, li, le			x	98		1							1	x						x			x				
424	20-c		0		93	il				67																			33				
399	22-c		0		98	he, il			5	88		2				1					4												
243	21-a		0		68	hi, ma, he				16		10				71	1	1		1	x	x				x	x		x				
MM 6	22-a		0		5	il			3							97	x		x														
KK 266	22-a		0		94	li, il			2	6		1	1			90	x		x														
397	22-a		0		99	he			3	32		2				62				1													
MAR 3	24-a		2		32	il, le			1	3	x	x				94	x	1	x		1	x							x				
24	32-d		2		27	il, he			1	1	3					95																	
KK 276	22-b		0		98	he, li			70	21						6			2			1											
456	16-c		0	gr	8	li			51	10						14		x												25			
312	29-c		0		79	ma, il, he,li			5	85		9							1														
293	29-c		0		95	il, ma		90	2	98																							
291	29-c		0		91	il, li			2	89		9											x										
418	21-c		0		0				x	100																							
400	31-a		0		78	le			15	85											x												
MM 23	23-a		0		?	il, le, hi			8	52		3	1			31	3		1								x		1				

Table 12 Heavy mineral composition of weathered rocks of the Falawatra Group (KK 437-424), the Paramaka Formation (KK 399), the Armina Formation (KK 243-291) and the Rosebel Formation (KK 418 - MM 23)

SAMPLE NUMBER	SAMPLE LOCATION (MAP-SHEET)	DEPTH (m)	LIGHT FRACTION: fsp (%)	LIGHT FRACTION: OTHER MINERALS (apart from quartz)	HEAVY FRACTION – OPAQUE: (%)	HEAVY FRACTION – OPAQUE: MINERALS	TRANSPARENT: Siderite	Biotite	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Sphene	Staurolite	Kyanite	Andalusite	Sillimanite	Corundum	Epidote	Hornblende	Augite	Enstatite	Hypersthene	Topaz	Spinel	Apatite	Monazite	Xenotime	Others (%)	Others (min)	REMARKS
KK 342	20-c		48	bi 11%	76	ma, il		1		29											7	60	x					2	1				
296	29-c		51	bi, ka	76	ma, il			x	24									x		76										x	th	
300	36-b		43	bi 4%	78	ma, il		1		35											65												
301	36-b		26	bi 1%	91	ma, il, li,le			1	89											10												
304	36-b		24	bi 4%	92	il, ma, he,le		3		99											x												
457	16-c		0		44	le, li				20				x		2													78				
455	16-d		0		24	he, il, li		x		22						x					x								76				
32	16-c		0	gi, ka	41	il, le			4	5		1				85	3	2															
458	16-c		0		47	li, hi, le			1	1						97	x	1												x			
459	16-c		0		74	le, hi, il			5	14		1				76	1	3															
460	16-c		0		?	hi, le, il			1	7		2				86	x	4															
402	18-d		0		10	le, il			2	85		3					1	2	2	5													
443	28-b		0		63	le, hi, il			15	56		3					3	6	15							1			1				
346	20-c		0		26	le, hi			3	85		5				1	x	5	x	1											x	vi	
130	20-c		0		61	il, le				97		1						2			x						x						
120	20-a		0		66	he, hi			2	93		1				x		2	x								x		x	x			
421	13-c		0		58	hi, il, le			7	77		13						1								2							
419	21-c		0		93	sec. ru			3	75		20				1				1													
W 38430	21-d		0		15				x	75		20				5			x			x					x						
KK 401	21-d		0		12	le, il			x	91		8				1																	
389	14-c		0		7	le, il			1	80		11				8																	

Table 13 Heavy mineral composition of weathered granites (KK 342-455) and sediments of the Onverdacht Formation (KK 32-460) and the Upper Coesewijne Formation (KK 402-389)

SAMPLE NUMBER	SAMPLE LOCATION (MAP-SHEET)	DEPTH (m)	LIGHT FRACTION: fsp (%)	LIGHT FRACTION: OTHER MINERALS (apart from quartz)	HEAVY FRACTION – OPAQUE: (%)	OPAQUE: MINERALS	TRANSPARENT: Siderite	Biotite	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Sphene	Staurolite	Kyanite	Andalusite	Sillimanite	Corundum	Epidote	Hornblende	Augite	Enstatite	Hypersthene	Topaz	Spinel	Apatite	Monazite	Xenotime	Others (%)	Others (min)	REMARKS
KK 465	14-c	1.00	0		28	le, hi, il			1	61		10				21	4	1		2										x	x		diamond
272	22-b	1.00	0		27	le, il			1	69		11				13	1		4	1							x		x				
408	15-d	1.00			0				10	1						80		9									x						
385	16-d	1.00	0		18	il, hi, le			1	62		5				26	1	2	1	2													
67	12-b	1.00	1		75	il, le			10	31		9	2			41	1	3	1							1			1				
70	12-b	1.00	0		60	il, le			13	44		12	1			21	1	5	2		1												
39	14-a	1.00	x		53	il, le			7	34		5	1			48		4	1		x												
216 A	14-a	4.00	n.d.		59	le, il			20	17		4	1			40	3	12	3														
216 B	14-a	4.50	n.d.		53	il, le			9	31		7	x			47	2	3	1														
216 C	14-a	5.00	n.d.		47	il, py, le		x	11	13		3				67	x	4	2														
382	15-a	1.00	n.d.		56	il, le			13	17		3	1			61	1	4	x														
383	15-a	1.00	n.d.		28	go, il, le			11	5		1				77	1	2	1	x	2												
MM 29	12-d	1.50	n.d.		85	li			2	78	1		1			8				1				4	4						1	ca	
38	12-d	1.00	n.d.		97	li, il				83		7				10																	
42	20-b	0.70	n.d.		65	li, il, le			5	53	4	2				32	x	2	1								1						
44	20-b	1.00	n.d.		99	li			8	31		1				50		8	1	1													
49	20-b	1.00	n.d.		97	li			1	86		2				9		1		1													
KK 117	14-c	1.00	n.d.		62	il, he				76		13				7			1		2								1				
HI 72	1-d		n.d.		57	il, py, li	38		2	44		5				12	6	2	9		13	4							3				
74	9-c		n.d.		82	li, il, le	12		2	50	4	2				5		2	3	1	19	12											
76	17-a		n.d.		63	il, le	1		1	44	2	3				11		3	9	1	17	6					1		x				

Table 14 Heavy mineral composition of sediments of the Upper Coesewijne Formation (KK 465-385), the Upper Coropina Formation (Offshore Bar Landscape: KK 67-383; Old Sea Clay Landscape: MM 29 - KK 117) and the Corantijn River (HI 72-76)

SAMPLE NUMBER	SAMPLE LOCATION (MAP-SHEET)	DEPTH (m)	LIGHT FRACTION: fsp (%)	LIGHT FRACTION: OTHER MINERALS (apart from quartz)	HEAVY FRACTION – OPAQUE: (%)	HEAVY FRACTION – OPAQUE: MINERALS	Siderite	Biotite	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Sphene	Staurolite	Kyanite	Andalusite	Sillimanite	Corundum	Epidote	Hornblende	Augite	Enstatite	Hypersthene	Topaz	Spinel	Apatite	Monazite	Xenotime	Others (%)	Others (min)	REMARKS
HI 78	17-d		n.d.		84	il, li			1	64							1	1	24	2									7				
79a	17-d		n.d.		71	go, il			4	1	13					2	2	2	21		21	32			2								h. fr. > 250 µm
79b	17-d		n.d.		65	il			x	80		5				2	1		6	1	1	1							3				h. fr. < 100 µm
82	26-a		n.d.		70	il, li, go, le			2	20	7								32		17	19			3								
89	25-a		n.d.		88	il, hi			3	83		2					1	2	7	2													
97	33-a		n.d.		75	il, go				36	18								19		10	16							1				
W 38782	2-c		n.d.		69	n.d.			6	46	1	1		1		5		1	27		2	9	1										
38770	2-c		n.d.		68	n.d.			5	18	1	2	x			4	1	10	40	x	5	12		x	x	1					1	tr	
HI 83	26-a		n.d.		78	il, go, le			3	30	7	1					2	4	26	1	10	15							1				
KK 217	26-c		n.d.		89	il, go			3	46	2	2					4	3	13	4	2	7		1	9		1		1	1	1	pi	pot hole
218	26-c		n.d.		86	il, le, ma			x	72	x	1					3	1	4	6	4	5			4		x		x				
HI 66A	2-c		n.d.		73	il, py, li, le	35	x	6	29	3	4	1			17	2	1	11	2	19	5											f. sandy clay
69	2-c		n.d.		77	il, li, go	60		6	17		1				2	6	6	62			x											m. sandy clay
GE 6	19-c		n.d.		47	n.d.			2	24	3	2				7	11	1	29	2	2	3			1	7	2		2		2	pi	
KK 482	19-c		n.d.		90	il			x	36		2					11	1	47	1		x							2	x	x	ca	natural concentrate
GE 105	27-a		n.d.		56	n.d.			3	20	6	2					15	5	27		4	3			1	9	2		3				
HI 71	10-b		n.d.		71	py, il, le, li	32		x	52	1	1		1		15	3	2	15		7	3	1										very fine sandy clay
GE 41	19-c		n.d.		40	n.d.			3	2	2	2					19	1	58		2	2			1	8							
KK 379A	35		n.d.		87	il, li				49								1			2	14	6		26					1	1	di	
HI 1	20-a		n.d.		85	il, li, le			7	75		3				2		3	9		x												
2A	20-a		12	op, ch	80	il, li, le	24		4	80		2				3	2	x	6		2	1											

Table 15 Heavy mineral composition of sediments of the Corantijn River (HI 78 - W 38770), the Kabalebo River (HI 83 - KK 218), the Nickerie River (HH 66A - GE 105), the Maratakka River (HI 71), the Falawatra River (GE 41), the Adampada Creek (KK 379A) and the Wayambo River (HI 1, 2A)

			LIGHT FRACTION		HEAVY FRACTION																												
					OPAQUE		TRANSPARENT																										REMARKS
SAMPLE NUMBER	SAMPLE LOCATION (MAP-SHEET)	DEPTH (m)	fsp (%)	OTHER MINERALS (apart from quartz)	(%)	MINERALS	Siderite	Biotite	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Sphene	Staurolite	Kyanite	Andalusite	Sillimanite	Corundum	Epidote	Hornblende	Augite	Enstatite	Hypersthene	Topaz	Spinel	Apatite	Monazite	Xenotime	Others (%)	Others (min)	
HI 3	12-c		n.d.		92	il, li, le			17	26	1	1					4	27	23	1													sand, 430 µm
27	12-b		11	bi, mu, op,ch	58	il, py, le	45		1	59	1	3	1			23	1	1	1		7	1							1		1	tr	f. sandy clay
23	12-a		n.d.		93	il, li, go			3	22							1	11	13	1	24	18	1		4				1				c. sandy clay, 610 µm
18	12-c		10	mu,bi,ct,op,vv	76	il, le	36		2	81						1			5		7	3							1				f. sandy clay
4	20-a		3		65	il, go, li,le			10	15		x				1		14	13		11	27			7						2	di	tr
12	29-a		n.d.		73	il, go, le			4	15		4				x	1	11	27	1	8	15	1		11				1		1	di	
KK 306	29-c		2		93	il, ma			1	80	1	1					2	1	6	1	2								5				natural concentrate
HI 44	28-d		n.d.		50	il, le, li			2	1								7	8		8	55	3		15						1	at	445 µm
KK 328	29-a	0.80	10	mu x	69	il, le			3	56		x				1	1	2	10		13	11			2						1	tr	natural levee, low
333	29-a	0.80	4	mu, op	68	il, le			5	54		2				1		4	11		7	9			6						2	ca	at; natural levee, low
314	29-c		8	bi, op	63	il, le			6	42		x	1						17		15	16			3						1	di	th; natural levee, low
327	29-a	0.80	5	mu x	73	il, le			4	75		5					1	3	3		6	3											natural levee, high
332	29-a	0.80	4	mu, op	65	il, le			4	81		x						2	7		4	2											natural levee, high
313	29-c		2		71	il, le			1	87		x				2	2	2	5		1	x											natural levee, high
367	20-a		0		80	il, le			8	78		1						9	1		1						1			2			Lower Terrace
368	20-a		4		83	il, li			4	64		2				x		6	23			1											Lower Terrace
369	20-a		1		63	il, li, le			2	88		x				1		3	6														Lower Terrace
372	20-c		0		68	il, le			1	85		x						5	7											2			Lower Terrace
351	20-c		8	bi, mu	87	li, il, le			6	74		1					1	9	8											1			Lower Terrace
363	20-c		2		74	il, li, le			3	82		1						6	8								x						Lower Terrace
375	20-a		n.d.		87	li, il			5	68		5				4	1	7	8	1	x								x	1	x	ca	silt, U. Coropina

Table 16 Heavy mineral composition of sediments of the Wayambo River (HI 3) and the Coppename River (HI 27 - KK 375)

			LIGHT FRACTION		HEAVY FRACTION: OPAQUE		HEAVY FRACTION: TRANSPARENT																											
SAMPLE NUMBER	SAMPLE LOCATION (MAP-SHEET)	DEPTH (m)	fsp (%)	OTHER MINERALS (apart from quartz)	(%)	MINERALS	Siderite	Biotite	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Sphene	Staurolite	Kyanite	Andalusite	Sillimanite	Corundum	Epidote	Hornblende	Augite	Enstatite	Hypersthene	Topaz	Spinel	Apatite	Monazite	Xenotime	Others (%)	Others (min)	REMARKS
KK 354	20-c		7		59	il, le			2	80		9	1			6	1		1														silt, U, Cor.
MM 7	20-c		1		93	li, il, le			8	68		7				9		1	7														silty clay, U, Cor.
HI 28	12-b		9	bi,ch,op,ct,mu	74	il, py	38		4	43	2		1	1		24	1		4		16	3									1	tr	f. sandy clay
30	12-d		1		89	li, il, hi			26	12	1	2				3	1	20	16		6	9			2				1		1	di	710 µm
31	12-d		n.d.		93	li, hi, le			7	37	2					21	2	7	11	7		1	1		1	2			1				1950 µm
32	12-d		2		72	il			3	30							3	4	8		8	34	1		8		1						
KK 124	20-c		n.d.		61	il, le, he			1	45	1	x				5		2	12	1	3	23			6		x		1				
123	20-d		n.d.		86	il, le			1	36	4	1				8		3	1		26	16		1				1	2				
336	20-b		10	op	81	il, le				53		3				4			17		15	7			1		x						natural levee, f.s. clay
285	20-d		1		76	il, li, le				67		4				3		5			12	8									1	tr	natural levee, f. sand
HI 35	29-c		5		86	il, go, le				53		1						2			5	37			2				x	x			980 µm
36	29-c		6		61	il, le, go			2	24								1	2		20	50			1								750 µm
KK 292	29-c		n.d.		86	il, ma, le				52						1		1			16	28			1						1	pm	1500 µm
295	29-c		15		45	il			1	70		x									7	22			x						x	th	280 µm
294	29-c		11		58	il, le			1	90		1							x		5	1									2	th	natural levee, cl. fine sand
HI 41	36-b		13		78	il, li, le			5	32								4	4		16	29			10					x			920 µm
42	36-b		4		76	il, le			7	16	1	2						5	3		13	52			1								770 µm
A-1	36-b		8		90	il, le, li			10	45	2	3						7	2	1	15	6	1		3			4	1				1220 µm
I-A	36-b		10		89	il, le			1	85								3			6	3							1	1			900 µm
KK 102	13-b		n.d.		92	il, li, le			12	37	1	10	1			27	1	2	6	1	x	1								1			
109	13-d		n.d.		72	il, le			2	62		12				7		x		1	10	1							4	1			

Table 17 Heavy mineral composition of sediments of the Coppename River (KK 354, MM 7), the Coesewijne River (HI 28), the Tibiti River (HI 30 - KK 285), the Kwama Creek (HI 35 - KK 294), the Tanjimama Creek (HI 41-1A) and the Saramacca River (KK 102, 109)

SAMPLE NUMBER	SAMPLE LOCATION (MAP-SHEET)	DEPTH (m)	LIGHT FRACTION		HEAVY FRACTION																												REMARKS
					OPAQUE		TRANSPARENT																										
			fsp (%)	OTHER MINERALS (apart from quartz)	(%)	MINERALS	Siderite	Biotite	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Sphene	Staurolite	Kyanite	Andalusite	Sillimanite	Corundum	Epidote	Hornblende	Augite	Enstatite	Hypersthene	Topaz	Spinel	Apatite	Monazite	Xenotime	Others (%)	Others (min)	
KK 111	13-d		8		40	il, le			3	2		x				1		x	1		75	18											
107	13-d		n.d.		51	il, le				74		11				14			1														
413	21-b		n.d.		63	il, li, le			3	71		12	x			13	x	x	x							1							silt, U. Coropina
381	22-a		n.d.		8	il			8	1		5				75	1	7	3			x							x				silty clay, U. Cor.
380	22-a		n.d.		19	il			3	3	x	2				84	1	5	2														
NED 1016	6-a		n.d.		52	il, py, le			1	27	18	x				51			x		2	1											natural levee
KK 134	14-a		4	op	64	il, le, py	11	x	7	19	5	x		1		27		1	1	x	24	10		1		1		2	1				
142A	14-c		n.d.		58	n.d.			1		1					11		4			39	43	1										210-420 µm
142A	14-c		n.d.		49	n.d.			1	7	1					6		x	11		51	29		x	x			x	1		2	tr	di, 105-210 µm
142A	14-c		n.d.		47	n.d.			2	35			x			11		x	1		43	5		x				x	3				< 105 µm
145	14-c		n.d.		44	n.d.			2	1					1	7		2		2	58	26							1				210-420 µm
145	14-c		n.d.		39	n.d.			1	1	1	1			1	5	x	1	1		45	43	x		x								105-210 µm
145	14-c		n.d.		59	n.d.			x	75	1	1				6		x	1		7	6						x	3				< 105 µm
148	14-d		n.d.		30	n.d.					1	1				5				2	50	40	x		x			x					210-420 µm
148	14-d		n.d.		37	n.d.			7	4	2				1	10		x	1	x	39	35		x				1					105-210 µm
148	14-d		n.d.		44	n.d.			5	7		1				15	1	x			50	19			1			1			x	di	< 105 µm
463	14-d		18	op, diatom	66	il, le, li			1	29	2	1		1		38	x		1		24	3											nat. levee, cl. f. sand
281	22-c		15	op, x	54	il, le, li			1	61		2				1			1		29	5											nat. levee, f. s. clay
464	14-c		n.d.		73	il, go, le			2	72		6				14		1	4	1													Lower Terrace
MM 9	31-b		n.d.		52	il, li, le			1	85		6						3	2	2									x	1			Lower Terrace
KK 279	22-a		0		73	il, go, le			x	81		2				15	x	x	x	1													Middle Terrace

Table 18 Heavy mineral composition of sediments of the Saramacca River (KK 111-413), the Para Creek (KK 381, 380) and the Suriname River (NED 1016 - KK 279)

			LIGHT FRACTION		H E A V Y F R A C T I O N																											
					O P A Q U E		T R A N S P A R E N T																									
SAMPLE NUMBER	SAMPLE LOCATION (MAP-SHEET)	DEPTH (m)	fsp (%)	OTHER MINERALS (apart from quartz)	(%)	MINERALS	Siderite	Biotite	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Sphene	Staurolite	Kyanite	Andalusite	Sillimanite	Corundum	Epidote	Hornblende	Augite	Enstatite	Hypersthene	Topaz	Spinel	Apatite	Monazite	Xenotime	Others (%)	Others (min)	R E M A R K S
KK 280	22-a		0		71	il, go, le			1	88		1				8		x	1	1							x		x	x			Middle Terrace
282	22-d		0		62	il, le, li			3	87		5				x	x	2	3	x							x			x			Middle Terrace
269	22-a		0		51	il, go			3	61		3				31	x	x	1	1		x									x	vi	High Terrace
283	22-d		0		80	il, go			1	91		2				1		1	2	2							x						High Terrace
HI 99	23-a		n.d.		68	il, li, le			14	12		x				72		2	x														
98	23-a		n.d.		44	il, le			14	4		1				73	4		4								x						
102	15-c		n.d.		22	il, li, le	52		5	8		1				81		1	3										1				
KK 485	16-b		n.d.		40	il, he, li,ma			10	x	x					80		6	1			3											
487	16-b		n.d.		69	il, li	34		4	25	8	2	2	1		41			3		6	4			1				2		1	pi	
MAR 7	24-a		3		63	il, he, le			1	30						19	1	x			36	10						1	2				
23	32-d		7	op	58	il, he, le			3	9	2					44	x	x	1		21	20									x	tr	
30	40-b		10	op	50	il, he, le				17	1					2	1	x			60	17							2				
39	49-d		7	op	83	il, he, le			2	32	20					10					29	2		1					3				
KK 212	69-d		7		56	il, go, le,ma				69	2	1						1			6	19				1			1				
214	16-d		x		76	he, il, li,le			4	67						19	1	7	1	1													Lower Terrace
196	16-d		1		75	il, le, he			2	67		2				25		2	2	x	x	x							x		x	th	spit, reworked L.T.
200	16-d		1		85	il, go, li,le			1	36						52	1	3	2		4												beach, reworked L.T.
208	60-c		3		77	il, le			6	44							x		1		29	20											
209	60-c		10		83	il, le, ma			3	51		1	1			x	x		1		40	3											natural levee
W 38780	10-b		n.d.		70	il, le			3	66	x	9	1			10	2	1	5	x	2	1					x						
KK 64	12-a		8		67	il, le			4	25	1	6				39	3	3	1		14	1									3	tr	ct

Table 19 Heavy mineral composition of sediments of the Suriname River (KK 280-283) the Kleine Commewijne River (HI 99), the Tempati Creek (HI 98), the Penninica Creek (HI 102), the Marowijne and Lawa Rivers (KK 485-200), the Assici Creek (KK 208, 209) and the fine grained sandy ridges of the Wanica phase (W 38780, KK 64)

SAMPLE NUMBER	SAMPLE LOCATION (MAP-SHEET)	DEPTH (m)	LIGHT FRACTION: fsp (%)	LIGHT FRACTION: OTHER MINERALS (apart from quartz)	HEAVY FRACTION: OPAQUE (%)	OPAQUE MINERALS	Siderite	Biotite	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Sphene	Staurolite	Kyanite	Andalusite	Sillimanite	Corundum	Epidote	Hornblende	Augite	Enstatite	Hypersthene	Topaz	Spinel	Apatite	Monazite	Xenotime	Others (%)	Others (min)	REMARKS
MM 19	13-b		n.d.		58	il, li, le		2	3	40	2	7	1			12		x	x		25	7	1					x	x		2	di	
KK 23	13-b	0.35	1		69	il, le			1	65		8	x			20	2	x			4												A-2 soil horizon
24	13-b	0.45	4		55	il, le			11	26		6				20	1	2	2		27	5											B-2 soil horizon
25	13-b	1.20	2		50	il, le			10	15		8	x			42	x	4	3		14	2				x	x	2			x	tr	B-2 soil horizon
26	13-b	2.00	5		57	il, le			5	48		6				12	2	1	1		16	9									x	ct	B-3 soil horizon
132	13-b	4.80	n.d.	ch	47	il, le	4	1	3	32	3	4			1	7	x		x		37	11			1			1			x	di	C soil horizon
133	13-b	6.80	n.d.	ch	54	il, le	7	2	6	15	2	4			1	11		2	1		38	14	1	2		1		1			1	ct	C soil horizon
215A	14-a	0.10	n.d.		57	il, le, py			10	28		4				50		5	x		2	x				1			x				A soil horizon
215B	14-a	1.00	n.d.		46	le, he, il			17	10		4				32	1	10	2	1	16	6				1							B-21 soil horizon
215C	14-a	1.60	n.d.		51	il, le			10	10		3				37		5	3		21	9				2							B-22 soil horizon
215D	14-a	1.80	n.d.		31	il, le			19	2		2				46	x	5	1		22	4									x	tr	B-3 soil horizon
215E	14-a	2.10	n.d.	ch	52	il, le			6	10	1	5	1			59		5	2	x	10	1					x	x					C soil horizon
215F	14-a	2.20	n.d.	ch	32	il, le			18	2	1	1				58	1	4	1		11	3							1				C soil horizon
44	14-b		2		42	il, le			11	20		5	1			53	x	5	2	1	1	x											
90	15-a		3		42	il, le			8	8	1	x	x			71	x	4	1		6	1											
W 37973	2-d		n.d.		64	n.d.			7	16	1	2	1			9	x	2	x		34	24	3			1							
KK 57	3-d		7		52	le, il, he			9	7	3	6	1		1	28	x	1	1		23	19											
50	12-a		8		44	il, le			14	9	6	2	x			30	1	7	4		14	13									x	pm	
100	5-d		5		55	il, le		2	5	22	9	4				36					15	9											
233	4-d		n.d.		61	go, il, le, py	4	x	16	8	2	2				38		5	10	x	3	15			1								
9	6-c	0.20	1		10	il			15		7					61		8	2		3	4											A-horizon

Table 20 Heavy mineral composition of sediments of the fine grained sandy ridges of the Wanica phase (MM 19 - KK 215F), the coarse grained sandy ridges of the Wanica phase (KK 44, 90), the fine grained sandy ridges of the Moleson and Comowine phases (W 37973 - KK 100) and the coarse grained sandy ridges of the Moleson and Comowine phases (KK 233, 9)

SAMPLE NUMBER	SAMPLE LOCATION (MAP-SHEET)	DEPTH (m)	LIGHT FRACTION		HEAVY FRACTION																												REMARKS
					OPAQUE		TRANSPARENT																										
			fsp (%)	OTHER MINERALS (apart from quartz)	(%)	MINERALS	Siderite	Biotite	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Sphene	Staurolite	Kyanite	Andalusite	Sillimanite	Corundum	Epidote	Hornblende	Augite	Enstatite	Hypersthene	Topaz	Spinel	Apatite	Monazite	Xenotime	Others (%)	Others (min)	
KK 10	5-d	1.50	4	mu 1%	22	il, py, le		56	16	1	10					46		7	2		5	13											B-hor. (below KK-9)
1	6-c		n.d.		67	n.d.			25	1	2					55		6	6		1	4							x				210-420 µm
1	6-c		n.d.		44	n.d.			16	1	11					64		2	2		2	1							1				105-210 µm
1	6-c		n.d.		62	n.d.			2	16	26	1				50		1		x	1								3				< 105 µm
KK 30	6-b		n.d.		12	see text			4		6					84	x	3	x		x	2							1				ridge, 250-420 µm
31	6-b		n.d.		23	see text			6		7					83		2	x		2	x											dune, 250-420 µm
30	6-b		0.8		21	see text			2	1	29					64		1			2	1							x				ridge, 105-250 µm
31	6-b		1.8		21	see text			2	1	19	x				73		1	x		2	2											dune, 105-250 µm
30	6-b		0.8		55	see text			1	27	23	2	1			42	x		x		3	x					x		x				ridge, < 105 µm
31	6-b		1.8		47	see text				15	27	1				57					x	x											dune, < 105 µm
18	6-a		3		55	li, py, il,le		3	10	5	6					69		1	2	1	3	3											beach, coarse
157	6-b		8		57	il, he, le,py	12	1	6	27	11					39		3	1		2	10						1					beach, coarse
153	8-d		n.d.		42	il, go, ma			1	6	27	1				64	1	x	x		'x			x		x	x		x	x			black sand, beach
478	16-b		n.d.		27	go, il			3		40					57																	beach, coarse
229	Fr.Guiana		n.d.		15	il			3	x	10					77	1	2	3		4	x						x					beach, coarse
IS 6	7-c		n.d.		53	il, go, le	x	7	5	5	6					56		2	1		14	9						1			1	tr	beach, medium
13	7-c		n.d.		41	il, go, le		2	3	2	13					66		2	1		7	6											beach, medium
KK 149	3-c		4	ch	41	le, il			8	17	1	6	x			17	x	1	2		39	9			x			x					beach, fine
75	3-d		10	ch	80	he, le, il,py		3	8	3	2	1				20	3	3	3		28	26			2				1				beach, fine
154	3-d		n.d.	ch	74	li, le, il		x	1	6	1	1				17	x	2	7	1	20	38	x	1				1	1		3	di	tr, beach, fine
IS 4	6-b		n.d.	ch	45	go, il, le	7	60	5	7	1	1	1			29					24	32											beach, fine

Table 21 Heavy mineral composition of sediments of the coarse grained sandy ridges of the Moleson and Comowine phases (KK 10-31) and the beaches (KK 18 - IS 4)

SAMPLE NUMBER	SAMPLE LOCATION (MAP-SHEET)	DEPTH (m)	LIGHT FRACTION		HEAVY FRACTION																											REMARKS
					OPAQUE		TRANSPARENT																									
			fsp (%)	OTHER MINERALS (apart from quartz)	(%)	MINERALS	Siderite	Biotite	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Sphene	Staurolite	Kyanite	Andalusite	Sillimanite	Corundum	Epidote	Hornblende	Augite	Enstatite	Hypersthene	Topaz	Spinel	Apatite	Monazite	Xenotime	Others (%)	Others (min)	
CICAR 25	fig. 26	30	1	n.d.	54	n.d.			25	31	4	5				19	4		4		6	1		x							1	cz	
CICAR 26	fig. 26	25	n.d.	n.d.	29	n.d.			33	3	5	1				34	7	3	3		9	1			1								
2475	fig. 26	40	9	n.d.	55	n.d.			5	10	1	2				3		6	3		41	19		1	7	1					2	pm	
C-23	fig. 26	<10	23	n.d.	12	n.d.			x	1		1			x	1					43	38	1	1	5						0	cz	gp, tr, cz
C-27	fig. 26	10	20	n.d.	10	n.d.		x	1	3		x		x		x		x	1		53	37	2		1						6	cz	ct, tr
KK 501	fig. 29		36	n.d.	27	n.d.			1	7	3	1	x		x	3	1	1	x		33	35	5	x	3			1			6	cz	ct, pm
2499	fig. 26	>50	n.d.		74	n.d.			9	35	1	2		x		4	3	5	5		27	6				2			1				di
J-009	fig. 26	40	n.d.		54	n.d.			5	12	1	1	1		1	1	3				47	20		1	4						3	cz	
G-036	fig. 26	35	n.d.		65	n.d.			3	19	2	4			x	4		1			46	13	4		1						3	ct	tr
CH-052	fig. 26	40	n.d.		43	n.d.			4	3	2	1	1	x	1	4	0	1	x		58	20	1		2						2	cz	tr, cz
B-001	fig. 26	<10	n.d.		28	n.d.			14	2	8	x				59	x	1	6		5	4									1	tr	

Table 22 Heavy mineral composition of sediments of the continental shelf of Brazil (CICAR 25 - C 27), the Amazon River (KK 501) and the continental shelf of French Guiana (2499 - B-001)

light minerals:

bi	biotite
ch	chamosite
ct	chlorite
gi	gibbsite
gr	graphite
ka	kaolinite
mu	muscovite
op	opal
vv	vivianite

opaque heavy minerals:

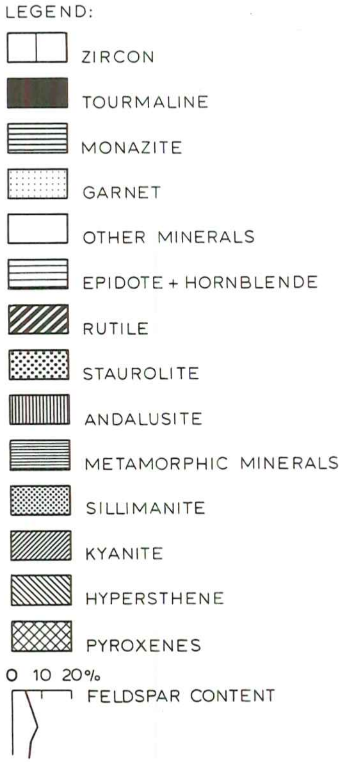
go	goethite
he	hematite
hi	hydro-ilmenite
il	ilmenite
le	leucoxene
li	limonite
ma	magnetite
py	pyrite
sec ru	secundary rutile

transparent heavy minerals:

at	anthophyllite
ca	cassiterite
ct	chlorite
cz	clinozoisite
di	diopside
du	dumortierite
gp	glaucophane
pi	pigeonite
pm	piedmontite
th	thorite
tr	tremolite
vi	viridine

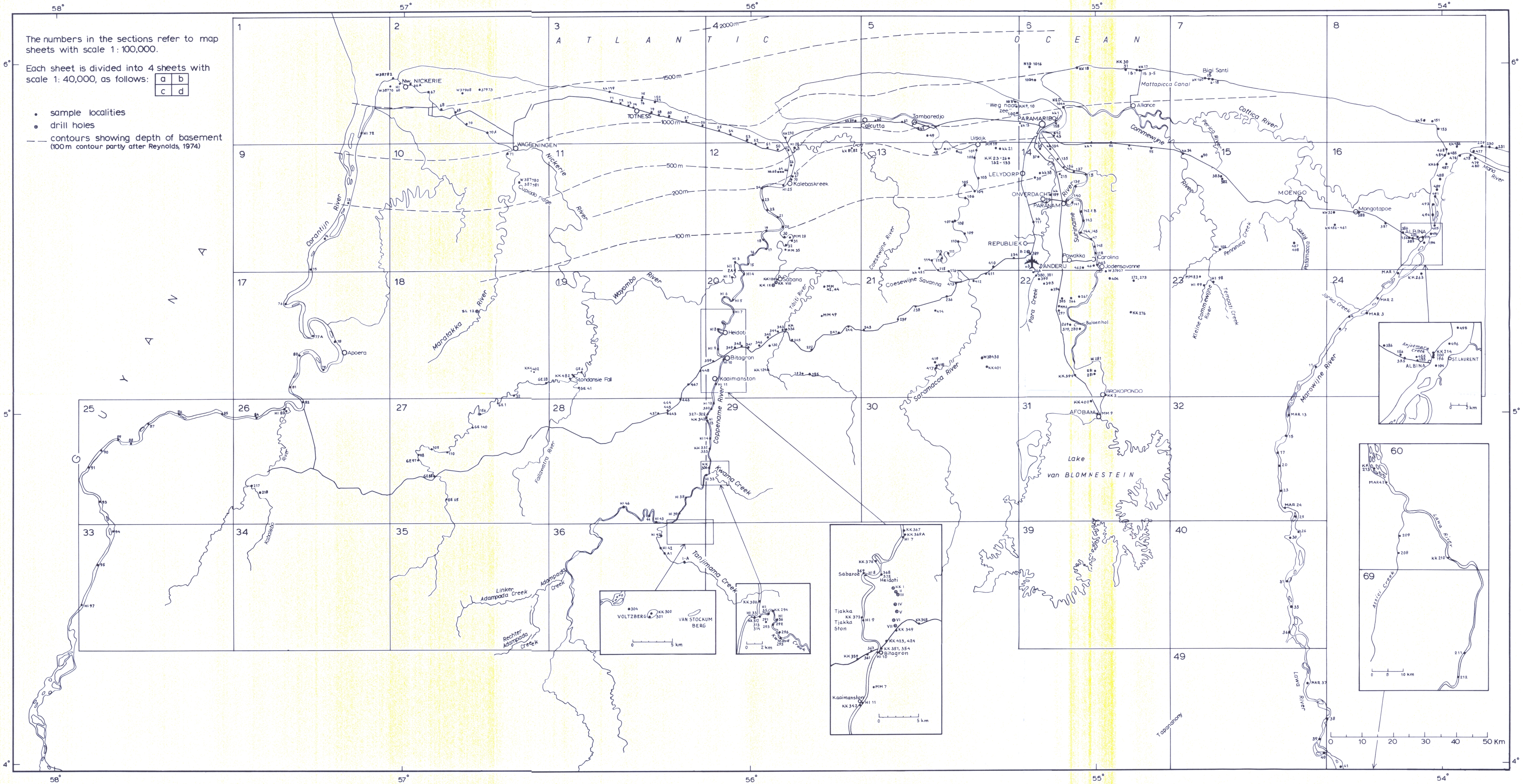
Table 22a Abbreviations used in tables 12-22

ENCLOSURE 4



L. KROOK SEDIMENT PETROGRAPHICAL STUDIES IN NORTHERN SURINAME

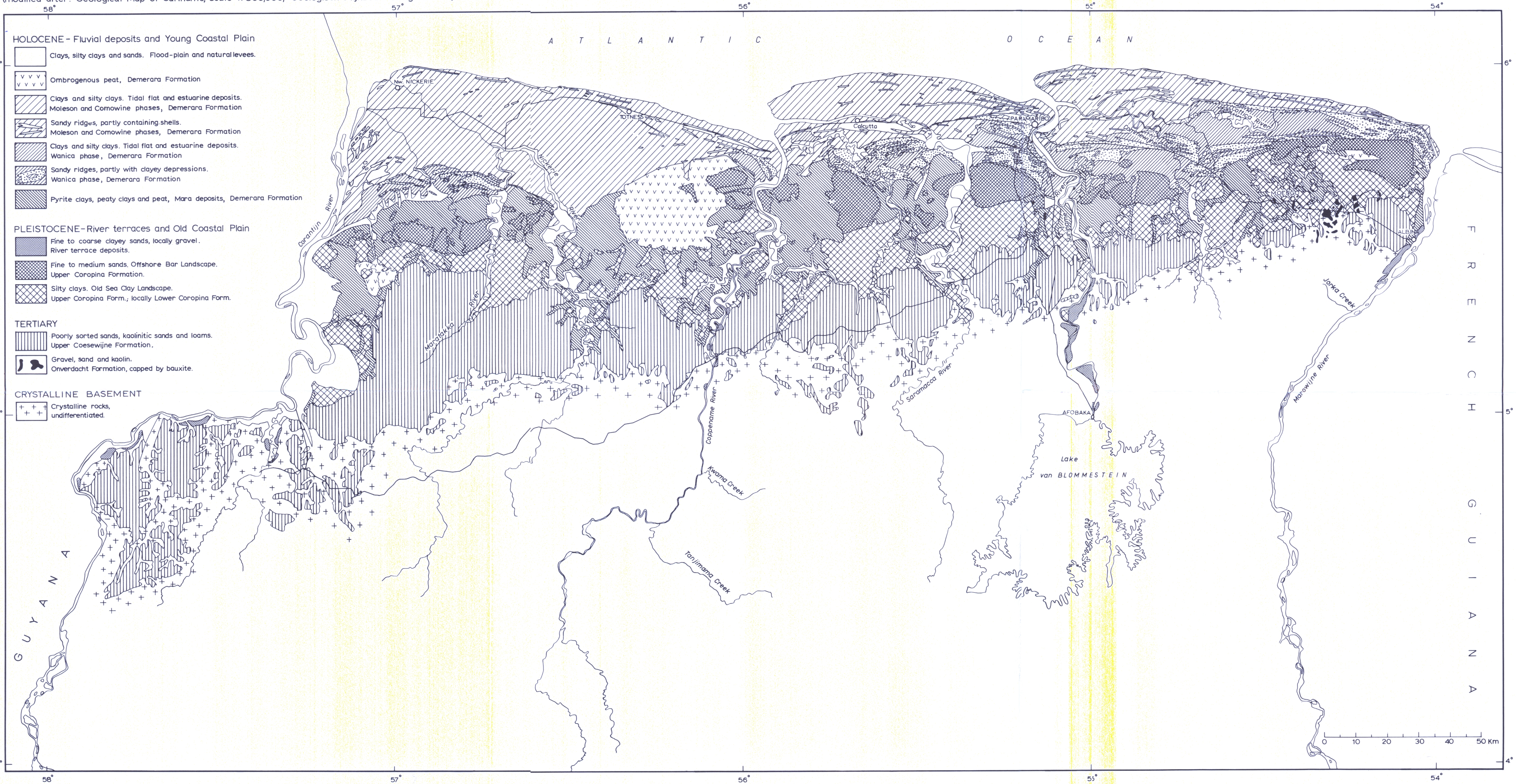
MAP OF NORTHERN SURINAME SHOWING SAMPLE LOCALITIES



GEOLOGICAL MAP OF THE CENOZOIC OF NORTHERN SURINAME

(modified after: Geological Map of Suriname, scale 1: 500,000, Geologisch Mijnbouwkundige Dienst, 1977)

L. KROOK   SEDIMENT PETROGRAPHICAL STUDIES IN NORTHERN SURINAME   ENCLOSURE 1



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HEAVY MINERAL COMPOSITION OF SEDIMENTS IN DRILL HOLES IN THE COASTAL PLAIN OF SURINAME