EVIDENCE OF AMAZON PROVENANCE OF A PART OF THE SANDY SEDIMENTS IN THE COASTAL AND SHELF AREAS OF THE GUIANAS

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Abstract

Heavy minerals were studied from deposits of the Amazon River bed and the continental shelf of northern Brazil and French Guiana. The Amazon supplies an association which consists mainly of augite, hypersthene, hornblende, epidote and some zircon and garnet. Toward the shelf a decrease of the pyroxenes is observed and an increase of the amphiboles.This gradual change is a consequence of the different hydraulic behaviour of these two mineral groups. In the lower Amazon and on the continental shelf a new element is added, viz.andalusite, the origin of which is still obscure.Samples from the shelf of French Guiana have an association of epidote, zircon, hornblende and some andalusite, while the contents of augite and hypersthene are very low. There is no doubt that the bulk of the sands containing these minerals has been supplied by local rivers during the low sea level stage of the last glacial. However, the sands also contain some typical Amazon derived minerals, viz. reddish brown basaltic hornblende, a typical light coloured hypersthene and slightly altered epidote, elements which would be inconspicuous for those not aquainted with the Amazon sediments. The same minerals have been encountered in Upper Miocene sediments on the Guiana continental shelf and in fine grained sandy ridges on the Surinam coast, cheniers of a kind not found in French Guiana. The occurrence of the typical Amazon minerals on the Guiana shelf can be explained by incision and reworking of the Amazon derived mudbelt during the regressive and transgressive sea-level movements of the last glacial and the Holocene.

Résumé

Une étude a été faite sur les minéraux lourds des gisements du lit de l'Amazone et des plate-formes continentales du Nord du Brésil et de la Guyane. L'Amazone a une association-type formée essentiellement par de l'augite, de l'hyperstène, de l'hornblende, d'épidote et d'un peu de zircon et de grenat. Vers le large, sur le plateau continental, on observe une diminution de pyroxène et une augmentation de l'amphibole, ce qui correspond à un comportement

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hydraulique spécifique de ces deux groupes minéraux. Dans le bas-Amazone et sur le plateau continental un nouvel élément apparaît, l'andalousite, dont l'origine reste obscure.Les échantillons de la Guyane française contiennent une association formée par de l'épidote, du zircon, de l'hornblende et d'un peu d'andalousite, tandis que les teneurs en augite et en hypersthène restent très basses. Il n'y a aucun doute que la majorité des sables contenant ces minéraux a été déposé par des fleuves locaux pendant la période de bas niveau de la mer, lors du maximum de la dernière glaciation. Toutefois, les sables contiennent aussi quelques minéraux amazoniens, à savoir l'hornblende basaltique brun rouge, l'hypersthène très peu coloré et l'épidote faiblement altéré, provenance qui peut passer inaperçue pour ceux qui ne sont pas familiarisés avec les sédiments de l'Amazone. Ces mêmes minéraux ont été observés dans des sédiments du Miocène Supérieur du plateau continental de la Guyane et dans des gisements de sable fin de certains cheniers du Surinam. L'existence des minéraux amazoniens sur la plate-forme continentale de la Guyane peut être expliquée par une reprise des rejets fins amazoniens pendant les variations du niveau de la mer qui se sont produites durant la dernière glaciation et au cours de l'Holocène.

Key-words : Heavy minerals, Guiana shelf, autochthnous sediment supply, Amazon sedimentation, sea-level changes, erosion..

Mots-clés : Minéraux lourds, plateau continental guyanais, apport de sédiments autochtones, sédimentation amazonienne, changements du niveau de la mer, érosion.

INTRODUCTION

Up to the present time comparatively few studies have been made on the heavy minerals of Amazon sediments. The first results of a heavy mineral investigation were given by LANDIM et al. (1978), who studied bed material samples taken during the 1976-1977 Alpha Helix expedition. At about the same time the geochemist G. IRION of the German "Senkenberg Institut" took many samples from the Amazon and its tributaries which were studied in great detail by STEIN (1979).

The continental shelf of northern Brazil has been closely sampled from the "Almirante Saldanha" (Brazilian Navy vessel) during the operation GEOMAR-I, in 1969. The heavy mineral results were given by POMERANCBLUM & COSTA (1972). During several other trips of the same Brazilian Navy vessel in the framework of a CICAR programme (Cooperative Investigation of the Caribbean and Adjacent Regions) other samples were taken (TJOE AWIE, 1975). Part of these, supplemented with others of the Amazon estuary and the shelf of French Guiana, taken during minor expeditions, were studied by KROOK (1979). For many years samples were taken from the shelf of Brazil during Woods Hole Oceanographic Institute-Brazilian cruises and Geomar cruises. BARRETO et al. (1975) reported on the mineralogy. At the Chapman Conference on the Fate of Particulate and Dissolved Components Within the Amazon Dispersal System: River and Ocean, held in Wild Dunes Resort, Charleston, SC, February 29 - March 5, 1988, the author obtained some samples taken from J. COUSTEAU's research vessel "Calypso" during the 1982/83 expedition from PH. DUSTAN of the College of Charleston (SC). The results of the investigation of part of these samples are used in this paper.

I - THE MINERALOGY OF SEDIMENTS OF THE AMAZON RIVER AND THE BRAZILIAN CONTINENTAL SHELF.

To facilitate comparison with data from other studies three grain size fractions, when available, have been studied from the Calypso samples, viz. 32-63 µm, 63-125 µm (STEIN's size limits) and 125-250 µm (BARRETO et al.'s fraction). Unfortunately the size fractions of POMERANCBLUM & COSTA (1972) are not known. Fig. 1 shows the Amazon and fig. 2 the continental shelf, both with sample locations. The composition of the heavy minerals of the Amazon River and the continental shelf off its mouth around the North Channel is shown in fig. 3. The Amazon has an association of hypersthene, augite, hornblende and epidote, and some garnet and zircon. The 63-125 µm fraction compares well with STEIN's data. The coarse fractions have considerable andalusite on the continental shelf and even some in the lower Amazon, the provenance of which is not clear, since it hardly occurs in the other Amazon samples. There is a decrease of pyroxenes towards the shelf and an increase of amphiboles. This is a result of the differences in hydraulic behaviour of these two mineral groups, partly caused by differences of cleavage. In the finest fraction, 32-63 µm, which occurs only in minor amounts in the Amazon River samples, zircon is an important component.

Fig. 4C shows the composition of the heavy minerals from samples taken along the same course, according to POMERANCBLUM and COSTA (1972). Their mineral countings had to be recalculated since they included biotite and muscovite.This is quite sensible, as these minerals form important components in recent Amazon sediments. Remarkably, chlorites,which occur quite frequently as well, were not even mentioned.The difference of POMERANCBLUM and COSTA's data with our data is striking: andalusite occurs only in the last two samples, hornblende contents are very high and epidote contents are low. The latter may be due to the altered nature of part of the epidotes. BARRETO et al. (1975) gave even more deviating results. They depicted an old river bed with an assemblage of hornblende, enstatite, hypersthene and sillimanite! Since these minerals all occur in the drainage basin of the Rio Araguari (SCARPELLI, 1969), this induced the present author to assume that they had been supplied by this river during the low sea-level stage of the early Holocene (KROOK,1979; 1988a). With the present heavy mineral data, however, the occurrence of enstatite and sillimanite is seriously questioned. At those places where only fine suspension material was deposited, an association of epidote and hornblende occurs (fig. 4A), with minor amounts of augite and hypersthene (KROOK, 1979). As distinct from the finest fraction of the foregoing, coarser, samples, this assemblage contains hardly any zircon.

Besides the bulk minerals there are some specific minerals which are very typical of Amazon sediments. These are reddish brown basaltic hornblende and a very light coloured hypersthene with an extremely faint pleochroism. Moreover, part of the epidote is often somewhat altered, a form not known from the Precambrian shield. It resembles the altered epidote of the Quaternary deposits of Western Europe and has possibly been formed under cold climatic conditions.

The sediments of the Amazon have almost entirely been derived from the Andes and the SW Amazon lowland. The greater part is supplied by the Amazon and the Madeira, typical "white water" rivers (SIOLI, 1984; FORSBERG et al., 1988). Most of the sediment is carried in suspension while only a small part is transported as bed material. The Rio Negro and many tributaries draining the Guiana Shield and the Brazilian Shield, "black" and "clear" water rivers, respectively, supply almost no sediments. This will be explained below.

II - SEDIMENT SUPPLY IN THE GUIANAS DURING THE LAST GLACIAL AND THE HOLOCENE

At present Amazon sediments are partly deposited in a large subaqueous delta on the continental shelf (NITTROUER et al., 1986b; KUEHL et al., 1988) and partly transported along the Guiana coast (EISMA & VAN DER MAREL, 1971; EISMA, 1988), where a belt of mud is deposited, in French Guiana down to the 30 m isobath in the east and to the 20 m isobath in the west (BOUYSSE et al, 1977). The same situation occurred during the high sea level of the last interglacial. When sea level fell at the onset of the last ice age this process went on until it was about 70 m lower than the present (MILLIMAN et al., 1975). The time when this low position was reached is still debated. According to the curves presented by SHACKLETON (1987) this was probably somewhere in the second half of the glacial. The falling sea-level resulted in a gradual seaward movement of the mudbelt on the shelf. Further lowering of the sea-level led to transport of the sediments through the Amazon canyon and deposition by turbidity currents on the Amazon Cone (MILLIMAN et al., 1975). On the emerged mud flat soil formation took place (NOTA, 1969). The rivers draining the Guiana Shield to the north supplied coarse clastic sediments as a consequence of increased erosion due to the decrease of forest cover in a relatively arid climate. Increase of the gradient as a factor of erosion as stated by PUJOS et al. (1990) is not very likely. In spite of the fact that the gradient of the emerged shelf surpassed the one of the rivers, and although the rivers on the shelf incised deeply in the recent non-consolidated sediments, these incisions hardly proceeded backward into the crystalline shield rocks. This is illustrated by fig. 5 which shows the profile of the Marowijne River and the continental shelf in front of it. Although there has been a gradual incision of the river in the course of time, the rapids (called soela's or sulas in Suriname) remained, and maintained a situation which was originally recognized as a "Dauerjugendstadium" or "stage of eternal youth" by BAKKER & MÜLLER (1957). According to these authors this was due to the lack of abrasive materials like gravel and sand due to intense tropical weathering. ZONNEVELD (1968) pointed to the possible complementary influence of recent "river conglomerates" which are often formed in the sula section from local components and apparently counteract erosion. Not all river conglomerates are recent, however. Some of them contain coarse pebbles and cobbles, supplied by streams which presently do not transport material of this size. According to DE BOER (1972), who studied the geomorphology of the Marowijne area, during times of "ice age aridity", planation surfaces or pediments were formed, covered by alluvial fans. When humid conditions returned, these fans were initially covered by fine grained floodplain deposits after which incision proceeded. This shows that during the lowest sea-level, connected with the glacial optimum and the most arid conditions in tropical areas, erosion was notably lateral and coarse clastics were produced. These were transported by braided rivers and eventually deposited in the coastal area. During the subsequent transgression, grainsizes gradually decreased, on the western part of the Guiana shelf (NOTA, 1958) as well as on the French Guiana shelf (PUJOS & ODIN, 1986; PUJOS et al., 1990). The transgressive sands often form a thin veneer on the soil formed on the muds deposited during the falling sea-level (NOTA, 1969). The coarse sandy submarine delta off the Marowijne is an exception to the rule (NOTA, 1971; PUJOS et al., 1990). When the rising sea attained about its present level the supply of Amazon mud was restored. Although no exact data are known of the shelf of Suriname, a near coastal fine sandy zone probably occurs here as well. These sands have been partly reworked and are found in the fine sandy ridges west of the Suriname River (fig. 6). The composition of the heavy minerals is shown in fig. 7. The gradual decrease of garnet and staurolite and the increase of epidote and hornblende in the direction of transport is a result of the hydraulic properties of the minerals. In the same direction AUGUSTINUS (1978) found a decrease in grain size and a decrease of the heavy mineral content. Although the heavy fraction consists mainly of shield-derived minerals it also contains the characteristic basaltic hornblende and the hypersthene, recognized as typical Amazon components. This indicates that most of the epidote and hornblende is also of Amazon origin. Which part of this was a component of the shelf sands and which part was supplied by the present Amazon derived mud, is hard to make out. Together with the shelf sands green glauconite-like pellets have been supplied. These grains, known as chamosite in Suriname (HARDJOSOESASTRO, 1971) may locally form as much as 30% of the sand in the fine sandy ridges. In French Guiana they received more attention and were studied in detail by PUJOS & ODIN (1986). It might be pointed out here that the Surinam rivers have supplied practically no sand for the formation of the cheniers in the Holocene coastal plain. This holds for the fine sandy ridges in the west as well as the coarse sandy ridges in the east. The sands of the latter have not been derived from the Marowijne, but from the rivers in French Guiana, as heavy mineral studies have shown (KROOK, 1979)

In Guyana, west of the Corantijn River, the situation is more complicated. According to BLEACKLY (1956) the cheniers are rich in staurolite but have low contents of sillimanite. This would point to little influence of the Corantijn which supplies much sillimanite but not staurolite (KROOK, 1979). AUGUSTINUS et al. (1984), however, found high sillimanite contents in the present beaches of eastern Guyana. This indicates that in relatively recent times the sediments supplied by the Corantijn River have reached the coast. This deserves further study along a N-S section.

III - AMAZON SEDIMENTATION DURING THE LAST GLACIAL AND THE EARLY HOLOCENE

After the lowering of the sea-level during the last glacial, the Amazon, which has an exceptionally low gradient, formed a long, deep, valley with a width of 30 to 50 km (IRION, 1976). The tributaries from the shields supplied coarse sediments to the Amazon which were eventually deposited on the Amazon Cone by turbidity currents. It is not known what the contribution of the Precambrian shields was to the whole of the sediment load. According to DAMUTH & FAIRBRIDGE (1970) the arkosic sands deposited during the last glacial by turbidity currents off the mouth of the Amazon were mainly derived from the shields in the lowermost part of the Amazon Basin. The evidence given was the grainsize, the angularity of the sand grains, and the high feldspar content. Unfortunately, a study of the heavy minerals, the classical way to determine provenance, has not been carried out.

When the sea-level rose, the large valley of the Amazon was transformed into a long ria-lake which was filled up gradually from the Andes (IRION, 1976). The mouths of the deeply incised tributaries which were also transformed into ria-lakes, however, were not filled up due to the lack of both transport power in these wide "mouth bays", and sediments (SIOLI, 1984). The latter was a result of the reforestation of the shields with the return of the humid conditions and the subsequent decrease of erosion (DAMUTH & FAIRBRIDGE, 1970). This explains why these rivers do not contribute to the heavy mineral composition of the Amazon. During the filling up of the Amazon ria-lake only the finest sediments could reach the sea. With the completion of the floodplain, the Amazon “várzea”, the sediments resumed their way to the ocean and to the coasts of Amapá and the Guianas.

IV - PROVENANCE OF THE SEDIMENTS ON THE CONTINENTAL SHELF OF FRENCH GUIANA

It has been mentioned above that fluvial sediments were deposited on the Guiana shelf during the lowered sea-level. The deposits on the shelf of French Guiana have been sampled extensively and the heavy minerals have been studied in great detail and compared with those from various rivers (PUJOS & BOUYSSE, 1988; PUJOS et al., 1990). Although the ways in which the samples of the shelf and those of the rivers were studied, differed considerably

(PUJOS et al., 1990) it could be shown that there is a relation between the composition of the shelf sands and the supplying rivers. Even the pattern of supply could be reconstructed which shows a clear agreement with the paleovalleys. As a matter of course the conclusion was drawn that the shelf sands were derived entirely from the shield and that "it did not seem necessary to suggest an Amazonian origin for the sandy phase present in the deposits of the Guiana shelf". However, no samples of the Amazon were studied to substantiate this assumption.

The results of the study of a number of samples of the French Guiana continental shelf were given by KROOK (1979). For the present study these samples have been carefully recounted, see fig. 4A. Most samples were from the area of "very fine grained sands" (PUJOS et al., 1990). They show an association of epidote, zircon, hornblende and some andalusite and garnet. The contents of augite and hypersthene are very low. It is difficult to compare these heavy mineral data with those of PUJOS et al. (1990), due to the differences of determination and presentation. However, on the whole the same minerals were found, albeit not with the same mutual relations. There is no doubt that the greater part consists of shield derived minerals. However, all of them contain low percentages of the typical Amazon minerals: basaltic hornblende, light coloured hypersthene and altered epidote. The content of the first varied from a trace to 3% and averaged 1.1%, as compared with 2.7% in 10 pure Amazon samples deposited from suspension. PUJOS et al. (1990) found "brown, highly coloured hornblende varieties" in the Oyapock, but painstaking research by the present author of samples from beaches and the Oyapock river mouth did not show any of the characteristic Amazon minerals. Furthermore, MACAMBIRA (1975), who studied many samples from the Amapá Territory on behalf of alluvial prospection, did not mention basaltic hornblende, although he distinguished four different types of amphiboles.

The characteristic Amazon minerals have not only been encountered in the fine sandy cheniers in Suriname and on the French Guiana continental shelf, but also in Upper Miocene deposits in a deep drill hole near the edge of the continental shelf of Suriname (KROOK, 1979). These sediments, deposited in an upper slope environment, have a thickness of 1200 m that has been formed in four million years. They were supplied by ocean currents and consist of fine grained Amazon sediments which remained in suspension when the bulk of the sediments was deposited as turbidites on the Amazon Cone (KROOK, 1979, 1988b).

As a final remark it should be stated that the author recognized the Amazon components in Miocene and Holocene sediments only after he had observed them in the fine grained sediments off the Amazon mouth (KROOK, 1979). In older publications the Amazon provenance has never been mentioned.

Once the evidence the Amazon provenance of part of the shelf sediments has been given, the question is how and when they were deposited. It has been mentioned above that Amazon muds covered a great part of the shelf during the gradually lowering sea-level. These muds contain small fractions of silt and fine sand. The contents given by different authors, however, differ considerably. PROST (1990) refers to BOUYSSE et al. (1977) and MIGNIOT (1989). According to the first the mud contains 10-50% greater than 50 µm, which seems rather high. MIGNIOT's contents vary from 0 to 2%. AUGUSTINUS (1986) mentions a sand content of 2%, but part of this may have been derived from fine grained shelf sand. According to NITTROUER et al. (1986b) the muds on the continental shelves "also contain some sand and, despite low proportions of sand, represent the greatest rates of sand accumulations in modern shelf environments". The sand content generally decreases in the direction of transport. A ternary diagram in their paper shows that the muds on the inner part of the shelf of Amapá consist of slightly sandy silty clay. PUJOS et al. (1990) showed that the shelf sediments, including the muds, were incised by the rivers during the lowering sea-level. This must have caused reworking and the mixing of the muds with fluvial sediments. Reworking probably played a role again during the subsequent transgressive sediment movements.

Amazon influenced sediments are also found at greater depths. Their occurrence in sample AM-33 at a depth of 107 m may indicate downward transporting agents, such as slump.

Acknowledgements:

The author wishes to express his sincere thanks to Dr. Ph.Dustan for part of the samples taken at the 1982/83 Calypso expedition. He is much indebted to Professor J. Tourêt for the French translation of the abstract and to Mrs. R. de Vries for the typing of the text.

REFERENCES

AUGUSTINUS P.G.E.F. (1978). - The changing shoreline of Surinam. Thesis Utrecht. Natuurwetenschappelijke Studiekring Suriname-Ned. Antillen, Utrecht, 232 p.

AUGUSTINUS P.G.E.F.; MEES R.P.R.; VAN ALPHEN J.S.L.J. (1984). - The behaviour of the coastline between the Essequibo and Corantyne Rivers (Guyana) since 1942. Study of approach channels to the Demerara and Berbice Rivers, Guyana, STUIP J.Ed., APPENDIX I, 42 p.

BAKKER J.P., & MÜLLER H.J. (1957). - Zweiphasische Flussablagerungen und Zweiphasenverwitterung in den Tropen unter besonderer Berücksichtigung von Surinam. LAUTENSACH-Festschrift.Stuttgarter Geographische Studien, B.69 : 365-397.

BARRETO L.A.; MILLIMAN J.D.; AMARAL C.A.B & FRANCISCONI O. (1975). - Northern Brazil. Contributions to Sedimentology 4. Upper continental margin sediments off Brazil., 11-43. Schweizerbart, Stuttgart.

BLEACKLY D. (1956). - The geology of the superficial deposits and coastal sediments of British Guiana. B.G.Geological Survey, Bull. 30, Georgetown.

BOUYSSE PH.; KUDRASS H.R.& LE LANN F. (1977). - Reconnaissance sédimentaire du plateau continental dela Guyane française (mission Guyamer, 1976), Bull.BRGM, IV, 2, Paris.

DAMUTH J.E. & FAIRBRIDGE R.W. (1970). - Equatorial Atlantic deep-sea arkosic sands and ice-age aridity in tropical South America. Geol. Soc. Amer. Bull., 81: 189 - 206.

DE BOER M.W.H. (1972). - Landforms and soils in Eastern Surinam. Thesis Wageningen. Agricultural Research Reports 771. Centre for Agricultural Publishing and Documentation, Wageningen, The Netherlands, 169 p.

EISMA D. (1988). - Dispersal of Amazon supplied particulate matter. Chapman Conference on Amazon dispersal system. Charleston (SC), Ext. Abstr.

EISMA D.& VAN DER MAREL H.W. (1971). - Marine mudsalong the Guiana coast and their origin from the Amazon Basin. Contr. of Min. and Petr., 31: 321-334.

FORSBERG B.R.; MARTINELLI L.A.; MEADE R. & RICHEY J.E. (1988). - Sedimentary delivery rates for the Amazon River and its principle Brazilian tributaries.Chapman Conference on Amazon Dispersal System,Charleston (SC), Ext. Abstract.

HARDJOSOESASTRO R. (1971). - Notes on chamosite in the sediments of the Surinam shelf. Geol. Mijnb., 50: 29-33.

IRION G.(1976). - The Entwicklung des zentral und ober Amazonischen Tieflands im Spät Pleistozän und im Holozän. Amazoniana VI, 67-79.

KROOK L. (1979). - Sediment petrographical studies in Northern Suriname. Thesis Vrije Universiteit, Amsterdam, 154 pp.

KROOK L. (1988a.) - Heavy minerals of the Amazon River and their provenance. An overview. Chapman Conference on Amazon dispersal system. Charlestown (SC). Ext. Abstr.

KROOK L. (1988b). - Heavy minerals in Amazon derived sediments on the continental shelf, the Guiana coastal plain and the Guiana Marginal Plateau. Chapman Conference on Amazon dispersal system. Charleston (SC). Ext. Abstr.

KUEHL S.E.; NITTROUER CH.A. & DeMASTER D.J. (1988). Amazon shelf sediments: past accomplishments future directions. Chapman Conference on Amazon dispersal system. Charlestown (SC) Ext. Abstr.

LANDIM P.M.B.; BOSIO N.J.; WU F.T.; MEYER Jr. A.E. & CASTRO P.R.M. (1978). - Heavy minerals from Amazon River bed. EOS 5, 277.

MACAMBIRA E.M.B. (1975). - Prospecção aluvionar do bordo sudeste do Escudo das Guianas. Anais da Décima Conf. Geol. Interguianas, Novembro de 1975, Belém, Pará, Brasil, 599-617.

MILLIMAN J.D.; SUMMERHAYES C.P. & BARRETO H.T. (1975). - Quaternary sedimentation on the Amazon continental margin: a model. Geol. Soc. Amer. Bull. 86, 610-614.

NITTROUER C.A.; DeMASTER D.J.; KUEHL S.A. & McKEE B.A. (1986a). - Association of sand with mud deposits accumulating on continental shelves. Shelf Sands and Sandstones. KNIGHT R.J. & McCLEAN J.R. Eds., Canadian Society of Petroleum Geologists, Mémoire II (1986): 17-25.

NITTROUER C.A.; KUEHL S.A.; DeMASTER D.J. & KOWSMAN R.O. (1986b). - The deltaic nature of the Amazon shelf sedimentation. Geol. Soc. Amer. Bull., 97: 444-458.

NOTA D.J.G. (1958). - Sediments of the Western Guiana Shelf. Reports of the Orinoco Shelf Expedition, II. Thesis Utrecht

NOTA D.J.G. (1969). - Geomorphology and sediments of Western Surinam Shelf: a preliminary note. Geol. Mijnb.,48, 185-188.

NOTA D.J.G. (1971). - Morphology and sediments off the Marowijne River, Eastern Surinam Shelf. Scientific investigations on the shelf of Surinam, H.NL. M.S.Luymes, 1969. Hydrographic Newsletter, Special Publication 6, 31-35.

POMERANCBLUM M. & COSTA M.P.A. (1972). - Sedimentologia da plataforma continental Norte Brasileira. Proc. Congr. Bras. de Geologia, 1972, Belém, Pará Brasil.

PROST M.T. (1980). - Les côtes des Guyanes. Rapport ORSTOM.Centre de Cayenne, Programme environnement côtier, Série Géomorphologie-Sédimentologie, mai 1990, 211 p.

PUJOS M.& ODIN G.S. (1986). - La sédimentation au Quaternaire Terminal sur la plate-forme continentale de la Guyane française. Oceanologica Acta, 9: 363-382.

PUJOS M.; BOUYSSE Ph. & PONS J.C. (1990). - Sources and distribution of heavy minerals in Late Quaternary sediments of the French Guiana continental shelf. Continental Shelf Research 10, 59-79.

SCARPELLI W. (1969). - Preliminary geological mapping of the Falcino River, Amapá, Brazil. Proc. Seventh Guiana Geol. Conf., November 1966, Paramaribo. Verh. Kon.Ned. Geol. Mijnb. Gen., 27: 125-130.

SHACKLETON N.J. (1987). - Oxygen isotopes, ice volume and sea level. Quaternary Science Reviews, 6 : 183-190.

SIOLI H. (1984). - The Amazon and its main affluents: Hydrography, morphology of the river courses, and river types. The Amazon, SIOLI H. Ed..Junk, Dordrecht, Boston, Lancaster : 127-165.

STEIN M.M. (1979). - Schwermineraluntersuchungen an Flussproben des Amazonas und seiner wichtigsten Nebenflüsse. Hauptprüfung Mineralogie. Institut für Sedimentforschung, Heidelberg, F.R.G., 74 pp.

TJOE AWIE E.C.(1975). - Report on sedimentological investigations as part of the reconnaissance survey of bottom sediments in the Amazon's mouth region. Netherlands Institute for Sea Research, Publications and Reports, 9: 51 p.

ZONNEVELD J.I.S. (1968). - Some aerial photographs from the Surinam jungle. K.N.A.G. Geografisch Tijdschrift II: 526-535.

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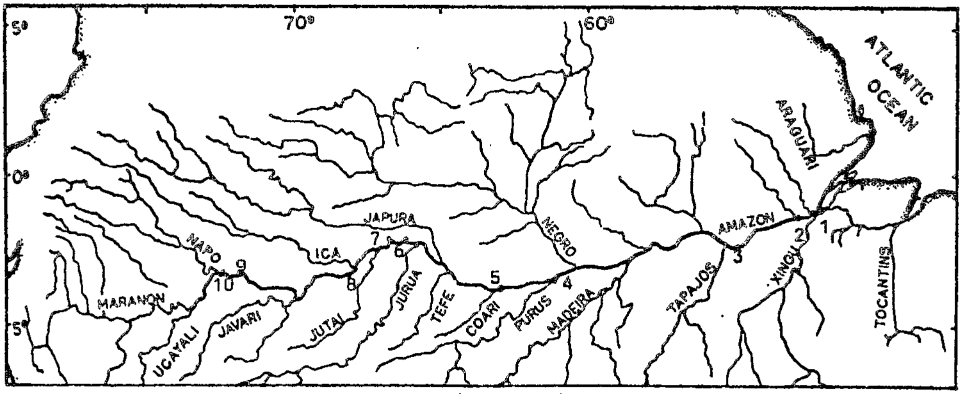

Fig. 1 Amazon River with sample locations

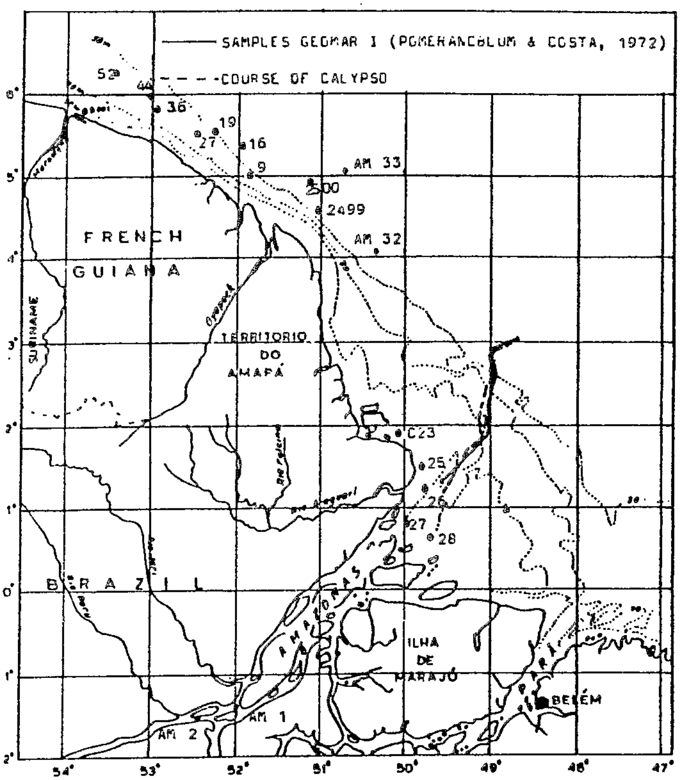

Fig. 2 Continental shelf of French Guiana and Northern Brazil with sample locations

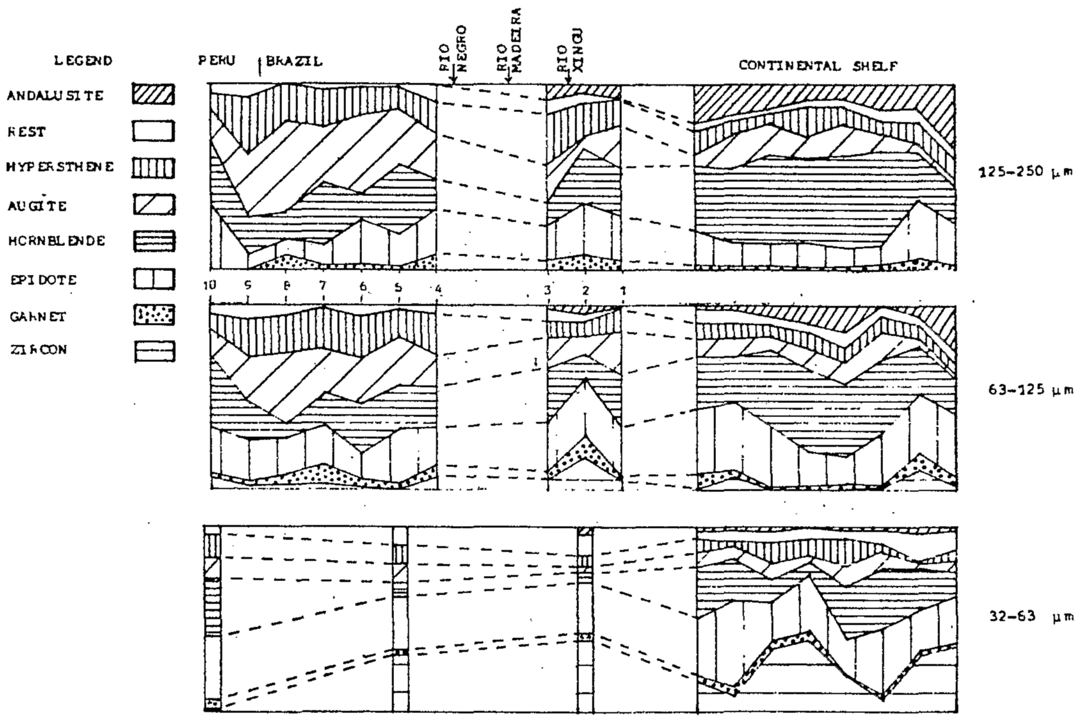

Fig. 3 Heavy mineral composition of the Amazon River and the continental shelf off its mouth. Locations in fig. 1 and fig. 2

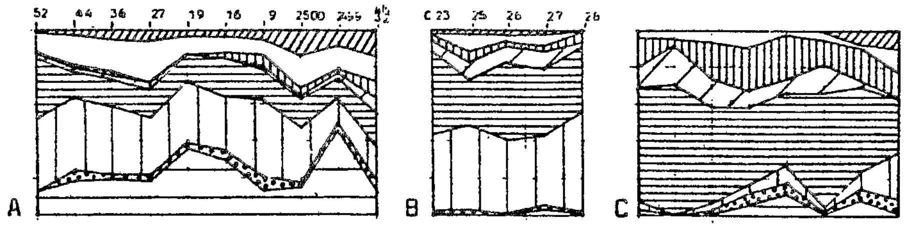

Fig. 4 Heavy mineral composition of the French Guiana shelf (A) and the Amazon River mouth (B), according to the author, and the continental shelf off the mouth according to POMERANCBLUM & COSTA (1972)

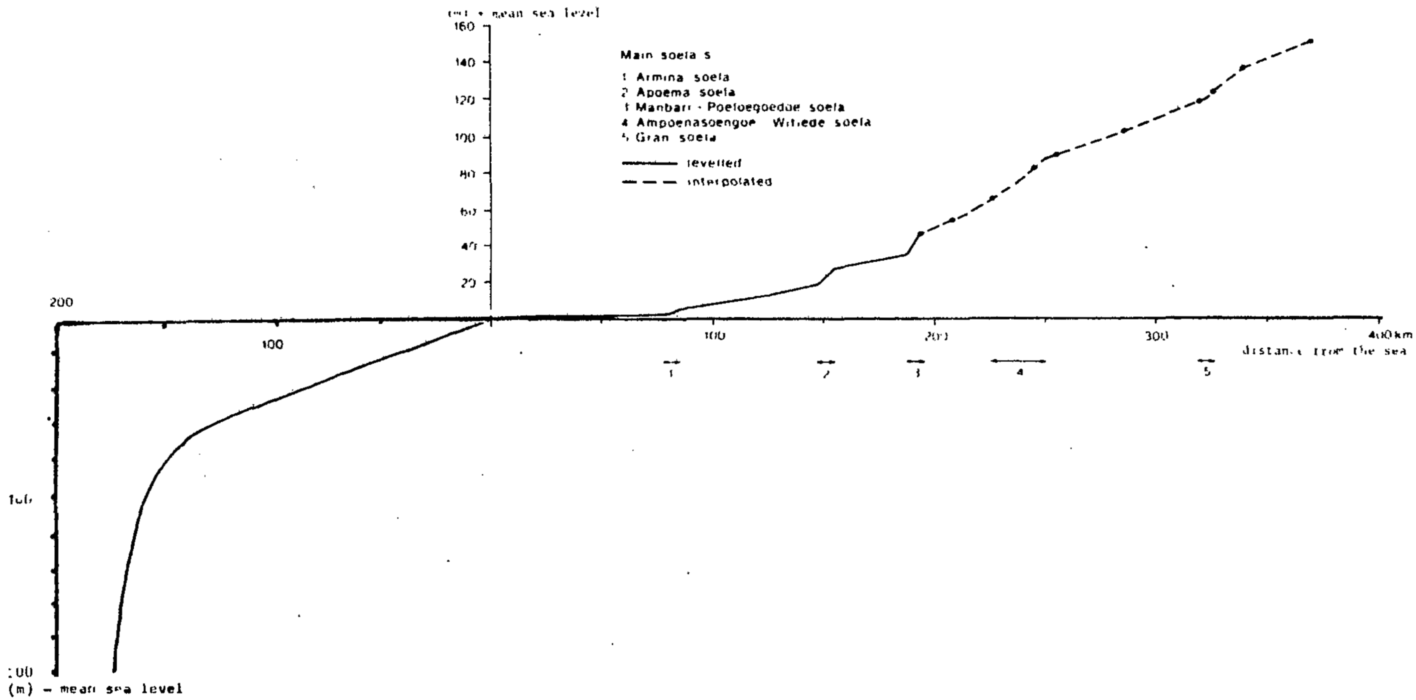

Fig. 5 Profile of the Marowijne River and the continental shelf off the mouth (partly after DE BOER, 1972)

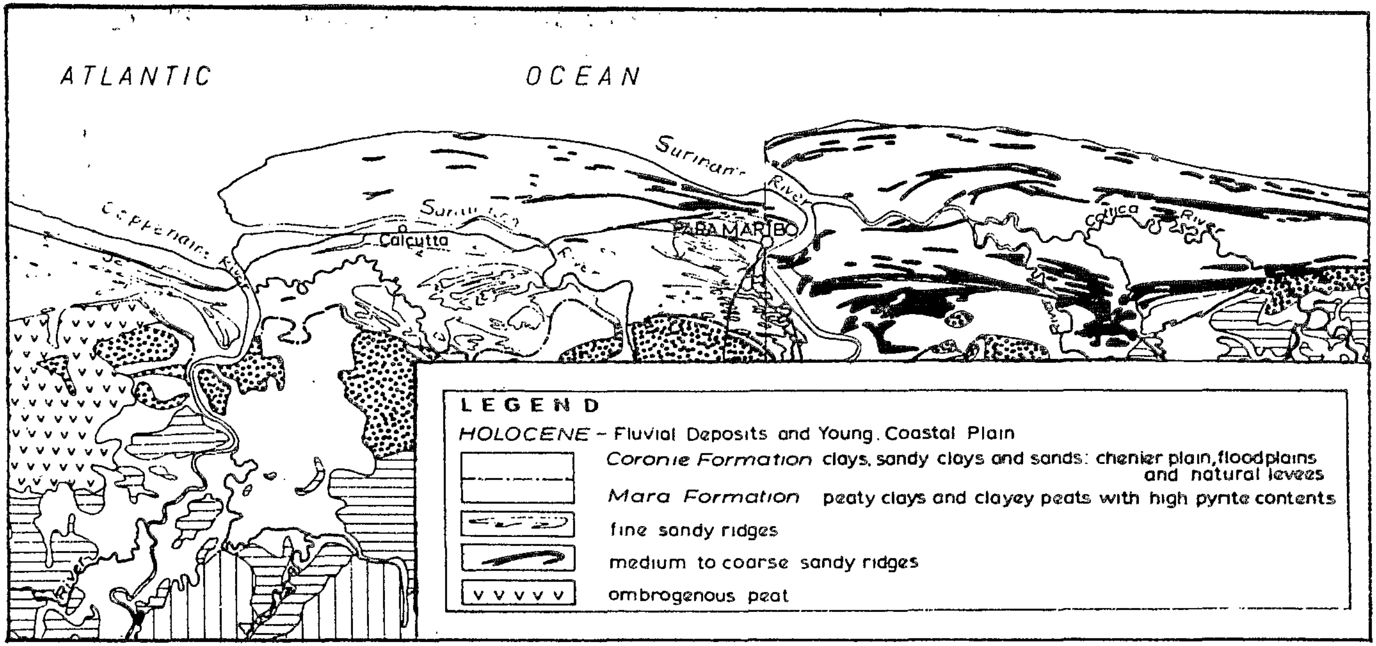

Fig. 6 Part of the Young Coastal Plain of Suriname showing fine sandy ridges and medium to coarse sandy ridges

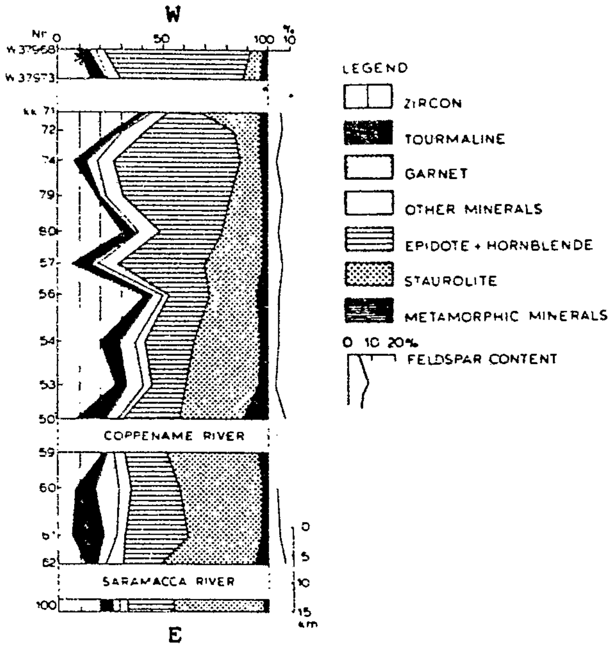

Fig. 7 Heavy mineral composition of the fine grained sandy ridges in Suriname