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LITTORAL AND SHALLOW MARINE GEOLOGY OF NORTHERN AND NORTHEASTERN BRAZIL

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In accordance with the Art. 15, decree n.º 62.493/68 (Reorganization of the Universidade Federal de Pernambuco, the former **Instituto Oceanográfico** is, at present, named **Laboratório de Ciências do Mar**.

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PREFACE

In a developing country, as is Brazil, basic knowledge on a great number of subjects in still scarce. This is also the case with the geology of the littoral environment and of the continental shelf of northeastern South America. There exist only a few studies, often unpublished, as internal reports or, when published, in magazines of small circulation.

Therefore, it is an honour for us, to introduce a publication which summarizes the actual knowledge on the littoral and shallow marine geology of northern and northeastern Brazil, between Cape Orange and the Abrolhos archipelago. We are aware that in such an extensive area, almost no detailed investigations can be presented. But we can also confirm that already much is known on the subject, although not always made public to a great number of scientists.

The Oceanographical Institute of the Federal University of Pernambuco in the person of Dr. Paulo da Nóbrega Coutinho, chief of the section of marine geology, in close collaboration with Dr. Jannes Markus Mabesoone, professor in sedimentology of the School of Geology of the same University, have undertaken the task of bringing together all for us available material on the subject, published or not, and resuming it into a volume of our magazine.

We are very obliged to the authors for their work. And we hope that it will serve as a base for further detailed investigation in a near future.

Lourinaldo B. Cavalcanti
Director

Recife, 1970
Oceanographical Institute (actually Laboratório de Ciências do Mar)
Federal University of Pernambuco.

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Finally, thanks are extended to Mr. Pedro Batista Neto and Mr. Paulino Machado Lira, for the drawing of the numerous figures and illustrations needed for this work.

1. INTRODUCTION

This monograph aims to resume the present knowledge of the littoral and shallow marine geology of northern and northeastern Brazil, an area still little known. This knowledge has substantially increased since 1958 when the Oceanographical Institute of the Federal University of Pernambuco began to function, often in collaboration with other institutions such as the Brazilian Navy and the SUDENE. Many shelf areas have been studied on their surface sediments and a number of isolated investigations, especially in the littoral environment have been carried out. Although the descriptions on this latter environment were made for other purposes, much useful information could be taken from them. Many of these studies have not been published, or only in the form of internal reports. In 1966, Botelho has undertaken a first tentative of mapping, emphasizing the scarceness of data, but nevertheless trying to present the characteristics of the Brazilian shelves and coasts in a map, from which some conclusions can be drawn.

All available data have been used in order to provide an idea as complete as possible on the geology of the coast and continental platform of northeastern South America. As figure 1 shows, the area in appreciation extends from Cape Orange, near the frontier between Brazil and French Guyana, alongside the coast of northern and northeastern Brazil, down to the Abrolhos Group off the south of the Bahia State. It includes also the shallow parts of the sea around the Brazilian oceanic islands, such as the Fernando de Noronha archipelago, the Rocas "atoll", the St. Peter and Paul's rocks as well as the banks which occur off the shelf area in the northern part of the country. It is quite natural that no complete information can be given on such an extensive area with a coast line of 3500 km. The existing studies deal with small isolated areas which are generally the most typical regions. In this way it is hoped that these preliminary studies "will fill the enormous gaps which remain in our knowledge of shelf sediments" (Guilcher 1964).

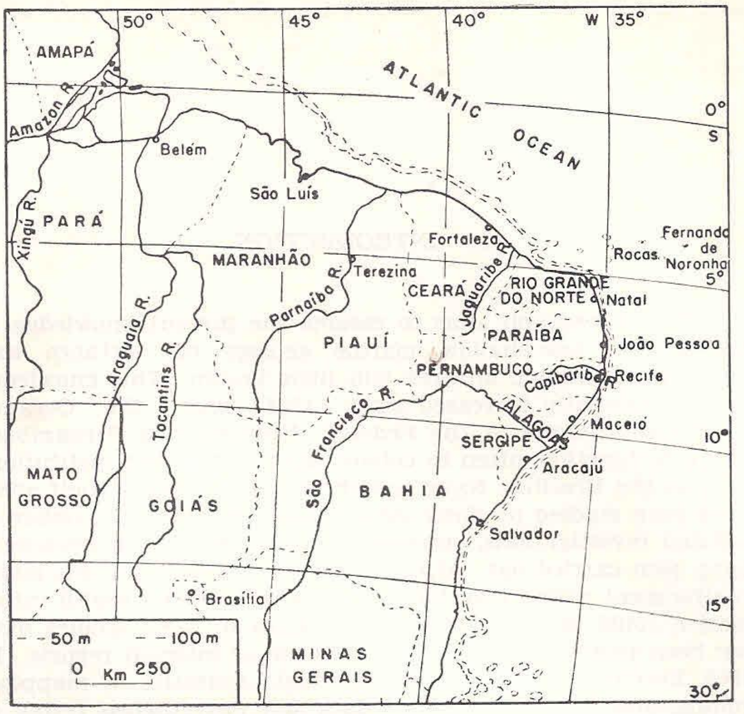

Fig. 1 — Investigated area.
Área estudada.

Much of the sampling of the sea bottom has been carried out by the oceanographical ship of the Brazilian Navy, R. V. "Almirante Saldanha", and by other smaller and adapted vessels, such as "Canopus" and "Akaroa" which were hired by SUDENE. Some data from foreign publications are also being included herein.

To the best of our knowledge, almost no data on the deep--sea bottom near the Brazilian coast are existing and therefore this area has been excluded. However, it is hoped that more information on this part will become available in a near future.

The oceanographical data necessary for the marine geology of the investigated area fairly scarce, but a general idea can be given. Most information is available on the deep-sea region farther from the coast. Especially the various Equalant--missions collected a lot of data which are not yet all published. Other information in given by Penteado (1964) is his resuming paper published in the book: "Brasil, a terra e o homem; vol. I — As bases físicas". Recently the R.V. "Almirante Saldanha" on its cruises "Operação Norte-Nordeste I, II; Leste I" collected a great number of data.

We are aware that many problems rise for which no acceptable solution is given. But we point to these to provide some basis for later detailed studies in the region. Particularly the age of the shelf sediments and the formation of recent limestones constitute not easily soluble problems and therefore they require quite a lot of more intensive study.

2. LITTORAL ENVIRONMENT

INTRODUCTION

Coastal types

Generalities. — A summary on the coastal morphology has been given by Silveira (1964). This author distinguishes in the investigated area the following coasts (fig. 2).

(1) Amazonian or equatorial coast — from Cape Orange to the eastern part of the State of Maranhão;

2) Northeastern or Barreiras cliff coast — from E of Maranhão to the Recôncavo area in the State of Bahia;

(3) Eastern coast — from the Recôncavo to the S of the State of Espírito Santo.

On the map published by Botelho (1966), the coasts have been subdivided after their sedimentary character. In this way one can recognize in the investigated area the following types:

(a) beaches and sandy cliffs — from the State of Pará to S of Sergipe, and at some extent S of the Contas river (Bahia State);

(b) low coasts and sandy-clayey cliffs — coast of Amapá, between Belém and Salinópolis (Pará) and the S part of the State of Bahia;

(c) clayey beaches and clayey hills — coast of the Marajó island;

(d) high slopes with a clayey cover — around the Todos-os-Santos Bay, near Salvador (Bahia).

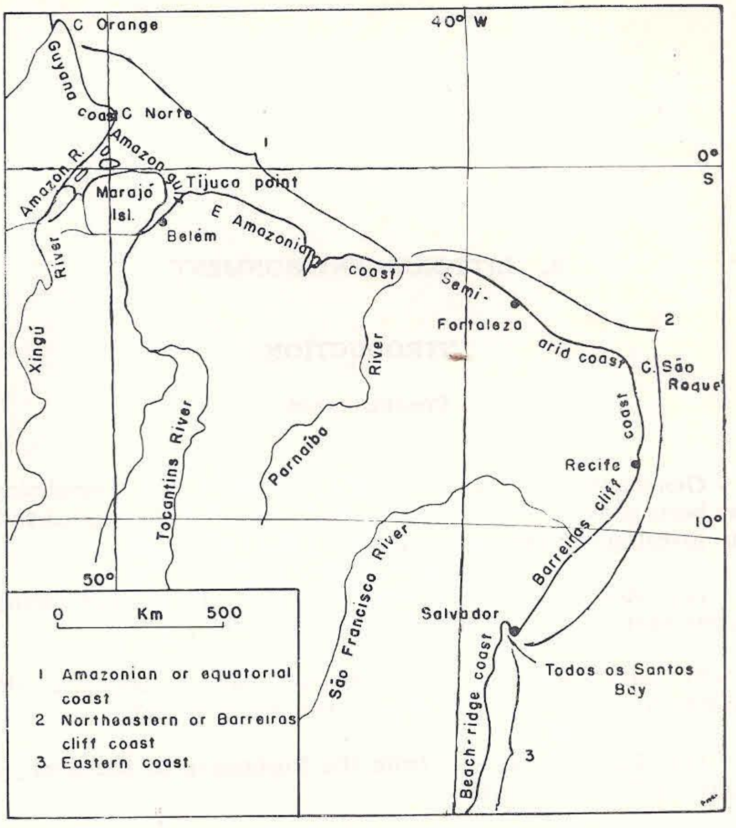

Fig. 2 — Coastal types.
Tipos do litoral.

Because the first classification gives a certain genesis of the coasts, it seems better to us to use this classification for further consideration.

Amazonian or equatorial coast. — This coast has a length of about 1500 km and has at some places a width of over 100 km, of low, sometimes inundated lands. The whole area shows recent and more rarely ancient sediments. Due to its shaping and the dynamic marine conditions, one can subdivide this equatorial coast into three parts.

The first part, the Guyana coast, is found between Cape Orange and Cape Norte. It is a low region constituted of recent sediments, belonging to the type of low coasts with sandy-

-clayey cliffs after Botelho (1966). This sedimentary strip has a variable width between 10 and 120 km. After Leinz (1949), the Amazon river is responsable for the sedimentation. The area can be divided into two different parts: "terra firme" and marsh. The "terra firme" is constituted of the more ancient sediments and situated at a height of 6-15 m above sea level. The more recent sedimentation occurs as a marsh area of mangrove swamps. In this area, an enormous deposition of fine clayey material takes place. This material has been supplied by the Amazon and the smaller rivers coming from the Guyana shield and transported towards north by the littoral currents. The mangroves sieve out this clay from the passing supension. Between these swamps, small lagoons may occur, separating islands from the continent. The biggest of these is the Maracá island.

The second part is the so-called Amazon Gulf. Its coast can only be difficultly traced. The coast line is extremely unstable due to the action of waves, tidal currents, littoral currents, river runoff, and winds. The big rivers Amazon and Tocantins form here an immense estuary. More inland still exists a terrace level, now being eroded by these rivers. Its remainders constitute the "ancient" islands, such as the SE part of the Marajó island. The tides exercise a strong influence in these estuary mouths, impeding a constant runoff of the river water and causing a flocculation of the finer suspended material. However, the Amazon river alone transports an average of 226.000 m^3 per second of water loaded with sediment; the major part of it is taken by the littoral currents and deposited at the coast of the Guyanas. The quantity of sediment deposited in the estuary is still very large. This causes a constant shifting of banks, filling-up of canals, etc., endangering the navigation and making necessary a constant revision of the nautical charts (Freitas 1967).

The third part is the Eastern Amazonian coast, in the States of Pará and Maranhão, up to the deltaic mouth of the Parnaiba river. Its aspect, with a great number of small estuaries bordered by low cliffs, proves that it is in full retreat. The high tidal differences (7-8 m) provoke strong currents with a highly destructive action. Mangrove swamps occur only at some quiet places which were before occupied by recent sediments. The sandy nature of the area and the strong winds caused the accumulation of dunes, particularly frequent in the State of Maranhão, attaining heights of several meters. However, the quantity of sediment-loaded water supplied to the sea is very high so that the offshore zone shows a strong sedimentation.

Northeastern or Barreiras cliff coast. — From the delta of the Parnaiba river up to the Todos-os-Santos Bay near the city of Salvador, the coastal phenomena are fairly continuous. The Cenozoic sediments of the Barreiras Group, of semi-arid climatic origin, constitute a surface which abruptly finishes at the coast by steep cliffs. Where at Cape São Roque the coast curves towards S, the littoral area can be divided into two parts which show also differences in climatic and oceanographic conditions.

The northern coast with a semi-arid climate is not well known. The recent sedimentary zone is very narrow. The shallow shelf area with a small slope causes the waves coming from ENE to supply a great quantity of sandy material to the coast, forming extensive beaches. The constant winds and the dry climate enable the accumulation of high dunes which remain in movement because of lack of vegetation. They also impede the water coming from the interior to run off freely, so that behind them lagoons and marshes are formed. At some places beach rocks develop. The environment is favorable for salt pans which produce the major part of the salt consumated in Brazil (fig. 3).

Fig. 3 — Salt pans, Rio Grande do Norte State.
Salinas no Rio Grande do Norte.

From southward Cape São Roque the coast is characterized by the Barreiras cliffs and by sandstone reefs. Coastal plains are narrow and have generally a height of 2-3 m above sea level being ancient terraces. The Barreiras cliffs are not continuous and thus permit the numerous rivers of this more humid climate to run their water off to the ocean. Two types of coastal lagoons can be found: the haff-type, parallel to the coast, and the liman-type, drowned river valleys closed by a bar from the sea. This latter type is the more abundant, especially in the State of Alagoas. The most remarkable features are, however, the sandstone "reefs" which occur in various lines parallel to the coast. They represent lines of beach rock, sometimes with a thin overgrowth of calcareous algae and corals. These reefs form a certain protection of the coast. At many places they are interrupted by inlets forming in this way excellent harbours, as is the case with the city of Recife. Where no reefs occur, the tidal currents can penetrate into the river mouths, developing extensive mangrove swamps; this is often the case with the area between the São Francisco river mouth and the north of the State of Bahia. More towards S, the coast becomes sandy with high dunes composed of white sands. This zone may be 10 km wide. The Todos-os-Santos Bay constitutes the end of the Recôncavo rift-valley in the State of Bahia. It penetrates some 80 km landward. It is a fairly deep bay with coasts and capes, marshes and peninsulae, and islands. It forms an excellent anchoring place, as shows the harbour of the city of Salvador.

Eastern coast. — This coast is low and characterized by a great number of beach ridges. There occur still Barreiras cliffs, but in a much less quantity. The recent sedimentation in the area is great. More towards south, where the shelf becomes wider and flatter, exists a number of coral reefs, for instance the Abrolhos Group. Furthermore, there are numerous greater rivers which embouch in this area.

Final remarks. — On a coast of over 3500 km length, no complete detailed studies can be given. Also there do not exist studies on a part of this coast considered as a whole. Therefore, in the next paragraphs the coastal phenomena will be considered as separate subjects, depending on the existing investigations.

Climate

The climate of the continent is well known, resumed in the paper of Andrade (1964). Alongside the north and northeast coast of Brazil one can distinguish the following types, grouped after the system of Köppen (fig. 4):

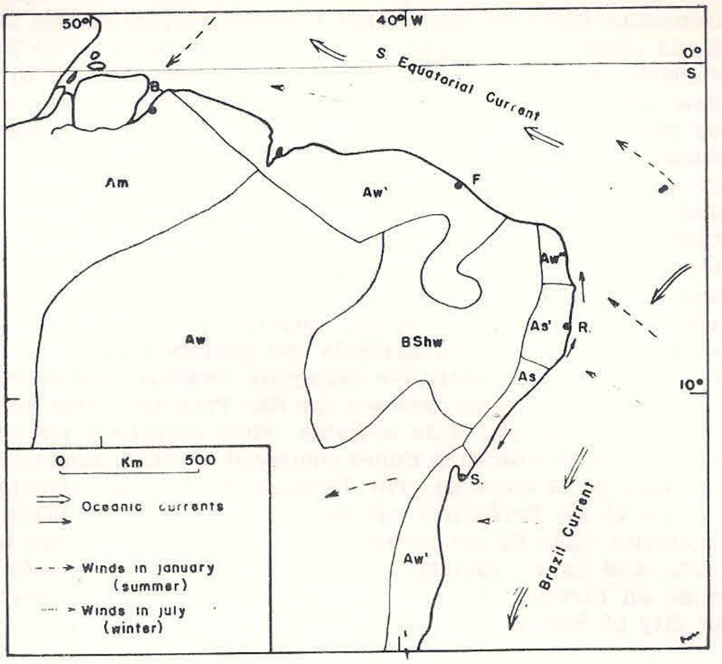

Fig. 4 — Climates, winds and oceanic currents.
Climas, ventos e correntes oceânicas.

(1) Aw' — tropical climate with precipitation in summer-autumn; this climate occurs alongside the northern coast from the Territory of Amapá to the State of Ceará, and alongside the eastern coast from Salvador (Bahia) toward south.

(2) Aw" — tropical climate with precipitation in two periods in summer, interrupted by a short dry season; it can be found in the State of Rio Grande do Norte, near the city of Natal.

(3) As' — tropical climate with precipitation in autumn-winter; the climate characterizes the coastal region of the States of Pernambuco and Paraiba.

(4) BShw — warn semi-arid climate with precipitation in summer; it is the typical climate of the interior of northeastern Brazil, but reaches the coast in the northern part of the State of Rio Grande do Norte.

In the interior part of northern Brazil one finds Am — tropical monsoon and Aw — tropical winter-dry climates.

The whole area is subject to the trade wind which blows fairly constantly but may differ in some seasons. The SE-trade wind dominates in northeastern Brazil and blows in northern Brazil in winter. The latter area has in summer a NE-monsoon. South of Salvador the trade-winds become deviated towards NE because of the circular action of the anticyclonic cell above the South Atlantic Ocean.

Tides

The tidal regime of northern and northeastern Brasil shows maximum amplitudes between 2 and 4 m, at some places reaching even more than 8 m (table I, after Penteado 1964). Only the Maracá island in front of the Amapá coast has still higher values, the highest in Brazil with an average at spring tide of 9,1 m and maxima of 11,7 m.

Table I — Tidal amplitudes in the investigated area
Amplitudes de maré na área estudada

Ilhéus (Bahia)	2,40 m
Salvador (Bahia)	3,60
Aracajú (Sergipe)	3,25
Recife (Pernambuco)	3,10
Cabedelo (Paraíba)	3,42
Natal (Rio Grande do Norte)	3,83
Fortaleza (Ceará)	4,20
Camocim (Ceará)	4,03
Luís Correia (Piauí)	4,36
São Luiz (Maranhão)	7,80
Itaquí (Maranhão)	8,16
Belém (Pará)	3,70

ESTUARIES

Various rivers of northeastern Brazil embouch into the ocean by estuaries. Only a few of these have been studied, and those investigated were done so because of the harbours built in them. More or less detailed investigations exist on the estuaries of the rivers Capibaribe, Paraíba and Potengi, in which occur the harbours of Recife, Cabedelo and Natal, respectively.

An older study exists on the estuaries near the city of São Luis (São Marcos Bay), whereas the Amazon mouth is a subject in itself.

Amazon

The Amazon estuary has a width of about 340 km at the ocean side between Cape Norte and the Tijuca point. The beginning of the estuary is generally considered at the mouth of the Xingú river (fig. 5). This means a length of 380 km, so that the whole region covers an area of 85.500 sq.km. And still not included are the alluvial lands at both sides. Whereas these terrains have been built by the Amazon, one may consider the estuary area having a surface of more than 100.000 sp.km (Sioli 1966b).

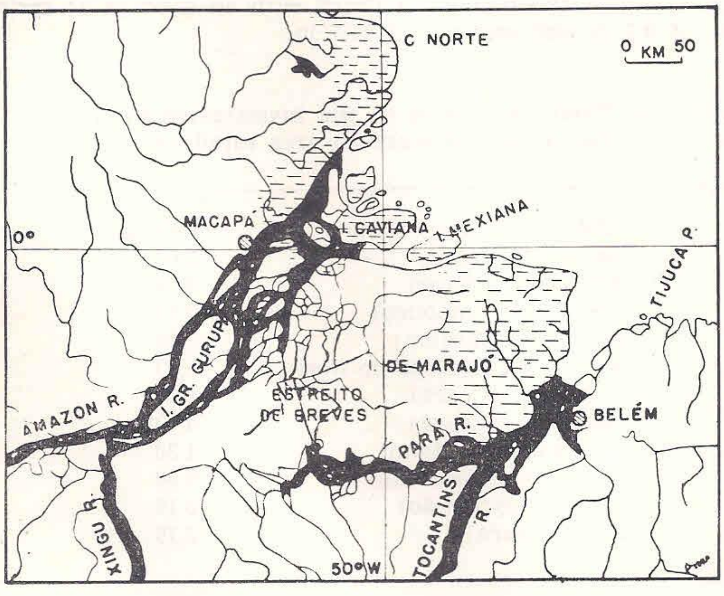

Fig. 5 — Topography of Amazon mouth.
Topografia da foz do Amazonas.

A great part of the area consists of recent alluvia, in the form of innumerable islands of which the largest are the islands of Marajó (47.964 sq.km), Caviana (4.968 sq.km) and Mexiana (1.534 sq.km) near the sea, and the Ilha Grande de

Gurupá (4.864 sq.km) at the beginning of the estuary. This enormous deposition which silted up the greater part of these islands, however, did not build a delta. Nowhere the islands advance towards the ocean; on the contrary, the Marajó island is even being eroded.

The river carries much material in suspension which has been estimated by Sioli (1957) as being about 50 ppm in the low-water and about 200 ppm in the flood season. This results in an average of 3×10^6 m^3 of material per day. The major part of this material is taken by the strong South Equatorial Current, and deposited alongside the Amapá (Brazilian Guyana) coast and those of the other Guyanas.

Only a part of the suspended load is deposited at the estuary borders and on the islands. During the dry season, these areas are partially dry with a muddy bottom, whereas they are flooded by 4 m of water during the rainy season. The zone is covered chiefly with grasslands and partially with forest subject to flooding.

The islands which are not totally constituted of recent alluvia, but partially of Eearly Quaternary deposits, divide the estuary into two main canals. The northern canal is the continuation of the proper Amazon river, the southern of the Tocantins river. The islands at the ocean side are surrounded by brackish water, influenced by the tides, and show mangrove swamps. More landward the islands are fluvial, surrounded by fresh water and showing the same vegetation as the alluvia of the lower Amazon course. The salinity has been measured in the Pará river (mouth of the Tocantins; by Moreira da Silva, 1959) showing that the waters in Belém are already fresh.

An intensive sedimentation occurs in one section. Here even a deltalike formation develops. It is situated SW of Marajó, where exists a communication between the Amazon and the Pará rivers by means of numerous channels (furos), narrow and separated by alluvial islands. This region is known as the Estreitos de Breves. The water in this area is fresh and, influenced by the tides, raise and lower their level twice a day with differences of 2 m. A part of the muddy Amazon water penetrates into the area, where the deltaic clayey islands have been built up. The creeks are very deep, 30-40 m, with steep walls, which is not easy to explain. Sioli (1957) supposes that the last sea level rise and the sedimentation were in a certain equilibrium. The silting up of the islands continued, whereas the creeks remained unaffected by the erosional action of the tidal currents.

An important phenomenon in the estuary is the so-called "pororoca", the three consecutive high tidal waves. They are sometimes 3-4 m high, roll up the river with a great force, exercise a very destructive action, and are dangerous for smaller vessels. The strong turbulent currents apparently contribute much to the instability of the depth of the river courses, particularly in the northern branch. Because of this, no definite nautical charts can be made, because long-known shallows disappear and are built up at places where formerly deep channels existed, whereas also the reverse occurs (Freitas 1967).

Unfortunately, not much is known yet about the character of the sediments in the estuarine area. The investigation of the Brazilian Navy effectuated in 1958 in the Pará river, mentions a sandy bottom in the centre. Furthermore, muds occur at the shores. Some studies of these alluvial soils have been made (Sioli 1966a). They are composed of detritus of ancient sedimentary and crystalline rocks; the silt fraction is the most abundant (50-60%). The clay mineralogical association shows a dominance of kaolinite (Bakker 1963). The procedence of the material is chiefly from the physical weathering products of the Andes Mountains, as showed studies on the material transported by the Amazon and its affluents, (Gibbs 1967).

The origin of the estuary constituted another problem; it is supposed to be the result of the younger geological history (Sioli 1966b). The lowering of the ocean level during the Quaternary glacial periods by some 100 m eroded a fairly deep river valley into the soft sediments. However, inside that excavated valley there must have been islands, as shows, for instance, the older part of the Marajó island with its "terra firme". It has also been proved that tectonic movements intervened, uplifting the part between the Xingú river and Marajó, where Amazon lake deposits of Plio-Pleistocene age occur at heights of 300 m, which is even the heighest section of the whole Amazonia.

The ultimate sea level rise caused the formation of the present estuary. The quantity supplied sediment to this area is only a small part of the total, but it is still enough to provoke a certain filling-up. At the shelf a submarine delta is actually being built. Russell (1958) even suggests that this loading of the shelf area could cause the uplift more landward by isostatic adjustment, as is the case with the Mississippi delta. The Amazon is apparently a delta-building river, as show the 400 m of delta-like deposits at the actual mouth since the beginning of the Mesozoic. The estuarine phases are only temporary and short (Pimienta 1959). This author considers the whole embouchure area as an intermittent delta.

Eastern Amazonian coast

The part of this coast between the cities of Belém and São Luís has been considered by Freyberg (1930). However, this author paid his attention almost only to the mangrove swamps. Only a summarized description of the other features is given.

As has been mentioned already in the introductory part, this coast is characterized by a great number of small bays which are in fact estuaries of the many rivers embouching here into the ocean. The sandy shore causes the accumulation of dunes; only behind these the mangroves grow. The rivers carry an enormous quantity of fine sediment derived from the chiefly clayey deposits of the Barreiras Group and the deep weathering profiles of the crystalline rocks. In the zone of tidal influence this mud flocculates, especially in the river bed and alongside its borders behind the coastal dune range. Only after this deposition the mangrove growth begins. This subject, however, will be considered in the paragraph dedicated to such swamps.

São Marcos Bay

This bay, the estuary of the Mearim river, reaches far landward over a distance of some 90 km. On the São Luís island, the city with the same name, capital of the State of Maranhão, has been built. Freyberg (1930) dedicated a part of his study on the Brazilian coast also to this area.

The São Luís island is in fact a separation between the São Marcos Bay and the São José Bay, estuary of the Itapecuru river (fig. 6). It is large enough to have some proper rivers which possess estuary-shaped mouths near the city of São Luís. The island itself shows still deposits of the Cenozoic continental Barreiras Group. At the other side of the city a small remainder of older sediments can be found, separated from the rest by a mangrove swamp, the so-called Campinas island. At low tide great surfaces of sandy and muddy deposits become dry in this area (fig. 7).

The Campinas island shows at its SW coast which is under the influence of the tides, a 20 m high cliff excavated in the Bar-

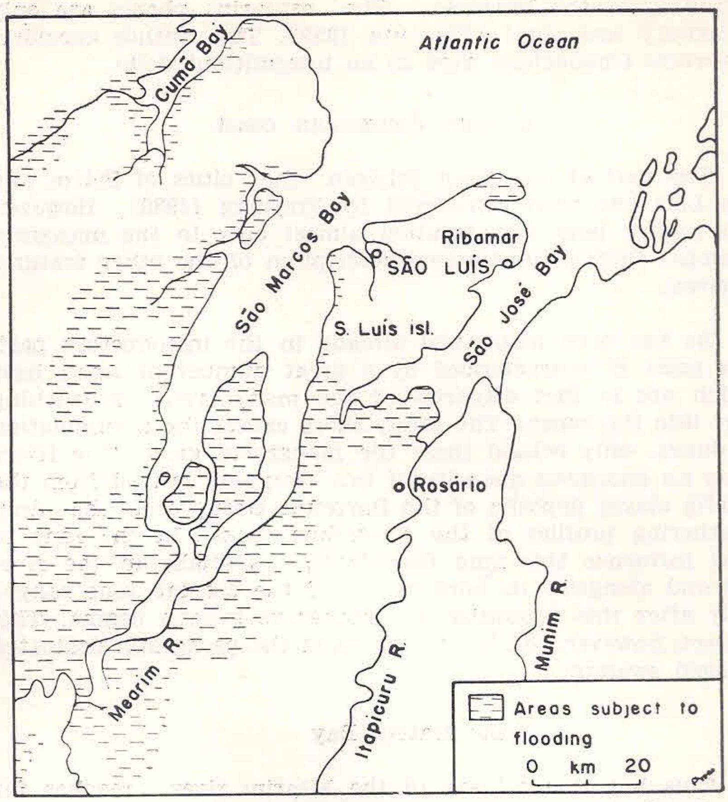

Fig. 6 — Topography of São Marcos Bay and surroundings (Maranhão State). Topografia da Baía de São Marcos e adjacências (MA).

reiras sediments. These deposits show layers of ironsandstone which cause the accumulation of its pebbles at the foot of the cliff. These pebbles accumulate at the low-tide line. The area between the cliff and this line is a muddy flat still without vegetation. Only more landward at the back side of the island, a gradual transition occurs from uncovered mud, via mud with grasses to a mangrove swamp. The incoming tidal current from W does accumulate spits of ironsandstone pebbles at the N and S points of the cliff. Interesting is the destructive action of marine organisms on these pebbles.

At the N side of the island, a narrow sandy spit can be found (called Ponta de Areia). It is connected to the São Luís island at the Barreiras cliff near the São Marcos light-tower.

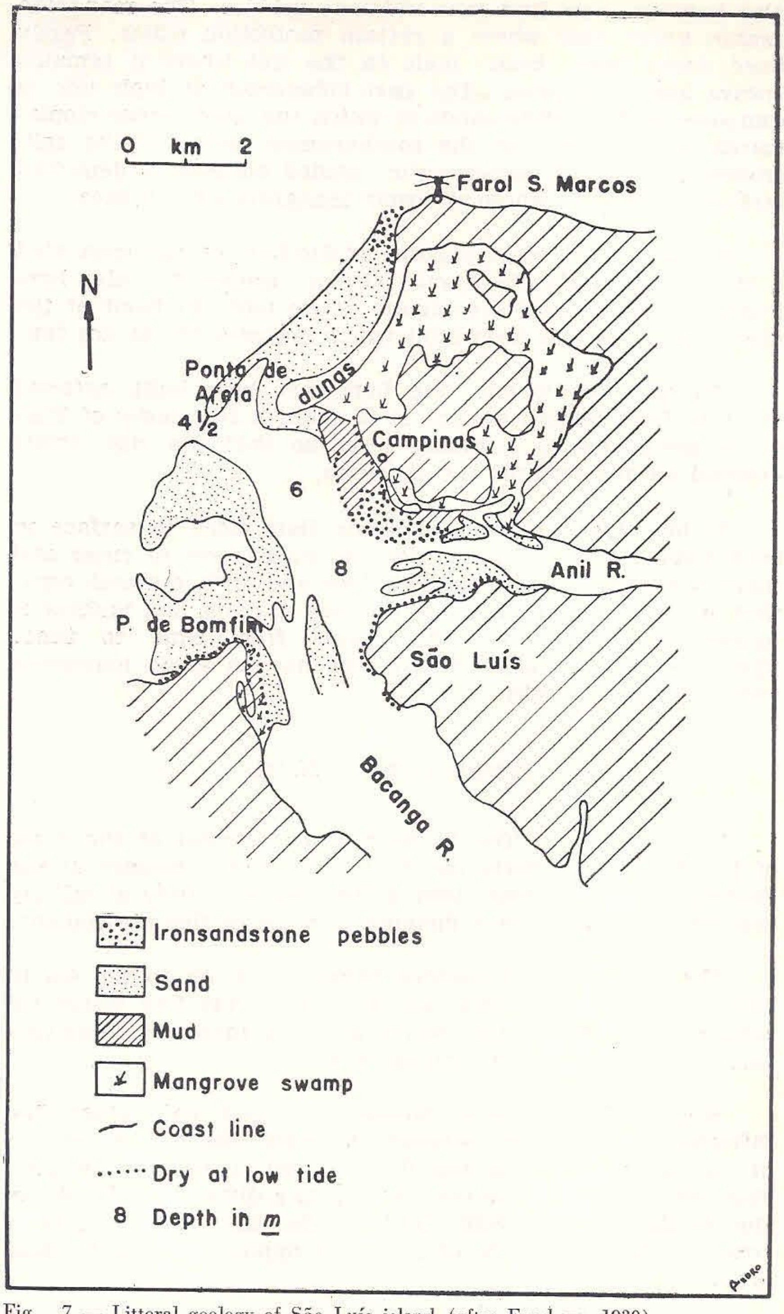

Fig. 7 — Littoral geology of São Luís island (after Freyberg, 1930).
Geologia litorânea da ilha de São Luís.

Also here one can find ironsandstone pebbles. The mangrove swamp grows only where a certain protection exists. Partly fixed dunes have been built on the spit where it remains always above sea level. The part submerged at high tide is composed of fine white sands in which the wind causes ripple-marks at low tide. At the southernmost point of the spit, erosion takes place, whereas the eroded material is deposited farther towards E, where it covers mangrove swamp areas.

At the Bomfim point, opposite of São Luís, erosion excavated a steep cliff in the Barreiras Group sediments. Also here ironsandstone pebbles accumulate at its foot. In front of the cliff a sand spit has been built which becomes dry at low tide.

The point on which São Luís has been built, suffered strongly from human action. It is again a remainder of Barreiras sediments on a higher level, so that the city streets descend steeply towards the estuaries.

At low tide a number of sandy flats come to surface in both river mouths. This causes the navegation to enter and leave the harbour only at high tide and with outmost care. The whole area suffers from a strong sanding up, making it necessary to dredge out the canals from time to time. Therefore, the harbour of São Luís has no great movement (580.000 tons in 1962).

Potengí river — Natal

Generalities. — The harbour of the capital of the State of Rio Grande do Norte has been built in the estuary of the Potengi river. Coutinho (1966, 1970a) made a study of salinity and sedimentation over a distance of 6 km in this enviroment.

The river brings a reduced volume of water to the sea in summer, so that its waters are clear with only fine suspended sediment. In winter this water quantity increases, supplying fine material during the higher floods.

Salinity showed rather homogeneous and high values. The difference at high tide between the river mouth and the end of the studied area was only 0,05°/oo and at low tide 1,85°/oo. The tides penetrate into the river up to a distance of 15-20 km. Due to the reigning SSE trade-winds, the surface flow is strongest at the W-side of the river opposite to the harbour area.

The point on which the city of Natal has been built, is not a spit, but a higher area constituted of Pleistocene sediments belonging to the Barreiras Group and ancient and recent dunes. Therefore, some cliffs have formed, which now are dead. Also most of the ancient dunes are now fixed.

Sediments. — The sediments have been grouped after their grain size distribution. One can distinguish four types: coarse, medium, fine and fine silty sands.

The coarse sand occurs only in the littoral area S of the city. Its quartz grains are subrounded, more or less frosted, with a medium diameter higher than 0,5 mm. Noticeable is the absence of micro-organisms. The sands are well sorted with a $Qd\phi$ between 0,25 and 0,43 and a skewness of about 0 (zero).

The sands of medium size occur chiefly in the estuary, in the canal alongside the harbour docks. The sand fraction varies between 84 and 99%, the medium size between 0,5 and 0,25 mm. The sand are medium-sorted ($Qd\phi$ = 0,20-1,30), and lightly skewed. The grains are subangular to subrounded chiefly not--worn. The organic material is poor and composed of fragments of pelecypods, gastropods, bryozoans and rare foraminifera of the miliolid family.

At the other side of the river, north of the land tongue and in the dunes, the fine sand facies is found. The sand fraction still constitutes 84-99% of the total, composed of subangular quartz grains with medium diameters between 0,25 and 0,125 mm.

Silty sands occur only higher up the river. Its combined silt-clay fractions is always more than 55%. The sand fraction shows besides angular quartz grains, chiefly mica. The sediments are poorly sorted, with a high fine fraction supplied in suspension by the river.

The suspended matter in the estuary waters showed a variation of 16-259 mg/l at low tide and 49-118 mg/l at high tide in August (end of winter). This material is silty to clayey, with vegetal roots, diatoms and near the river mouth rare foraminifera. Most of this material in suspension settles already higher up in the river area, wherea the transition zone of brackish water occurs.

Furthermore, the dominance of clastic quartz grains in the sediment is important. The lime content in most of the samples is low, 0,5% in the dunes, 3% in the littoral sands, 5% near the bar, and somewhat higher in the river canal. This means that the contribution of marine organisms to the deposit is only minor.

Sedimentation processes. — After data provided by Coutinho (1966, 1970a), a facies map was drawn. It is summarily represented in figure 8, together with the occurrence of the dunes in this area, a subject to be treated in a following paragraph.

In the Potengí river estuary the water masses are homogeneous and with a high salinity. At high tide the incoming current forces the suspended particles towards the bottom where they remain in suspension. Two to three hours after the high tide point, the bottom water velocity decreases even to almost zero, permitting the fine material to settle. During the low tide the surface current runs towards the sea, leaving the bottom waters without movement. The equilibrium between river and sea water near the bottom determines the sedimentation, especially higher up the river. At a distance of about 20 km, near the town of Macaiba, the major part of the clayey material settles and enables mangroves to grow over an extensive area. At high floods this clay sedimentation may reach up to about the Navy Base. In the estuary mouth almost no sedimentation occurs; the material found here has been derived from the shore and the dunes, before the building of the city and the fixation of these dunes. Only a certain marine reworking takes place in this estuary part. The dike constructed at the river mouth (Dique da Limpa) in 1923 caused the eolian currents to leave their material behind it. In this way a bank which before 1923 came to surface in the river mouth, has now totally disappeared, whereas the same is now a 9 m deep gully excavated by the strong currents. All material coming out of the estuary is taken by the longshore current and deposited at considerable distances. The area in front of the dike has now been sanded up to 3 m; its calcareous fraction is in process of dissolution and precipitation as a cement in the nearby sands.

The great quantity of beach and dune sand existing at the ocean side has apparently accumulated in an earlier period with a lower sea level stand. The sandstone reef which occurs parallel to the coast at a certain distance, protects the area from the sands coming from the south and transported with the coastal current to northward. Because of this the wide sandy coastal area remains almost eroded.

Conclusion. — From the sedimentary processes actually working in the Potengí river estuary, one may conclude that

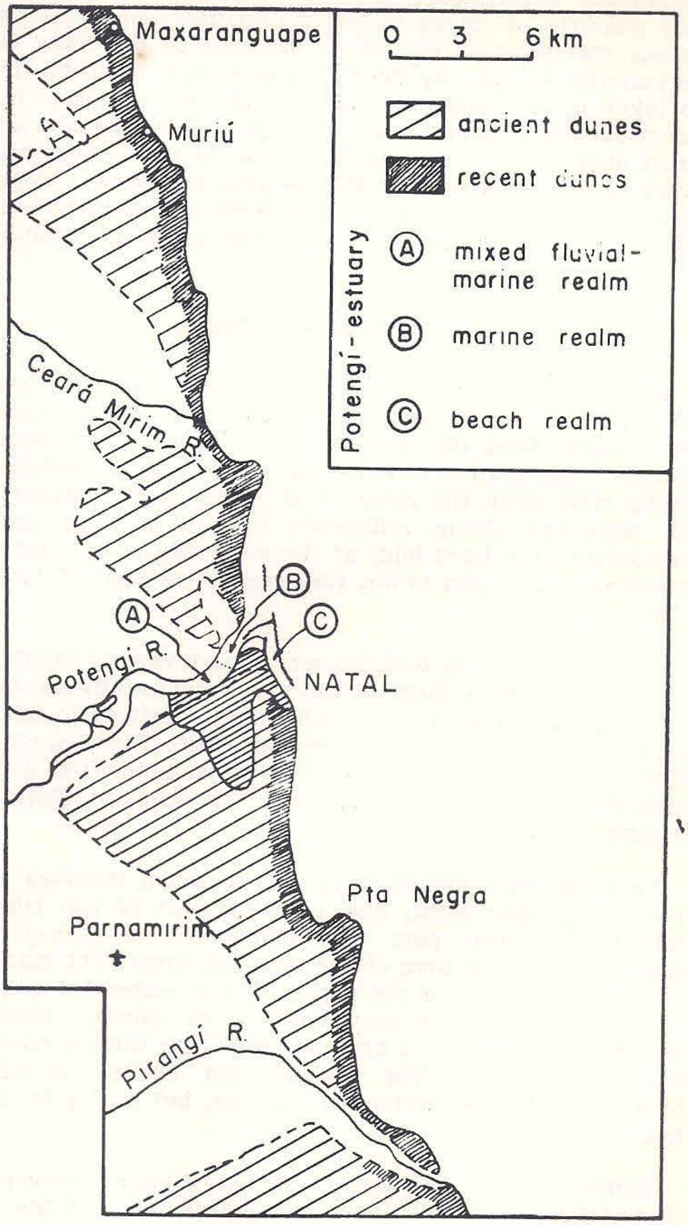

Fig. 8 — Sedimentary realms of Potengí river estuary, and dunes of the coast near Natal (Rio Grande do Norte State).
Ambientes sedimentares do estuário do Potengí e dunas da costa perto de Natal (RN).

the harbour installations are not in danger. At high tide a small quantity of clayey material flocculates near the docks, whereas this process retreats at low tide to the Navy Base. The material brought by floods is transported towards the sea and taken by the longshore current. The sea influence in the estuary mouth is almost zero, as is proved by the absence of marine organisms in the deposits. Only the tides exercise some reworking. The dike impedes the material transported alongside the coast to enter the estuary. The sediment quantity actually available for transportation is low, because of the fixation of the dunes.

Paraiba river — Cabedelo

Generalities. — The Paraiba river estuary has been studied by Freyberg (1930). Later Ottmann & Coutinho (1962) analyzed some samples from the river mouth area near the harbour of Cabedelo. The town is situated on a spit which separates the Paraiba river from the ocean, and is tied to the higher area with Barreiras Group sediments in the S. The harbour installations have been built at the river side of the spit. The movement in this port is not very great, totalling 280.000 tons in 1962.

The river embouches into the sea through various canals with small islands between them. In this area recent sandy and muddy sediments are found which are still being deposited. In the more quiet areas extensive mangrove swamps exist. The tidal currents are only superficial, whereas the river water runs off as a strong undercurrent. These currents cause the constant shifting of the sand banks.

Near the river mouth exists the so-called Restinga island between two river arms. The northern part of this island is sandy, the southern part has mangroves. In that part the surface is muddy, because of the tidal influence. The mangrove roots do not only sieve out a part of the suspended sediment load but cause also an accumulation of shells. Especially oyster banks grow in this area in which also various species of *Littorina* are living. The accumulated shells are strongly attacked, chiefly by mechanical action, but partly by boring organisms.

Sediments of the estuary mouth. — Figure 9 presents the different facies types distinguished in this area. In the Canal do Forte Velho occurs a sediment of fluvial origin, a fairly coarse sand with rounded, brilliant grains of quartz. This

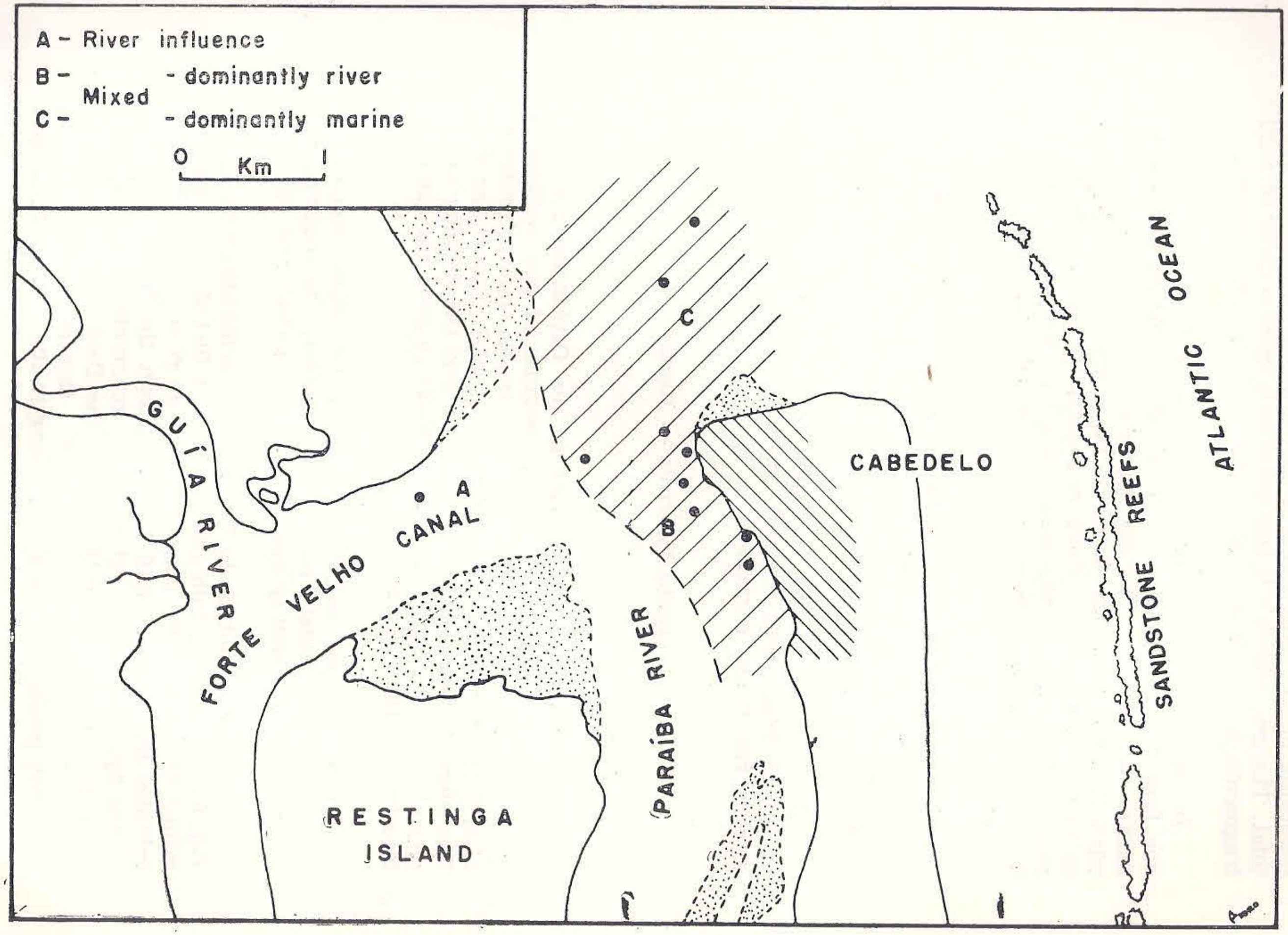

Fig. 9 — Sedimentary realms of Paraiba river estuary, (Paraíba State).
Ambientes sedimentares do estuário do Paraíba (PB).

reworking of the sand grains is due to strong currents, chiefly tidal. The sea influence is also noted by a small number of shell fragments, but the deposit as a whole is dominantly fluvial.

In front of the harbour installations and the river mouth one finds also deposits of fluvial origin, but with a higher marine contribution. The quartz grains show the same strong current action as in the Canal do Forte Velho. The fragments of organisms are chiefly shells of pelecypods and gastropods, of marine to brackish environment. The few calcareous algae and bryozoans must have been supplied by tidal currents into the estuary.

The study also includes some investigation in the open sea. The deposits there belong to the facies types which are commonly occurring in that realm. These types are described in detail in Chapter 3.

The conclusion is this that the Cabedelo port shows deposits of fluvial origin with a small marine influence due to the existing runoff and currents.

Capibaribe river — Recife

1. River

Generalities. — The estuary of the Capibaribe river has lost much of its proper character, because of the building of the city of Recife. The river is from time to time subjected to high floods which become disastrous in a highly populated area. Therefore, various studies on the river and the harbour of the city at its mouth have been made. Figure 10 gives the sampling localities of the river area.

Tidal influence. — Ottmann & Ottmann (1959b) studied the influence of the tidal current in the river, determining the salinity, water turbidity and also oxygen content and pH.

The tidal amplitude in Recife shows a maximum of 2,40 m (-0,10-2,30) and a minimum of 0,90 m (0,70-1,60) with medium values of 1,80 m. The tidal delay in the river is some 50 to 70 minutes at points 11 and 12. Although the harbour area is closed by a reef, the tidal currents are notable in the narrow river part, where, for instance near the Derbi bridge, velocities of 1-2 m/sec have been measured. One may conclude that sampling points 1, 2 and 3 still belong to the harbour zone with high salinities; 4-7 represent the brackish zone, whereas 8-12 are already fluvial. Because in the harbour area the salinity values remain always high, point 1 — the Giratória bridge — is the real river mouth.

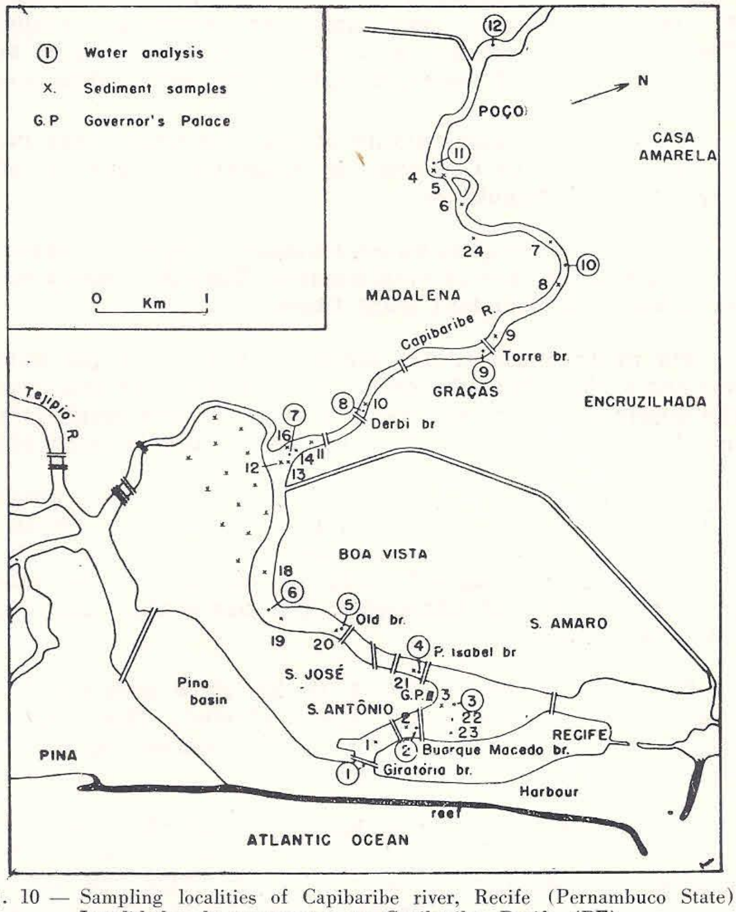

Fig. 10 — Sampling localities of Capibaribe river, Recife (Pernambuco State). Localidades de amostragem no Capibaribe, Recife (PE).

The pH and dissolved oxygen values show a parallelism. Their variations are not due to salinity but to the influence of the sun (Ottmann & Ottmann 1959b).

Turbidity values show themselves extremely variable. Near the Princesa Isabel bridge it is influenced by city wastes. Near the Derbi and Torre bridges also a relatively high turbidity value is found; this may be due to the flocculation zone at the saline and fresh water limit, where also mud banks accumulate. The dry residue consists of three fractions: (1) sand — in a low quantity, with a medium size of 0,1 mm; (2) clay — in a high quantity, composed of flocs more than of free particles; (3) organic material — very abundant, especially diatoms (*Cosninodiscus deucereus*) in simbiosis with green algae, and also plant fibers and some ostracodes in the more saline zone.

Sediments. — The deposits of the Capibaribe river have also been studied by Ottmann & Ottmann (1959a). Several types can be distinguished.

The sediment of quiet waters (samples 4, 13) are black muds with a low percentage of sand fraction. They are chiefly clays and micas with abundant plant fibers.

The medium-size sands, (samples 5, 6, 16, 18 in the fluvial part and 3, 20, 23 in the brackish area) are generally well sorted. The quartz grains are rounded and glossy. Heavy minerals are abundant, feldspars rare. The clay content may be fairly high.

The coarse, sometimes gravelly sands have been directly derived from the ancient deposits which constitute the plain of Recife. They are sorted by the tidal currents and show a lack of fine material (samples 7, 9, 10, 11, 12, 19, 21). The quartz grains are angular to subangular. The clay content may vary, but is never high.

The mixed sediments (15, 8, 17, 22) show high quantities of all three fractions: gravel, sand and mud. This mixing is due to the currents which reworked older coarser deposits and deposited fine material between them.

Concluding one may say that the Capibaribe river has a bed of ancient sediments. It transports only mud from the interior, especially during the rainy season. This fine material flocculated at the river banks chiefly in the brackish zone between the Derbi and Torre bridges. The stream channel, however, remains with a sandy bottom due to the current.

Floods. — From time to tome high precipitations in the upper course area of the Capibaribe river cause high flash floods. Because of the human intervention within the city limits which channelled the river into one principal stream, these floods become often disastrous. This occurred, for instance, in 1960, 1962, 1965 and 1966.

On the 1960 flood Ottmann (1960a) was able to make some studies. The river transborded at various places, and carried off an enormous quantity of floating plant material and suspended load. Measurements were made at the Giratória bridge, Princesa Isabel bridge and Derbi bridge (1, 4 and 8 on fig. 10). The results are mentioned in table II.

Table II — Salinty and suspended material in the Capibaribe river during normal circumstances and the flood of 1960, after Ottmann (1960)
Salinidade e material em suspensão no rio Capibaribe em circunstâncias normais e durante a cheia de 1960, segundo Ottman (1960)

		suspended material flood g/l	suspended material normal mg/l	salinity flood S°/oo	salinity normal S°/oo
1—Giratória bridge	surface	14,6		0,3	25—30
	bottom	13,3	220—260	0,3	30—35
4—Princesa Isabel bridge	surface	12,0	200	0,25	20—32
	bottom	12,5	90	0,25	25—35
8—Derbi bridge	surface	10,3	—	0,2	7—25
	bottom	12,7	55		

The transported material in the river consisted chiefly of silt and clay (90-95%), which flocculated apparently in the harbour basin, where the salinity increased rapidly and the currents lost much of their velocity especially at incoming tide. The sand fraction had a medium grain size of 100-200 microns, but some grains of 2 mm size were found (near the bottom at the Derbi bridge).

It was also observed that the salinity in the river decreased almost to zero. This caused the muddy suspended material to flocculate only in the harbour area.

In 1966, two thirds of the city suffered from the flood, whereas various parts were totally inundated. At present a regulation of the river runoff is being prepared.

2. Harbour

Generalities. — The city of Recife possesses the most important harbour of northeastern Brazil. Its movement in 1962 was of 1.900.000 tons.

It is a harbour at the mouth of the estuaries of two rivers: Capibaribe and Beberibe. A very peculiar phenomenon is that it is protected by a barrier of sandstone (reef), forming already a natural break-water. The most important problem is its constant filling-up by the material transported to the sea by these two rivers. The mechanisms of this deposition has been the subject of a study by Coutinho (1961), whereas a resuming paper appeared by Ottmann & Coutinho (1963); also Ottmann (1965) dedicated a few lines to this study.

Description of the sediments. — Figure 11 gives a map of the harbour area with its sedimentary facies types. One can distinguish some four groups of deposits: the coarse ones at the mouth of the harbour, those in the so-called Pina basin, the fine ones in almost the whole central harbour area, and the transition types between these.

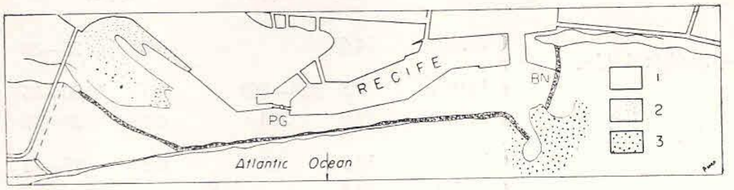

Fig. 11 — Bottom sediments in Recife harbour (Coutinho 1961); 1: mud and sands, 2: sands of Coroa dos Passarinhos, 3: sands of harbour entrance.
Sedimentos do fundo no pôrto do Recife; 1: lama e areias argilosas, 2: areia da Coroa dos Passarinhos, 3: areia da entrada do pôrto.

In the Pina basin at the inner part of the harbour area is found the so-called Coroa dos Passarinhos, composed of coarse sand with a few organisms covered with a 1 cm thick of brownish clay. This part is exposed at low tide. At its two sides exist canals, the southern one being dredged out in 1936-37 and serving as the outflow of the river waters, and the northern one extended in 1960 to the Cabanga Yachting Club. The medium sediment of the area consists of some 85% of sand size fraction; the organic material is composed almost entirely of shells of pelecypods.

The other occurrence of coarse sediments is at the harbour entrance. They are composed for about 50% of quartz and about 50% of organogenous material, such as benthonic foraminifera, gastropods, pelecypods, algae, sponge spicules, etc., all accumulated as a detrital fraction.

The central harbour area has a bottom of fine sediments, of dark gray to black colour. The sand fraction varies between 2 and 20% and is composed of quartz grains and rare organisms, such as small foraminifera, ostracodes, sponge spicules and others. The fine fractions consist of silty and clayey material of fluvial origin, chiefly supplied by the Capibaribe river.

Between the fine sediments of the central zone and the coarse ones of the harbour entrance and the Pina basin occurs a gradual transition. The clayey sands and sandy muds are found in narrow zones. They are composed of quartz grains, some shell fragments and silt and clay size material.

Sedimentation processes. — In the Pina basin one can thus distinguish two zones, one with coarse sandy sediments — the Coroa de Passarinhos —, the other with fine muds, with a small transition zone between them. The sand of the Coroa is of marine origin, proved by the presence of typical marine organisms, absent in the estuarine environment. The calcareous fraction may even attain 70% of the total sample. That part of the Coroa which becomes dry at low tide, shows lower $CaCO_3$ percentages because of dissolution. The small layer of clay has been supplied by the rivers Tejipió and Jequiá, chiefly during their floods. Actually, the sedimentation is almost zero, with only a very small supply from (1) river floods, (2) waves passing the break-water, (3) some eolian transport from a small beach at the basin, and (4) possibly during floods of the Capibaribe river, when a part of the material is thrown into the Pina basin. The deposits met with in this area are thus chiefly fossil, partly caused by human interference which closed its direct contact with the sea and covered the dunes by building a suburb. This lack of recent sedimentation makes the basin well profitable for harbour expansion.

The central zone possesses chiefly clayey deposits of fluvial origin. Therefore, the Capibaribe river is of great importance for the sedimentation in this area, especially because of its floods. The marine influence is only because of the tides. Formerly, the Capibaribe river embouched into the harbour area by various canals, but sucessively these have been closed due to the expansion of the city. So, actually the river is restricted to only one stream, dividing itself into two arms, of which one enters the harbour of Recife in the south, passing the Giratória bridge (PG on fig. 11) — the most important branch —, and the other passing northward where it joins with the waters of the Beberibe river continuing through the entrance of the Navy Base (BN on fig. 11). In summer this runoff of the Capibaribe river is very small, which is proved by the tidal influence reaching up to 12 km landward. In this season the river waters are very clear with some 50-250 mg/l of dry residue, consisting of clayey material, diatoms and microscopic green algae. The low quantity of sediment coming from the interior flocculates in the area influenced by the tides, forming irregular clayey barriers alongside the river banks. In winter, however, the river shows muddy waters, ocre coloured, thus transporting large quantities of clay and fine sand. During the catastrophic flood of 1960, an enormous amount of clay deposited in the proper harbour basin, in this way contributing to its filling-up. These facts were confirmed during the desastrous flood of 1966, when the already dredged part of the harbour was totally filled up again (R. Nóbrega, personal communication), so that the dredging had to be started anew. Only regulation of the river runoff can stop such enormous sedimentations in the central zone.

The entrance of the harbour is characterized by coarse sediments composed of organogenous fragmental material and some partly hardened and laminated clay of fluvial origin. This latter material is deposited at low tides by flocculation. The sandy facies forms a tongue penetrating into the harbour area. The presence of this material is apparently due to the existence of bottom currents which may attain velocities of 0,5 m/sec, when entering at rising tide. Actually, this penetration of the tidal current in the harbour is reduced due to the building of the northern pier. This pier also impedes the sandy material transported at NE winds towards the harbour basin, from entering this area. Thus, only the currents from the S contribute still to the sand accumulation.

DELTAS

Introduction. — There exist only a few river mouths in the investigated area which develop more or less as deltas, although real ones with the classical shape are not present. The rivers which show such a deltaic accumulation, are the Parnaíba and the São Francisco. But a detailed study of neither the first, nor the second was made. So it is only possible to give some general information provided by Maio (1962).

Parnaiba. — This river serves as the frontier between the States of Maranhão and Piauí and is one of the most important of the region. It shows a more or less intermittent character, because it receives only a few perennal affluents on its left border and a great number of temporary ones on its right border. This, of course, has its influence on the delta formation. Also the intermittent Longá river which embouches into the Parnaiba at a small distance from the delta area, has its influence on the whole complex. For this reason Ab'Sáber (1956) prefers to speak about the Parnaiba-Longá delta.

Another important phenomenon for the shape of the river mouth is the fairly strong longshore South Equatorial Current. As can be seen on figure 12, this current did curve the accumulation zone towards the W, just as it does with the material of the Amazon.

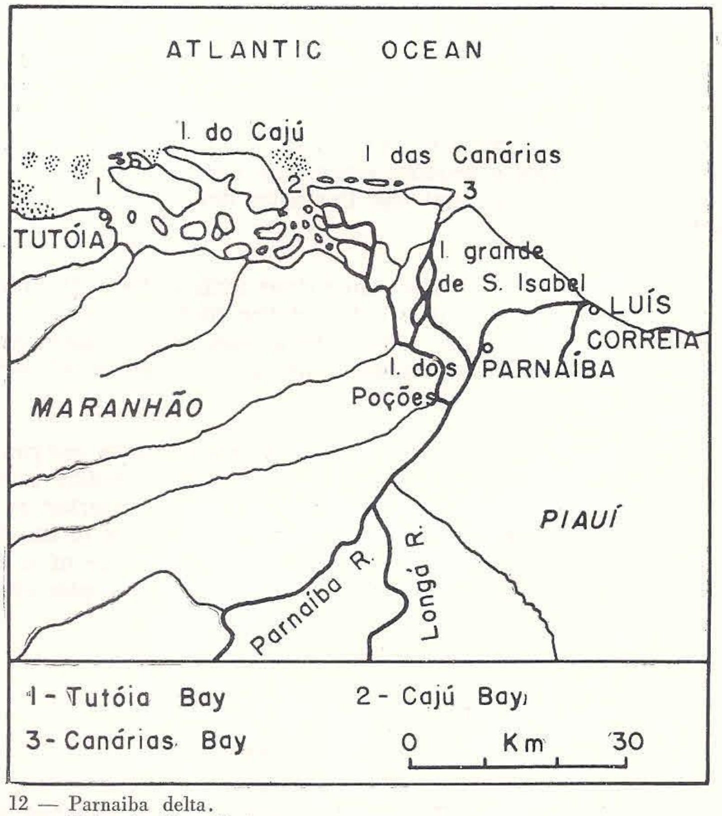

Fig. 12 — Parnaiba delta.
Delta do Parnaiba.

One can distingue three different parts in the delta:

(1) between the Tutóia and Cajú bays, a part with many islands;

(2) between the Cajú and Canárias bays, with only small islands;

(3) between the Canárias bay and the town of Luís Correia, with one island in an area of marine abrasion.

It appears that the fluvial material is deposited more towards W, whereas the marine erosion and reworking dominates in the eastern part. Therefore, the river arms tend to shift in the western part of the delta.

During the recent survey of the shelf area in front of the Parnaiba delta, by the R. V. "Almirante Saldanha" on its cruise 35, it was discovered that the fluvial deposits occur on a rather extensive area on the sea bottom. The sediments dredged up are composed of fine to medium gray sands of fluvial character. The extent of this facies has been figured on the general map, and a broader explanation is given in Chapter 3. As yet one can say that the Parnaiba delta possesses a great submarine part.

São Francisco. — The other river with a delta-like mouth is the São Francisco river between the States of Alagoas and Sergipe. It is a cuspate delta with a wide coastal plain and a great number of sandy ridges (fig. 13), on which no estudy exists.

At the sea side of the delta there exists a deep canyon cut in the narrow shelf area. In this, a steady surbidity current deposits the muddy material coming from the interior by the river, because its sandy fraction is already deposited in the delta area. Submarine investigations proved the existence of a delta at the outlet of the canyon, at a considerable depth on the continental slope.

BAYS

Tamandaré Bay

Introduction. — The Tamandaré Bay is situated some 150 km S of the city of Recife in the State of Pernambuco. It has a surface of 3 sq.km and is partly closed from the open ocean by a line of reefs. In this line a passage of 1 km width exists by a line of reefs. In this line a passage of 1 km vessels. The geology of this bay and its surroundings has been studied by Rebouças (1962, 1967).

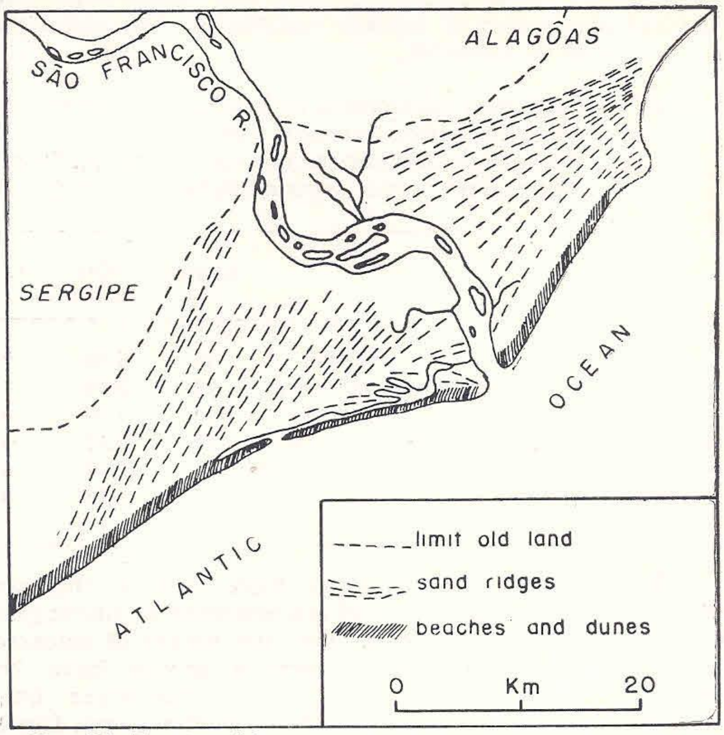

Fig. 13 — São Francisco delta.
Delta do São Francisco.

The bay has an average depth of 7 m and an almost flat bottom. The coast is sandy with dunes. The tidal differences attain maximum values of about 2 m . Inside the bay the wind causes a circular current.

Sediments. — With simple sampling devices the bottom of the bay has been sampled with distances of about 100 m between each sampling point. This means that some 200 bottom samples were collected, which have been analyzed on grain size and composition.

Rebouças (1962, 1967) grouped the sediments first after their grain size and secondly after their composition. In this way he distinguished: terrigenous sand of great, medium and small dispersion, terrigenous sand rich in biodetrital material, biodetrital sand rich in terrigenous material, very fine biodetrital sand, medium-coarse biodetrital sand, and sandy mud. Some statistical parameters of average samples of each group have been presented in table III.

Table III — Statistical parameters of sediments in Tamandaré Bay, data after Rebouças (1962, 1967)
Parámetros estatísticos dos sedimentos na Baia de Tamandaré, dados segundo Rebouças (1962, 1967)

		sample	Mdϕ	Qdϕ
	— great dispersion	45	1.00	0.80
terrigenous sand	— medium dispersion	74	2.20	0.55
	— small dispersion	119	1.07	0.35
terrigenous sand rich in biodetrital material		111	2.32	0.87
biodetrital sand rich in terrigenous material		90	3.45	0.65
fine biodetrital sand		17	4.04	0.29

The terrigenous sands have more or less the same character as the beach sands and are composed of quartz grains of sand size and sometimes a low percentage of calcareous fragments. Three grain size dispersion groups have been distinguished: great, medium and fine. The larger quartz grains have a pitted surface character, sometimes even frosted. The most frequent heavy minerals are the common ones: tourmaline, zircon and rutile; some others are present in smaller percentages. The organogenous fraction, if present, shows fragments of algae, corals, bryozoans and foraminifera.

The terrigenous sands rich in biodetrital material may contain up to 32% of organisms and fragments, whereas this percentage rises to 62% in the biodetrital sands rich in terrigenous material. The lime fraction consists of the common organisms of the area, such as algae (chiefly *Halimeda* stems), corals, spines of echinoids, fragments of molluskan shells, crustaceans, foraminifera, etc.; besides these, there occur spicules of sponges and fish remains. The quartz and heavy minerals are the same as in the terrigenous sands.

The fine biodetrital sands occur in the centre of the bay. They are dark-coloured, and their lime content attains 81%. The inorganic material consists of fine angular quartz grains and mica. The organogenous material is chiefly composed of foraminifera and ostracodes, very transparent and fragile.

Medium-coarse biodetrital sand is called by Rebouças that sediment which is composed almost entirely of *Halimeda* stems. In the finer fractions occur also other organisms among which ostracodes are abundant. Quartz and mica are rare.

Muddy biodetrital sand and sandy mud are restricted to a few places only, chiefly in the smaller depressions of the bay. Their mud content varies between 22 and 33%, thus never dominates. The sand fraction is a mixture of terrigenous and calcareous mud.

Facies types. — The sediment types distinguished by Rebouças, can be grouped into the following subfacies (fig. 14), common of the near-shore environment off the coast of northeastern Brazil:

(1) terrigenous subfacies — deposit containing more than 50% of quartz grains, generally rounded and glossy, as occur in the beach environment, and less than 50% of organisms and fragments, such as foraminifera, ostracodes, mollusks, etc.; this subfacies includes the terrigenous sands and those rich in biodetrital material;

(2) organogenous material subfacies — deposit in which the percentages are inverted, less than 50% quartz and more than 50% organisms; includes the biodetrital sands and those rich in quartz;

(3) biodetrital mud subfacies — constituted of biodetrital material mixed with mud deposited at quiet places;

(4) algal subfacies — deposit chiefly composed of *Halimeda* stems, the medium-coarse biodetrital sands of Rebouças.

These subfacies are neatly zoned in the Tamandaré Bay. Alongside the shore occurs the terrigenous subfacies, whereas the central part of the bay is almost filled up with organogenous material subfacies. The algal subfacies is found in the reef zone, in the N as well as in the S. Finally, the biodetrital mud subfacies shows irregular patches in the central bay area where somewhat greater depths occur.

The zonation of these sedimentary realms shows that the Tamandaré Bay is without strong currents, subject only to tidal movements. The terrigenous material has been derived from the nearby continent and beach; its organogenous fraction shows only littoral forms.

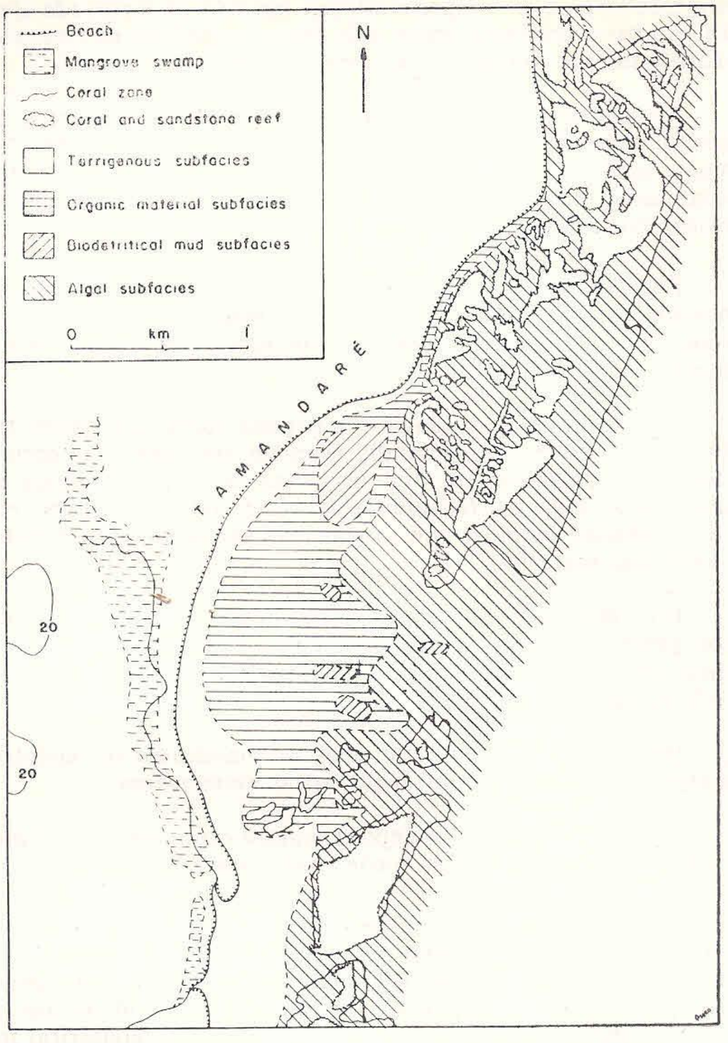

Fig. 14 — Sedimentary facies of Tamandaré Bay (Rebouças 1962, 1967).
Fácies sedimentares da Baía de Tamandaré.

The only feature which merits some more attention is the reef zone. An abundant coral growth occurs there. However, the base of these coral "reefs" is always a sandstone "reef", that means: beach rock, as states Laborel (1965). This sandstone base has a cover of corals, especially Hydrocorallia and Madreporaria. The first are important for the construction of the reef, whereas the second fix the structure and fill up the open spaces. At the seaward side, chiefly were the waves attack heavily, an algal crust develops, composed of the calcareous algae *Lithothamnion* and *Lithophyllum*. In the more quiet lagoons inside these reefs abundant *Halimeda* grows, contituting the algal subfacies.

It may be concluded that the Tamandaré Bay is an excellent example of all similar features alongside the northeastern coast of Brazil, where a reef zone protects the shore.

Todos-os-Santos Bay

One of the most interesting bays of Brazil is the Todos--os-Santos Bay at which shore the city of Salvador, capital of the Bahia State, has been built. It is, however, also one of the less known bays of the Brazilian coast.

A brief description was given already in 1879 by Rathbun who studied the rather rich coral fauna of the area. The bay is bordered partly by high cliffs of weathered crystalline rocks, partly by the low coast of the sediments of the Recôncavo basin. At many places, there occur sandy beaches. Other parts become dry at low tide.

A few bottom samples have been taken by the R. V. "Calypso" (Forest 1966), all more or less in front of the harbour of Salvador. The samples taken near the coast are chiefly muddy, whereas those at some distance become sandy with algae and corals. More inside the bay, the cement factory Aratú explores the calcareous bottom deposits for the fabrication of cement. A few samples of these deposits have been analyzed; they appeared to be algal sands in which the *Halimeda* stems dominate. Some sedimentological data have been presented in table IV.

Recently Laborel (1967b) published a complete description of the corals occurring in the area.

Cabrália and Pôrto Seguro Bays

These two fairly small bays are situated at about 16°30' S 39°00' W in the State of Bahia (fig. 15). Although no detailed sedimentological studies of their coast and sea bottom have been made, some work on this subject was done for historical reasons.

Table IV — Data on samples collected in Todos-os-Santos Bay (R.V. "Calypso, after Forest 1966, and Aratú district)
Dados sôbre as amostras coletadas na Baia de Todos-os-Santos (N.Oc. "Calypso", segundo Forest 1966, e distrito de Aratú)

sample	location		depth, m	sediment character
57	12°56,4' S	38°33,5' W	18	sand, algae
58	12°56,4'	38°34,3'	60-44	sand, pebbles, shells
59	12°56,5'	38°31,5'	20	mud
60	12°51,0'	38°31,2'	24	mud
61	Anse Sapoca		—	sand, pebbles
62	12°49,7'	38°31,4'	20-30	mud
63	12°56,0'	38°32,2'	27	mud, pebbles
Aratú				
1	Wharf cement factory		—	medium algal sand
2	idem		—	medium-coarse algal sand
3	near Ilha do Maré		2	medium algal sand
4	idem		3	medium biodetrital sand
5	idem		3	medium-coarse algal sand
6	idem		4	medium algal sand
7	idem		3	medium algal sand
	idem		1,5	medium algal sand

Câmara (1942a) published a study effectuated by the Brazilian Navy on these bays in order to find the exact landing place of Pedro Álvares Cabral, discoverer of Brazil in 1500. The work carried out consisted of the normal investigation on topography of the coast and sea bottom, on tidal differences and on related features, for the determination of the navegability of both bays and their possibility of having served as an anchoring place for the discoverer's vessels. The reefs which gave a secure port, both at Santa Cruz Cabrália and at Pôrto Seguro, are so similar that a confusion could easily rise, when considering only the historical descriptions of the voyage.

As the map (fig. 15), drawn after the official nautical chart, shows, both bays have a sandy shore with beach rock near the mouths of the two principal rivers, the João de Tiba river at Santa Cruz and the Buranhém river at Pôrto Seguro. Both reefs have been described by Branner (1904). They

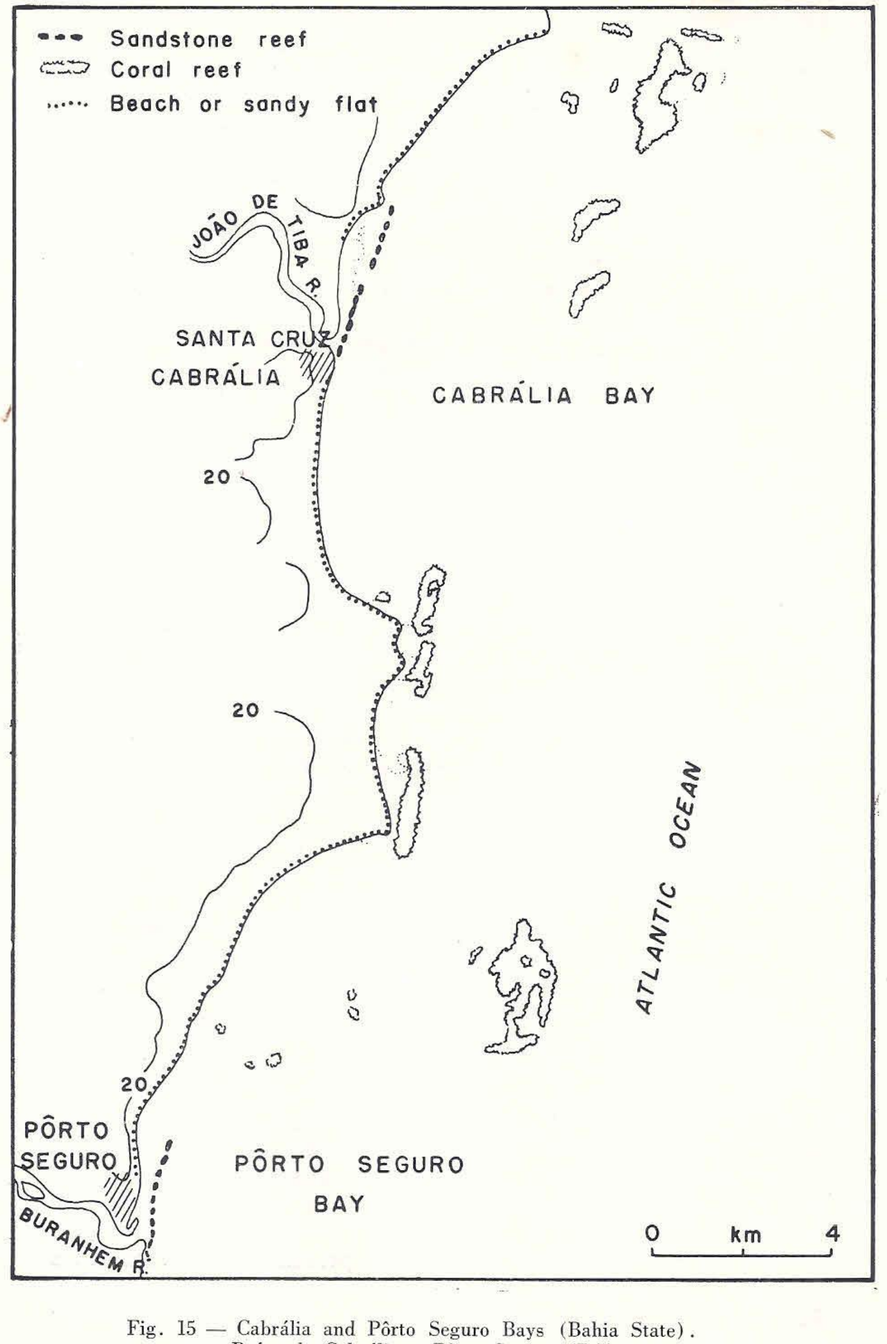

Fig. 15 — Cabrália and Pôrto Seguro Bays (Bahia State).
Baías de Cabrália e Pôrto Seguro (BA).

constitute bars which are tied to the land S of the river mouths. The reefs of Santa Cruz Cabrália have the common aspect of all other reefs alongside the coast. Those of Pôrto Seguro, however, are somewhat different, composed of coarse white quartz sand with many rounded pebbles and only a few shells. They are also somewhat more friable than the other reefs.

Offshore and at the points which separate the two bays, the Coroa Vermelha and the Grande points, coral reefs occur. This coral cover proved to be only 50-60 cm thick; under it sandstone was found. The sandy bottom of the bays is constituted of a mixture of quartz and biodetrital fragments.

The conclusion of Câmara's study (1942a) was that only the port of Santa Cruz Cabrália could have served as a safe anchoring place for the vessels which came for the first time to Brazil.

MANGROVE SWAMPS

Introduction. — A typical phenomenon of tropical shores is the presence of mangrove swamps which have already attracted the attention since the 3rd century B.C. On the Brazilian mangrove areas exist various publications, however, dealing with regions S of investigated area. But the general descriptions may serve as a base for those of northern and northeastern Brazil, because no differences were found alongside the whole coast where such phenomena occur. Gerlach (1958) published an extensive study on the ecological conditions, giving a long list of refences.

Freyberg (1930) studied some parts of the coast in the investigated area. In the whole region the mangrove swamps occur chiefly where mud has been accumulated at quiet places. This means that such swamps can be found only in protected areas, behind dunes, beaches or reefs, but where tidal influence is still strong. This means that also that the mangrove swamps do not constitute an uninterrupted area, but remain restricted to the river valleys and its surroundings (fig. 16). A section is given in figure 17.

From the creek to landward one has first a mud flat without vegetation, then a grass zone, low mangrove bush and finally high mangrove forest (fig. 18). The represented species are, for instance, in Pernambuco: *Laguncularia racemosa* Gaertn. with 50% of the total number, *Rhizophora mangle* L. with 35%, whereas the rest is represented by *Avicennia*

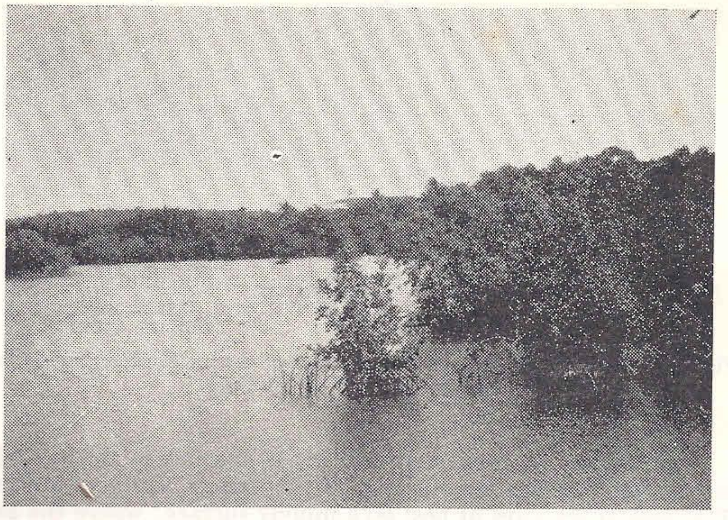

Fig. 16 — Mangrove swamps, high tide, SE of Goiana (Pernambuco State; photo A.J.R. do Amaral).
Mangue, maré alta, SE de Goiana (PE).

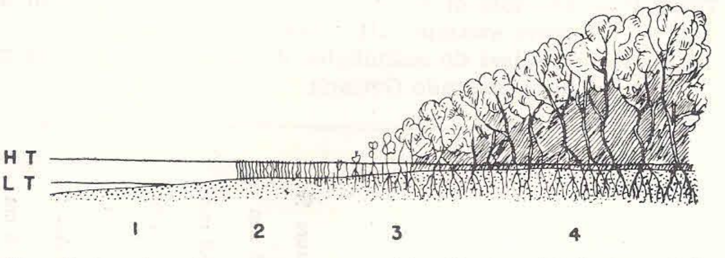

Fig. 17 — Section through mangrove swamps (after Freyberg 1930); 1: mud flat, 2: grass vegetation, 3: low mangrove shrub, 4: high mangrove trees.
Perfil de mangues; 1: lama, 2: vegetação de herbáceos, 3: mangues baixos, 4: mangues altos.

tomentosa Jacq., *A. nitida* Jacq. and *Conocarpus erectus* Jacq. (Vasconcellos Sobrinho 1937). The grass *Spartina brasiliensis* Radd. covers the zone between the mud flat without vegetation and the mangrove area in which it also grows between the trees (Gerlach 1958). *Hibiscus tiliacus* L. forms the transition towards the sandy continent.

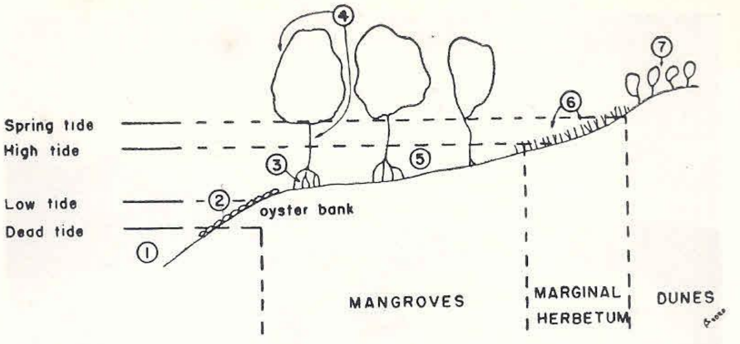

Fig. 18 — Zonation of mangrove swamps of northeastern Brazil (after Coelho).
Zonação de mangues no Nordeste brasileiro.

Sediments. — The environment is dominated by the tides, but at quiet places where no strong currents and waves occur. The mangroves grow at best on a muddy surface; where the sand size percentage increases the trees are not well developed. When, for instance, a creek changes its course and covers a mangrove mud bottom, the trees will die. Gerlach gives the characteristics of some typical samples from the different vegetation zones (table V). One sees that the bottom samples

Table V — Analyses of sediments from different zones of mangrove swamps, after Gerlach
Análises de sedimentos de diferentes zonas de mangues, segundo Gerlach

		grain size				salinity		
	moisture %	>0,5 mm	0,5-0,2 mm	0,2-0,1 mm	<0,1 mm	S°/oo	depth cm	$CaCO_3$ %
1 — mud zone without vegetation	40	0,3	4,0	69,7	12,4	—	—	0,15
2 — mud with *Rhizophora*	46	2,8	5,2	50,2	41,8	27	30	0,12
3 — mud with *Laguncularia*	35	2,1	4,2	71,3	22,3	25	30	0,08
4 — mud with high *Laguncularia*	25	2,1	13,1	78,6	6,0	25	15	0,11
5 — sand with *Hibiscus* (continent)	21	0,9	8,3	85,9	4,3	20	60	0,05

are fine sandy, whereas only the *Rhizophora*-mud has a high percentage of material smaller tham 0,1 mm (41,8%). However, the high water content makes the soil almost fluid.

Ottmann & Ottmann (1960) studied a number of mud samples from the mangrove swamp of the Barra das Jangadas area, S of Recife in the State of Pernambuco (fig. 19). On this area various studies have been effectuated. Table VI gives the results of the samples analyzed from the mangrove zone. Also in this case one sees that they have still a high sand content, although the mean size falls in the fine sand fraction. It means also that the mud must not be too clayey for mangrove

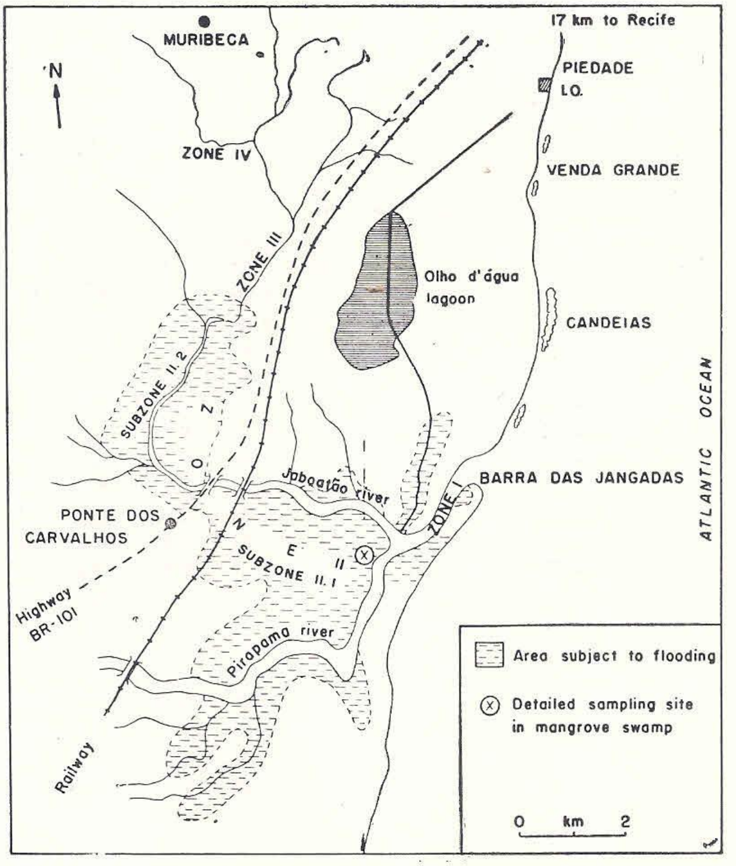

Fig. 19 — Ecological zonation of Barra das Jangadas estuary and mangrove swamp (Coelho 1966).
Zonação ecológica do estuário e mangue da Barra das Jangadas (PE).

Table VI — Some data on sediments from mangrove swamps at Barra das Jangadas, after Ottmann & Ottmann (1960)
Alguns dados sôbre sedimentos de mangues da Barra das Jangadas, segundo Ottmann & Ottmann (1960)

sample	depth cm	moisture %	Grain Size sand %	mud %	Mdφ	Qdφ	$CaCO_3$ %	C/N fine fraction
AB 1	surface	46	71	29	3.79	1.94	23,2	31
2		54	72	28	3.07	1.17	17,0	20
3		39	72	28	3.76	1.63	18,5	23
4		40	72	28	3.87	1.37	21,7	34
5		30	82	18	2.74	0.85	13,5	27
6		33	85	15	3.12	0.83	17,0	28
7		32	82	18	2.89	0.82	19,3	34
8		36	82	18	3.27	0.70	22,4	18
9		33	85	15	3.80	0.46	26,7	24
10		25	95	5	2.48	0.37	6,0	—
11		43	76	24	3.80	0.97	22,0	26
12		88	70	30	3.46	1.89	13,5	32
C 2—1	0— 10		74	26	3.56	1.22	23,0	10
2	10— 22		74	26	3.18	1.24	15,0	24
3	22— 33		74	26	3.50	1.20	22,0	35
4	33— 44		71	29	3.25	1.70	26,0	27
5	44— 55		76	24	3.23	0.95	28,5	34
6	55— 66		83	17	3.04	0.80	31,5	29
7	66— 77		83	17	2.31	0.85	13,5	26
8	77— 90		96	4	1.91	0.34	30,5	32
C 3—1	0— 14		77	23	2.62	1.12	6,5	26
2	14— 28		81	19	2.53	0.98	30,0	26
3	28— 42		69	31	3.12	2.04	8,0	30
4	42— 56		92	8	2.41	0.46	24,0	28
5	56— 70		90	10	2.62	0.50	28,0	24
6	70— 84		90	10	2.76	0.62	36,0	30
7	84— 100		92	8	2.16	0.51	30,0	26

growth. A difference with the samples analyzed by Gerlach is that in the Barra das Jangadas area the $CaCO_3$ content is much higher. This calcareous matter is composed of micro-organisms and fragments which are generally filled up with black organic material or iron sulphides. The high C/N values are due to the abundance of plant detritus and the relative poor fauna. The C% varies between 3 and 7%, but may be a high as 10%; the N% varies between 0,13 and 0,40%. The surface samples suffer leaching which decreases their contents of $CaCO_3$, C and N.

One may thus conclude that the sediment on which the mangroves grow, are muddy fine sands of black colour, in a reducing environment.

Swamp environment. — Typical for the mangrove swamps are the creeks occurring in this environment. The mangroves occupy the area at the medium high-tide level. The decomposition products of the trees causes the water to become acid.

Within the swamp Gerlach (1958) distinguishes five different faunistical zones:

(1) the creeks;
(2) the muddy bottom;
(3) the rand zones;
(4) the algal zone at the base of the mangrove trunks;
(5) the airy space between the roots.

This zonation gets the influence of the water salinity, the height above the sea level, the oxygen content of the ground water and its pH, and the available food for the animals.

The creeks show generally a decreasing salinity landward; the water higher up becomes even acid brown-coloured. The macrofauna is fairly rich and consists of fishes, crabs and sometimes crocodiles, whereas the microfauna is composed of the typical sea plankton.

The muddy bottom zone is suject to a constant silting up of material between the roots of the mangroves. The macrofauna is very monotonous, with only a few species of shrimps, crabs and worms.

The rand zones of the swamps at the upper side show a strong fresh-water influence. Here the transition occurs to the non-marine faunal assemblages. The typical vegetation is of *Hibiscus tiliacus*. Still some crabs are found in this area.

The trunks and roots of the mangroves show a rich algal growth. They have a reddish-brown colour and contain much mud in the open spaces. The algal assemblage is a Bostrychietum.

The study of the Barra das Jangadas, effectuated by the team of the Oceanographical Institute of the Federal University of Pernambuco (Okuda & Nóbrega 1960; Okuda, Cavalcanti & Borba 1960a, b; Ottmann & Ottmann 1960; Carneiro da Silva & Coelho 1960; Okuda & Cavalcanti 1963; Coelho 1966; Ottmann & others 1967; Eskinazi 1967), showed that:

(1) The salinity depends on the tides the precipitation. Especially during the flood season the saline water does not reach farther than the confluence of the Jaboatão and Pirapama rivers. The seawater did, however, reach the upper parts of these rivers during the dry season. The current velocities are higher at the surface than at the bottom and vary between 0 and 1,10 m/sec (Okuda & Nóbrega 1960).

(2) pH values do not show great differences, neither between the tides, nor between the seasons (always around 7.0). Oxygen values and $KMnO_4$ consumption, however, show great variations; especially during low tide in the dry season the O_2 content is very low and the permanganate consumption high (Okuda, Cavalcanti & Borba 1960a).

(3) The concentration of nutrient elements, such as phosphorus and nitrogen, showed a strong influence of the water coming out of the mangrove zone and of the pollution caused by the sugar factories in the upstream river areas. The inorganic nitrogen concentration was ammonia-N > nitrate-N > nitrite-N, whereas in summer almost no nitrate-N and nitrite-N were detected in the upper part of the river (Okuda, Cavalcanti & Borba 1960b). At low tide, the outflowing water from the mangrove zone brings into the rivers and creeks the nutrient elements which were formed by decomposition of the organic matter in the sediments (Okuda & Cavalcanti 1963).

(4) The water suffers from a strong pollution by the wastes of the sugar factories. This is the more felt because these waters are thrown away during the dry season. A high mortality of the fauna is noted during that period. In winter this fauna recuperates, but it is not known whether this occurs every year the full 100% (Ottmann & others 1967).

Interesting is the establishing of some zones on the basis of crustaceans decapodes by Coelho (1966). This author could distinguish four different zones, represented in figure 19, of which zone II refers to the mangrove swamp area. The characteristics of each zone have been mentioned in table VII.

Table VII — Zonal subdivision of the Barra das Jangadas area and its characteristics, after Coelho (1966)
Zonação da área da Barra das Jangadas e suas características, segundo Coêlho (1966)

Zone I	— fauna with chiefly marine species, eurihaline — river mouth (*Ocypoda quadrata* — "Maria Farinha" crab)
Zone II	— fauna with hyphalmirobiontic species — mangrove swamps, with subzones: II 1 — with *Cardisoma guanhumi* — "guaiamum", II. 2 — with a relatively poor fauna
Zone III	— mixed fauna of hyphalmirobionitic and fresh-water species — river above the swamp area (two shrimp species: *Palaemon paudaliformis* and *Macrobrachium acanthurus*)
Zone IV	— fauna with exclusively fresh-water species — river upstream (shrimps: *Ortmannia mexicana, Macrobrachium olfersi* and *M. acanthurus*)

The vertical distribution of the crustacean fauna in subzone II. 1, the proper mangrove swamps, is represented in figure 18. There occur at site:

1 — the creeks; *Penaeus brasiliensis, Palaemon northropi, P. pandaliformis, Macrobrachium acanthurus, Clibanarius cubensis, Callinectes danae, C. marginatus* and *C. exasperatus*.

2 — oyster bank; *Panopeus herbsti* and *Eurythium limosum*.

3 — open spaces between the mangrove roots; *Goniopsis cruentata, Panopeus herbsti* and *Alpheus heterochaelis*.

4 — trunks and branches of the mangroves; *Aratus pisoni, Pachygrapsus transversus, Sesarma rectum* and *S. miersi*.

5 — bottom between high and low tide level; *Uca leptodactyla, U. rapax, U. mordax, U. maracoani, U. thayeri* and *Ucides cordatus*.

6 — marginal grass area (herbetum); *Cardisoma guanhumi, Pachygrapsus transversus, P. gracilis, Sesarma rectum, S. ricordi, Uca mordax, U. rapax* and *U. salsisitus*.

7 — dune vegetation; *Cardisoma guanhumi*.

The diatoms of the Barra das Jangadas area have been studied by Eskinazi (1967). The flora appears to be rich in species: 67 have been classified. The author could, however, only distinguish the common three environments: marine, brackish and fresh.

LAGOONS

Introduction

Silveira (1964, p. 287) distinguishes two types of lagoons alongside the coast of the investigated area. The first is directed parallel to the coast, separated from the ocean by a sand bar. The second is directed perpendicular to the coast, generally a drowned river valley and also protected from the sea by a bar; this type may be called "liman".

Almost no detailed studies on these lagoons have been made. There is one exception: the Mundaú Lagoon, near the city of Maceió, capital of the Alagoas State. On another small lagoon, not belonging to the two mentioned types, the lagoon "Olho d'Água" near the Oceanographical Institute of Recife, an especially ecological study was effectuated.

Olho d'Água Lagoon

This lagoon is situated some 17 km S of the city of Recife and some 2 km from the sea from which it is separated by a wide sand barrier with dunes (fig. 20). Coelho (1967) gave an ample description of this lagoon, especially with respect to its ecology.

In pre-historic times this lagoon had a connection with the sea, so that its water was brackish, as testify the shell beds of marine origin at shallow depth near the lagoon border. Its origin seems to be connected with the Barra das Jangadas mangrove swamp estuary (compare fig. 19), to which it may have belonged. Slowly, the connection with the sea became more difficult, so that in 1940 Coutinho, Gouveia & Lucena described it as a fresh water area, occupied by isolated swamps in summer, joined in winter to one whole water mass. Because

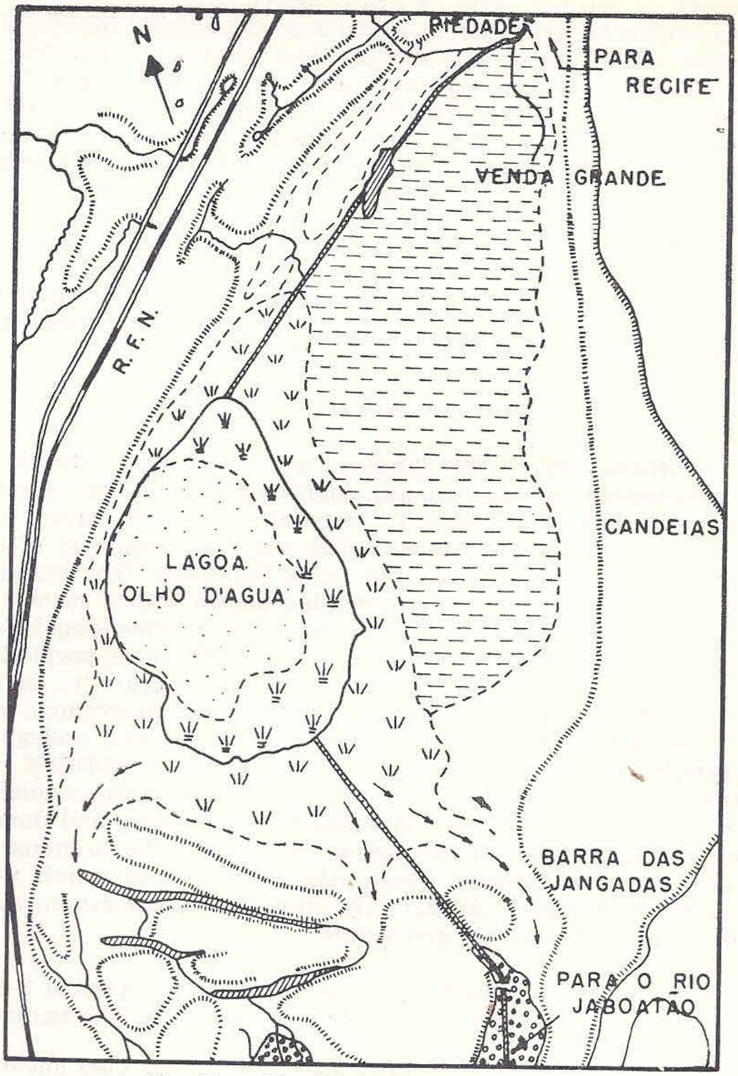

Fig. 20 — Olho d'Água lagoon (Coelho 1967).
Lagoa Olho d'Água.

of that, the area was a focus of malaria, forcing the opening of canals to the Jaboatão and Capibaribe estuaries in order to extinguish the malaria mosquitos.

Actually the Olho d'Água lagoon is a shallow area with a medium depth of 50 cm in winter and 10 cm in summer. Its bottom is covered with a fine black mud constituted of remainders of vegetation of which it is still possible to recognize larger fragments of *Ruppia maritima spiralis* L. and *Nitella* sp. These plants live in winter and die in summer with their decaying products incorporated in the mud. The canal which connects the lagoon with the Capibaribe river supplies fresh water during the whole year. That of the Jaboatão river brings in summer some brackish water into the lagoon. This results in an average salinity of 29⁰/oo in summer, the dry season, and of 5⁰/oo during the rainy season.

The fauna is mixed brackish-fresh water. The fresh water species are most active during the wet season, whereas the others live during the whole year (Coelho 1967).

Mundaú Lagoon

Introduction. — The littoral of the Alagoas State is characterized by an almost continuous series of lagoons, perpendicular to the coastline, generally in a river valley, and protected from the sea by a barrier (fig. 21). They are of the "liman" type, as occur on the Black Sea coast. The nortern-most lagoon is known as the Mundaú lagoon with a surface of about 23 sq.km. Around this lagoon lives a dense population, in the suburbs of Maceió, capital of the state; these people live chiefly from the fishing of *Mytella falcata* ("sururú"). In the years 1965, 66 and 67, an intensive survey programme was carried out in the lagoon, studying the biology and ecology of *Mytella falcata,* by the Fisheries Department of SUDENE and the Oceanographical Institute. At the same time the sediments of the lagoon and its surroundings (beach, barrier and dunes) were studied by samples dredged or cored (Coutinho, in preparation). In the Mundaú river, solid and liquid runoff were measured upstream. All data are presently in elaboration; some preliminary results are given here.

Sediments. — The lagoon shows maximum depths of 3-5 m in the canals and minium depths of 0,3-0,5 m on the banks.

The description of the lagoon by Lima (1965) does not refer to the sediments and sedimentation processes.

The following sedimentary facies can be distinguished:

(1) Coarse quartz sand, with subangular to subrounded grains, fairly well sorted, occurring in the canal, communication between river and sea, on the adjacent islands and at the righthand margin of the lagoon. This sand seems to be of

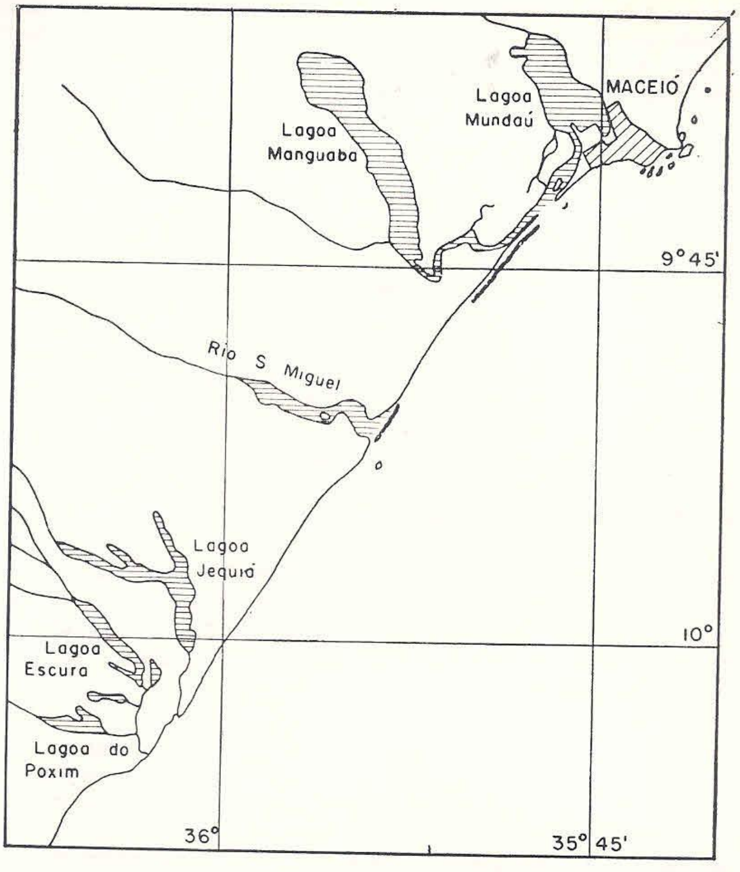

Fig. 21 — Liman zone in Alagoas State.
Zona de "'liman" em Alagoas.

marine origin, reworked by currents, and therefore without a fine fraction. Towards the middle of the lagoon the sand becomes finer with an increase of fine material brought in suspension by the Mundaú river.

(2) Fine sand, at the northern side of the lagoon, and at some other places where almost no water circulation exists. This sand is very clayey, of a dark colour, and rich in diatoms.

(3) Dark-coloured muds, rich in fecal pellets, is found in the centre of the lagoon and at the banks with a major concentration of sururú.

(4) In the Mundaú river bed and on a small delta developed at its mouth, river sands are found, being coarser upstream. These sands contain 20-25% of fine fraction. It is transported along the centre and the righthand margin of the lagoon. At the lefthand margin finer sediment accumulates.

Generally, the sediments are poor in $CaCO_3$, with exception of the places where many shells and fragments occur. Organic carbon showed an irregular variation, depending on locality and sediment type, with values of 0,38-1,16% C in the fine fraction. Where the sediments are coarse, the C-content is low.

The underground of the lagoon seems to be composed of coarse sand of fluviomarine origin. The thickness of the mud layer on it varies between 1 and 1,5 m.

The quantity of suspended matter in the Mundaú river, at low tide in November 1966, was 0,290 g/1, and at high tide 0,301 g/1. At the inlet of the lagoon near the sea, this quantity was 0,024 g/1 and 0,090 g/1, respectively. The water in the centre of the lagoon is always turbid with a high percentage of suspended material. This remains in suspension, due to the small depth, the river and tidal currents and the wind-caused waves which, in winter (August), may attain heights of 1,0-1,5 m.

Sedimentation processes. — The muddy waters of the Mundaú river which carries great quantities of clay especially during the flood period, cause the filling-up of the lagoon. The material is transported in suspension and distributed in the lagoon along the current pattern of the environment. This material attains the whole central part of the lagoon included the areas with a small water circulation, up to the inlet. Besides this there is a large organic sedimentation due to the abundant life. The contribution of the sea, even at high tide, is small. The tidal currents bring only an insignificant quantity of material due, possibly, to the protection existing at the barrier by sandstone reefs and the proper morphology of the inlet canals.

The thickness of the clayey-silty layer, rich in fecal pellets, existing in the centre of the lagoon, is not exactly known, but does not excced 2 m. Below it is found the coarse fluvio-marine sand, deposited in former times when the contribution of fluvial and marine sediment to the lagoon was greater.

Conclusions. — The surface distribution of the sediments and the content of organic carbon makes the following conclusions possible:

(1) The fine sediments (silts and clays) of the central part of the lagoon, absorb better the organic material and the impermeability of the sediment protects the organic mater from decay.

(2) The benthonic population (sururú) is an important factor, because it may locally form a reductional environment in which the organic agents may concentrate.

(3) In the upper part of the lagoon, where the organic carbon content is low, the oxygen content is higher, causing an oxidation and following decomposition of the organic matter.

(4) In the lower central part, where the highest organic carbon values are found, the oxygen content is low, favouring an abundant benthonic life. The reductional environment is also proved by the presence of small pyrite crystals on the quartz grains. On the contrary, in the northern central part the quartz grains have a cover of iron oxides.

BEACHE

Introduction. — Beaches which are interrupted sometimes by capes and river mouths, are found alongside the whole coast (fig. 22). They are almost entirely sandy because the cliffs provide only loose material. Only at a few places, for instance near the Santo Agostinho Cape (Pernambuco), pebbly beaches occur. North of the Amazon mouth, at Amapá coast, the beaches are more muddy because of the material brought by this river and deposited alongside this coast.

One cannot expect that all beaches alongside a 3500 km coast have been thoroughly studied. Even beach investigations with modern methods have not been carried out. It is also impossible to reach all these beaches from the land side, because at many places there are no access roads. Therefore, it is quite understandable that the better known beaches are found near the bigger population centers. Especially near the city of Recife, and also at the greater part of the Pernambuco State coast, the sandy beaches have been studied. In this way the papers of Rodrigues da Silva (1959) and Ottmann & others (1959) may be mentioned.

The major interest of the effectuated beach studies has been that of the possibility for economic exploration of rare

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(2) The benthonic population (sururú) is an important factor, because it may locally form a reductional environment in which the organic agents may concentrate.

(3) In the upper part of the lagoon, where the organic carbon content is low, the oxygen content is higher, causing an oxidation and following decomposition of the organic matter.

(4) In the lower central part, where the highest organic carbon values are found, the oxygen content is low, favouring an abundant benthonic life. The reductional environment is also proved by the presence of small pyrite crystals on the quartz grains. On the contrary, in the northern central part the quartz grains have a cover of iron oxides.

BEACHE

Introduction. — Beaches which are interrupted sometimes by capes and river mouths, are found alongside the whole coast (fig. 22). They are almost entirely sandy because the cliffs provide only loose material. Only at a few places, for instance near the Santo Agostinho Cape (Pernambuco), pebbly beaches occur. North of the Amazon mouth, at Amapá coast, the beaches are more muddy because of the material brought by this river and deposited alongside this coast.

One cannot expect that all beaches alongside a 3500 km coast have been thoroughly studied. Even beach investigations with modern methods have not been carried out. It is also impossible to reach all these beaches from the land side, because at many places there are no access roads. Therefore, it is quite understandable that the better known beaches are found near the bigger population centers. Especially near the city of Recife, and also at the greater part of the Pernambuco State coast, the sandy beaches have been studied. In this way the papers of Rodrigues da Silva (1959) and Ottmann & others (1959) may be mentioned.

The major interest of the effectuated beach studies has been that of the possibility for economic exploration of rare

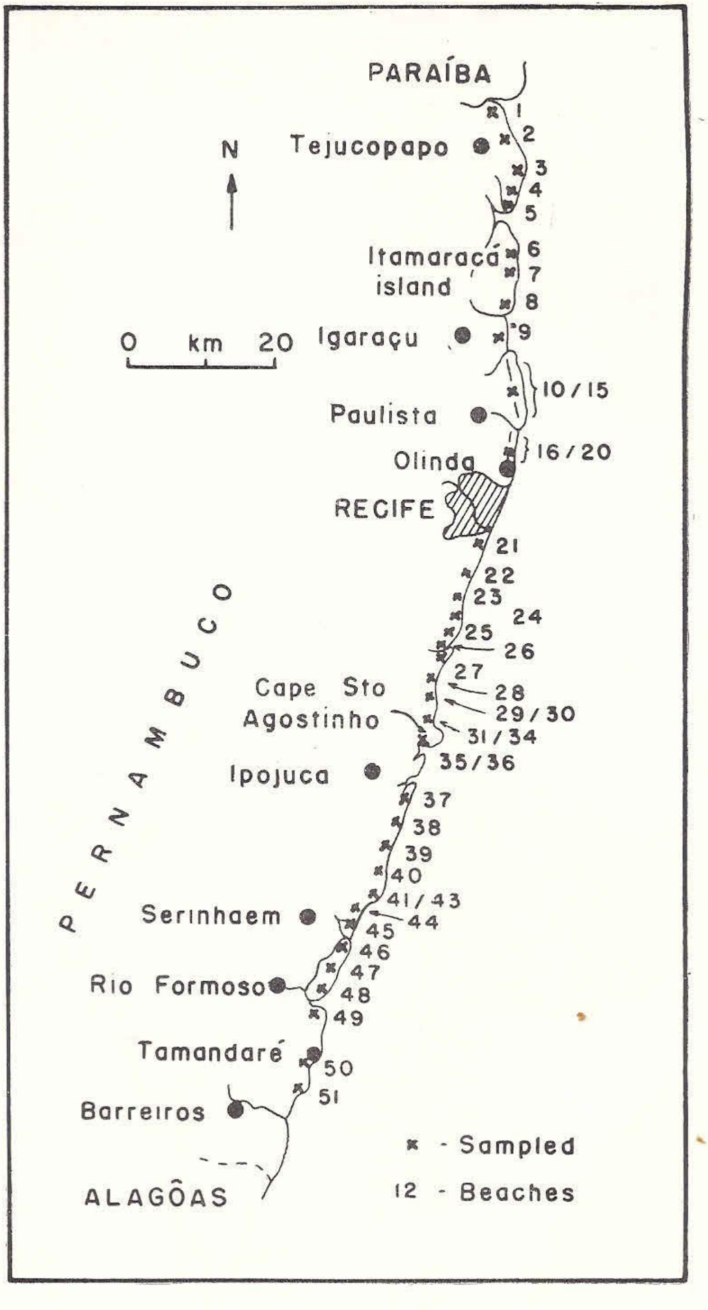

Fig. 23 — Sampling locations of beaches in Pernambuco State.
Localização de amostragem das praias em Pernambuco.

Table VIII — Beaches mentioned in figure 23 and studied by various authors
Praias mencionadas na figura 23 e estudadas por vários autores

1 — Carne de Vaca (Goiana)
2 — Tabatinga (Goiana)
3 — Pontas de Pedra (Goiana)
4 — Catuama (Goiana)
5 — Ponta do Funil (Goiana)
6 — Jaguaribe (Itamaracá)
7 — Pilar (Itamaracá)
8 — Bom Jesús (Itamaracá)
9 — Capitão (Igaraçu)
10 — Foz Rio Timbó (Paulista)
11 — Maria Farinha (Paulista)
12 — Conceição (Paulista)
13 — Nossa Senhora do Ó (Paulista)
14 — Pau Amarelo (Paulista)
15 — Janga (Paulista)
16 — Foz Rio Doce (Olinda)
17 — Rio Doce — Casa Caiada (Olinda)
18 — Bairro Novo (Olinda)
19 — Farol (Olinda)
20 — Milagres-Carmo (Olinda)
21 — Pina (Recife)
22 — Boa Viagem (Recife)
23 — Piedade (Jaboatão)
24 — Candeias (Jaboatão)
25 — Barra das Jangadas (Jaboatão)
26 — Foz Rio Jaboatão — left (Jaboatão)
27 — Foz Rio Jaboatão — right (Cabo)
28 — São José do Paiva (Cabo)
29 — Itapuama (Cabo)
30 — Pontas de Pedra Preta (Cabo)
31 — Bôto (Cabo)
32 — Gaibu (Cabo)
33 — Gaibu — bays (Cabo)
34 — Cape Sto. Agostinho (Cabo)
35 — Suape (Cabo)
36 — Foz Rio Massangana — right (Cabo)
37 — Gamboa (Ipojuca)
38 — Cupe (Ipojuca)
39 — Porto da Galinha (Ipojuca)
40 — Porto da Lama (Ipojuca)
41 — Maracaipe (Ipojuca)
42 — Foz Rio Maracaipe — left (Ipojuca)
43 — Enseadinha — Ponta de Serrambi (Ipojuca)
44 — Cacimbas (Ipojuca)
45 — Toquinhos (Ipojuca)
46 — Foz Rio Serinhaém — Barra (Serinhaém)
47 — Serinhaém — Guiamum (Serinhaém)
48 — Guadalupe (Serinhaém)
49 — Carneiros (Rio Formoso)
50 — Campas — Tamandaré (Rio Formoso)
51 — Mamocabinas — Pontas das Ilhêtas (Rio Formoso)

Inaccessible beaches:
Fortim (Itamaracá)
Tubarões (Itamaracá)
Outeiro Alto (Ipojuca)

sometimes coarse sand, well sorted and almost not skewed. The chief purpose of this author was, however, the determination of the heavy minerals in these sands. The average heavy mineral content in the samples is about 1% of weight, with the exception of some layers in which these minerals have been concentrated. Table IX shows the relative abundance of the determined species. It was concluded that the minerals came from the adjacent crystalline and sedimentary rocks, and have been supplied only partly by the rivers from the interior. The monazite content is always low, whereas local concentrations are chiefly composed of ilmenite.

Table IX — Relative abundance of heavy minerals in the Pernambuco beaches, after Rodrigues da Silva (1959)
Abundância relativa dos minerais pesados nas praias pernambucanas, segundo Rodrigues da Silva (1959)

abundant:	ilmenite, zircon
frequent:	limonite
present:	garnet, monazite, hornblende, rutile
rare:	sillimanite, tourmaline, kyanite, olivine, epidote
very rare:	leucoxene, andalusite, hematite, augite, corundum

Rand (1967) made a magnetometric and radioactivity study of the Jaguaribe beach on the Itamaracá island (6, fig. 23). The magnetometric results have been presented in figure 24. At first sight, the anomalies are fairly irregular, especially when comparing the maps of H_v and H_h. The major anomalies point to local concentrations of magnetic minerals at low depths; direct propection revealed only darker layers of a few tenths of cm thick. The heavy mineral most abundant was ilmenite. The γ-radiation pattern showed only in a small area the presence of some monazite.

The sedimentological study of Ottmann & others (1959) on the Piedade beach gave the following results. The medium grain diameter increases landward. The sorting of the sand is much poorer in the offshore zone than in the fore and backshore. The calcareous matter content is generally high, being about 70% in the offshore area and decreasing to 10-20% in the backhore zone. This organogenous material is chiefly composed of fragments of shell, algae, corals, bryozoans and echinoderms, and of benthonic foraminifera.

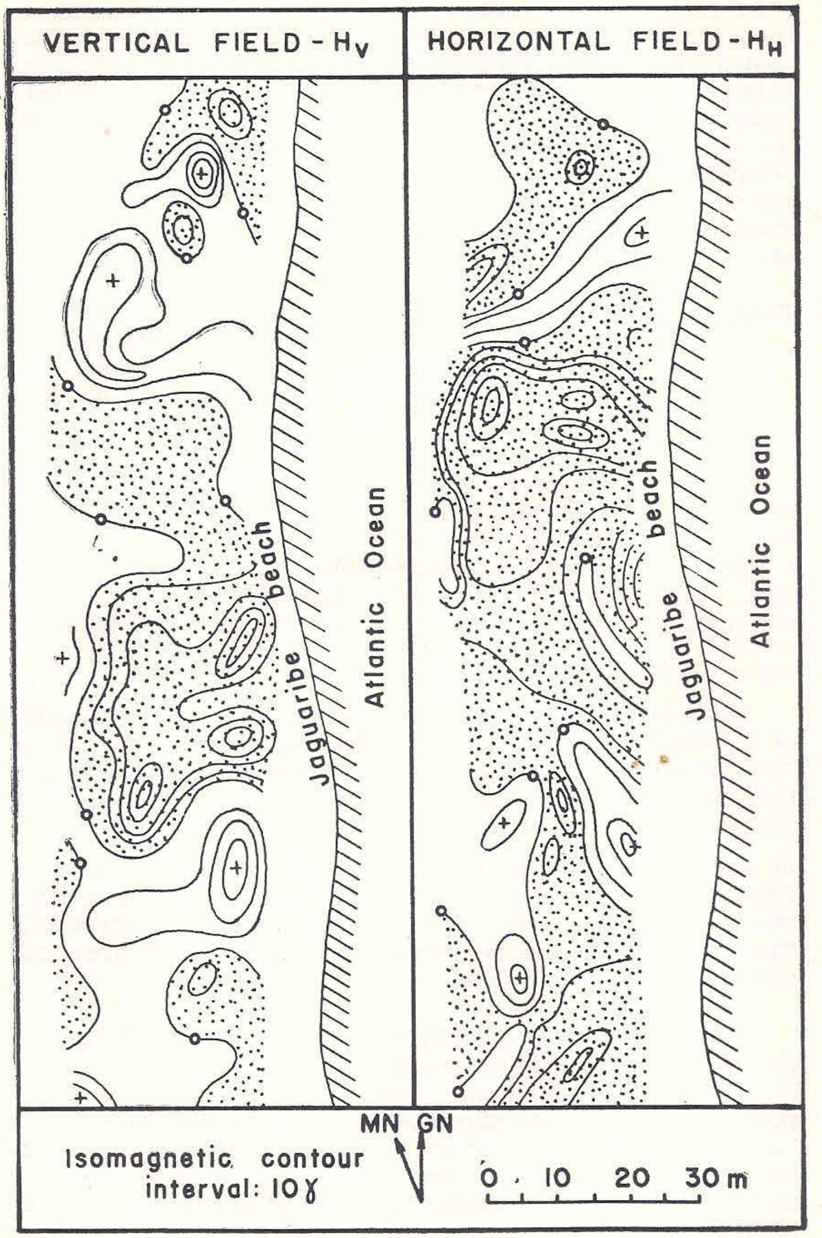

Fig. 24 — Magnetometry of Jaguaribe beach, Itamaraca, Pernambuco State (Rand 1967).
Magnetometria da praia de Jaguaribe, Itamaracá (PE).

Finally, Mabesoone (1964) studied also some beach and offshore sands for comparison with the reef sandstone, in his paper on the beach rock of the coast between Olinda and Piedade. This was done especially by means of grain size composition and the improved statistical parameters. It was concluded that the beach sands in this are generally fine to very fine, well to moderately sorted, negative-skewed and mesokurtic. The higher terrace sands of the 2-3 m level, called "sandy flat", are medium to fine grained, without typical sorting, positive-skewed and leptokurtic. The analyzed offshore sands are coarse to very coarse, moderately to poorly sorted, with a negative or positive skewness and platykurtic or leptokurtic but never mesokurtic. However, it has to be be emphasized that these variations are due to the micro-environment which was not taken into consideration.

Some samples of beach sands taken for special purposes were analyzed by Rebouças (1962, 1967) in the Tamandaré Bay area; the aim of this work was to compare these beach sands with those of the bottom of the bay.

Also samples from various beaches near Recife have been taken for a study of the benthonic foraminifera in them. The results have been published by Boltovskoy & Lena (1966); the determined species of this area are mentioned in Chapter 5.

Paraiba. — In this state a beach study has been made between João Pessoa and Cabedelo, with the special purpose to determine origin and composition of a flat composed of "red sand", exposed at low tide near the offshore reef zone. Beach and offshore sand samples were taken in two sections, also from some depth.

The grain size distribution shows that also in this area the medium grain diametres increase landward. But the sorting is only poor in the intertidal zone, and the skewness shows its highest negative value in the same area.

The red sand plate near the reefs is constituted of a fairly coarse grained sand composed of organogenous fragments, especially algae. This is valid to a depth of at least 50 cm. Its accumulation is apparently due to circular currents in the zone between the reefs and the beach. The exact determination of these currents is actually being made.

Others states. — In the other states of the investigated area no detailed beach and offshore studies have been published. Only sometimes one or a few samples have been taken, generally for special purposes such as comparison with estuary sands (Natal — Potengí river), study of the malacofauna (State of Rio Grande do Norte), study of foraminifera (Barra beach, Salvador, Bahia), or beach rock studies (various states). Data on grain size and mineralogy have never been communicated.

REEFS

Sandstone reefs

Introduction. — Already since the discovering of Brazil the so-called "reefs" have attracted the attentation. The first mentioning was of Pero Vaz de Caminha, companion of Pedro Álvares Cabral, discoverer of Brazil in 1500, saying about the landing place at Pôrto Seguro: "um recife contendo um pôrto muito bom e seguro nêle" (a reef having a very good and secure port inside of it; Branner 1904). Later Darwin (1841) gave a scientific description; this author knew already that these reef constructions were not made by corals, but were formed of lime-cemented sandstones with small pebbles and shell fragments. The first detailed consideration came from Branner (1904), being still a basis for later studies. Only in recent time Oliveira (1942), Andrade (1955), Tricart (1959), Ottmann (1960b), Laborel (1965a), van Andel & Laborel (1964), Mabesoone (1964, 1966), and Ferreira (1969) dedicated more modern studies to these sandstones. Morais (1969) made ultimately a comparative petrographical study of a number of reef sandstones from Ceará to Pernambuco. In this subtile, a resumed consideration of these rocks will be given, based on these papers.

Description. — The term "sandstone reef" has been selected for this subtitle for the following reason. Although all authors, with the exception of Morais (1969), consider only the cemented beach sands (beach rock), not all "reefs" are composed of this material. One can distinguish three different rock types in the investigated area, which all are exposed in the beaches and offshore zone, and may called "reefs" in the nautical definition of the word. The types are:

(1) beach rocks — cemented beach sands, dating from fairly recent time (fig. 25);

(2) reddish ironsandstones — sandstones with a ferruginous cement, belonging to the Cenozoic Barreiras Group deposits;

(3) limestones — calcareous sediments, chiefly belonging to the Palaeocene Maria Farinha Formation, sometimes also to the Maestrichtian Gramame Formation.

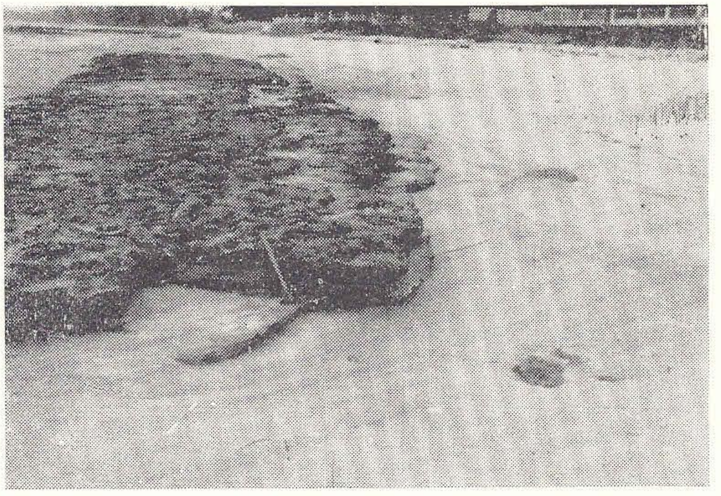

Fig. 25 — Sandstone reefs (beach rock), Piedade, Recife.
Recifes de arenito, praia de Piedade, Recife.

Of these three rock types only the first is of real littoral origin; the others only casually crop out at the coast, in the form of "reefs".

Occurrence. — The reef zone of the investigated area covers almost the whole coastal region between Fortaleza and Abrolhos (fig. 26), where they have been studied at various places. A major interruption occurs only S of the São Francisco river mouth off the State of Sergipe, where the muddy waters impede the formation of sandstone as well as organic reefs. It is again Branner (1904) who gives an almost complete list of occurrences; table X gives the localities studied by this author. Also inclued are the sites where coral reef phenomena are found. More to the south of the investigated area still some beach rock occurrences are found, even up to State of Rio Grande do Sul and Uruguay (Delaney 1965).

Beach rock. — The real beach rock is the most studied, part, by the authors mentioned above. Particularly the work of Branner (1904) gives a very detailed description over almost the whole area, although only macroscopic, but illustrated with a great number of photographs.

This author came to the following conclusions:

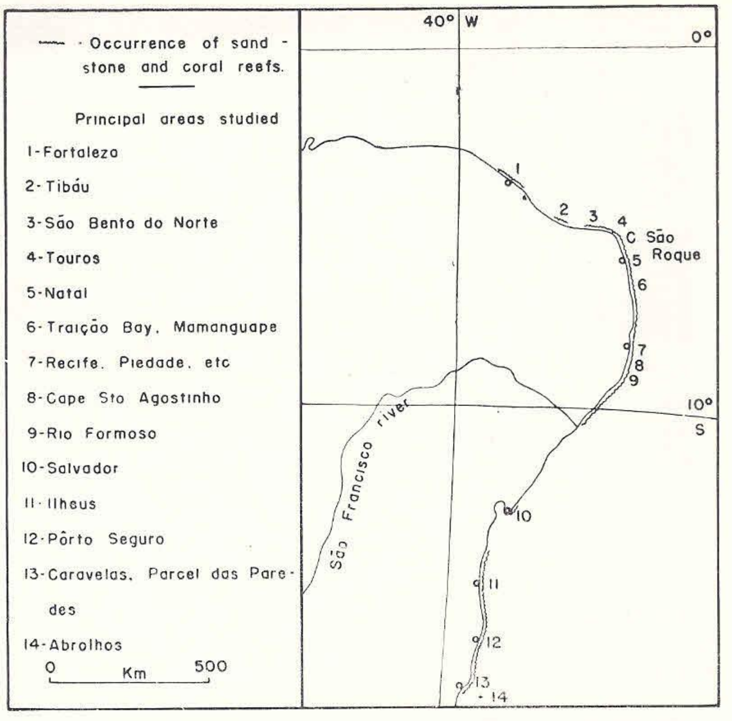

Fig. 26 — Location of reefs in northeastern Brazil.
Localização dos recifes no Nordeste brasileiro.

(1) The reefs are almost straight; their bedding dips seaward at the same angle as ordinary beach sands. The rock has a thickness of maximum 4 metres. They are apparently lime carbonate cemented beach sands.

(2) No changes of the reefs in historic times have been proved.

(3) The sandstone as well as the coral reefs protected the shores.

(4) Stone reefs are formed where exist streams and lakes of fresh water entirely or partially restrained by the beach sand. The cementing material is chiefly lime. Their consolidation is due to partially dry seasons and related to the density of the sea water.

Table X — Sandstone and coral reefs studied by Branner (1904)
Recifes de arenito e de coral estudados por Branner (1904)

State	sandstones reefs	coral reefs
Ceará	Fortaleza	some off coast
Rio Grande do Norte	Natal	Cape São Roque and off coast
	Pirangi do Norte	
	Rio Cunhaú	
Paraíba	Baia da Traição	S. Cabedelo
	Rio Mamanguape	
	Cabedelo	
Pernambuco	Rio Goiana	Candeias
	Rio Doce	Cupe
	Recife	Santo Aleixo
	Piedade	
	Venda Grande	
	Gaibú	
	Suape	
	Porto das Galinhas	
	Barra do Serinhaém	
	Santo Aleixo	
	Rio Formoso	
Alagôas	Paripueira	
	Rio Pratagi, N. Riacho Doce	
Bahia	Salvador	Ilha Itaparica
	Santa Cruz Cabrália	off Caravelas, Parcel das Paredes
	Porto Seguro	Abrolhos

(5) The fossils and coastal fauna are too little known to determine exactly the age of the reefs; it is inferred that the reef formations began in early Pleistocene times.

Not all reef sandstones are of the same type. The major part consists of cemented quartz sand with only a few fragments of organisms. Sometimes coarser quartz pebbles can be found. Near Salvador some beach rocks contain fragments of crystalline rocks, constituting lime cemented breccias. In the Rio Grande do Norte State many beach rocks show an important mollusk component, often as complete shells which made their determination possible (Campos e Silva & others 1964; Mendonça 1966).

Macroscopically, the beach rock is a quartz sandstone with a calcareous cement, and at some places even a calcarenite with quartz. At Piedade and Gaibú their stratification is almost horizontal with a slight dip seaward; cross-lamination can be found (fig. 27). The quartz grains are rather well

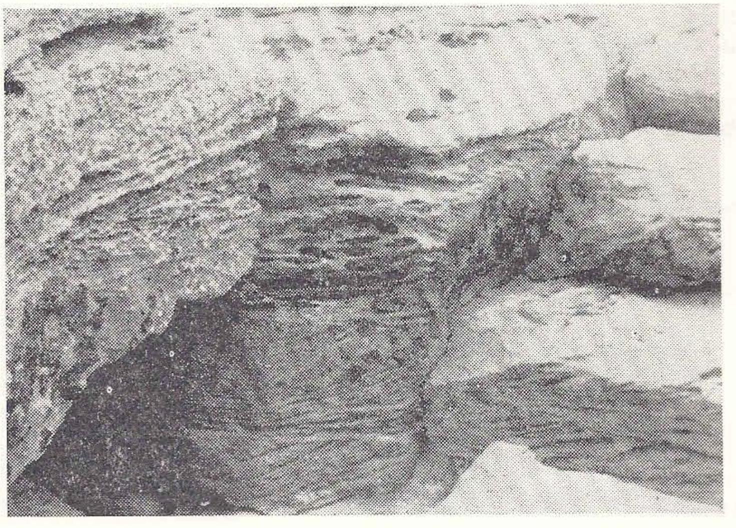

Fig. 27 — Cross-bedding in beach rock, Gaibu (Pernambuco State).
Estratificação cruzada em arenito de praia, Gaibu (PE).

rounded and have commonly a frosted surface character. Quartz pebbles, when present, are also rounded. The biogenic part consists chiefly of algal detritus of which *Halimeda* stems are frequent. The remainder of this fraction is composed of fragments of mollusks, sea urchins, calcareous sponges and sometimes corals. Vertical sections through the reefs show the typical beach lamination, caused by alternation of layers with more or less detritus of calcareous organisms and sometimes with more or less dark coloured heavy minerals. These lamination differences tend to disappear when the rocks become older and more strongly cemented due to a certain recrystallization. These rocks are under biological attack, especially of sea urchins, which cause characteristic surface features on the exposed sandstone. Where actually cemented reef sandstone is being formed, the still very friable mass is due to wind abrasion, showing typical eolian abrasion forms on a minor scale.

The beach rocks in the State of Rio Grande do Norte have a more coquinite character. A mass of shells and fragments, filled up with beach sand and with a sandy matrix, is cemented by calcareous matter.

In the section, the normal beach rock shows a majority of quartz grains scattered in a mass of microcrystalline calcite (micrite) cement. The rounded quartz shows still a few signs of chemical attack by the calcareous cement; but it has to be emphasized that frosting of the grain surface is almost invisible in thin section. The biogenic fragments show the typical structures of each organism, of which especially algae are easily recognized. The cement is micritic which must point to a chemical precipition.

Ironsandstones. — These rocks have a continental origin. They are reddish-coloured quartz sandstones with a ferruginous cement which may even constitute about 50% of the total. Belonging to the Barreiras Group of pre-Quaternary age, they may crop out at the coast. And because they are much harder than the surrounding sandy and clayey deposits of this group, they may form reef-like constructions. For instance, they constitute the Areia Preta point in the city of Natal. Where these ironsandtones suffer the influence of the tides they show generally a strong attack by marine organisms. At Cabo Branco (João Pessoa, Paraiba) numerous pebbles cover the fore and offshore zones, and on top of these another crust of ironsandstones has developed with a cover of marine animals.

Morais (1970) made a petrographical study of various occurrences of these ironsandstones. This author distinguishes three types: (1) ironsandstones whose cementation is exclusively by iron oxides; (2) conglomeratic ironsandstones; (3) ironsandstones with marine interference. This latter group is the most interesting. The thin sections show presence of spots of secondary calcite dispersed in the iron oxide cement. This iron oxide has been substituted by microcrystalline calcite, without any proof that siderite participated in the substitution process.

Limestones. — In the States of Pernambuco and Paraíba, at some beaches, limestone formations are exposed. This is especially the case at the Tabatinga, Pontas de Pedra and Ponta do Funil beaches (2, 3, 5 on fig. 23) in Pernambuco, and at Coqueirinhos and Jacumã in Paraiba. These limestones belong to the Palaeocene Maria Farinha Formation, with the exception of the southernmost part of Ponta do Funil. At this latter point, a small exposure of the Maestrichtian Gramame Formation limestones occur. All these limestones, although of marine origin, have nothing to do with the Holocene beach rocks. However, they have generally been abraded and show flat surfaces at some places. Therefore, also these constitute reef-like features. As is the case with the ironsandstones, where the limestones are under the influence of the tides, they suffer a strong attack of recent marine organisms, which may sometimes form a thin crust.

Conclusion. — Restricting ourselves to the phenomenon of the beach rock, we draw the following conclusions on their petrographical origin and age.

First, one has to conclude that not all interpretations given by Branner (1904) are right, but one may admire that this author, already at that time, explained many features so well. Actually, all other authors, with the exception of Ottmann (1960b), agree that the beach rocks are of recent age and the consequence of a rising sea level. The age was confirmed by the malacofauna and the C-14 absolute age determinations, these latter mentioned below.

The study of Mabesoone (1964) concluded that the formation of the beach rock is closely related to the level of the ground water table, where relatively fresh water supersaturated with calcium carbonate is available (explanation after Russell, 1962) near the shore line. This was confirmed by beach rock actually being formed at some places at the Bairro Novo beach of Olinda. It occurs at retreating coasts, or at parts which are eroded only. The cementation is due to temporary dry periods, or even seasons, later increased by recrystallization of the calcareous matter. Such an origin is also proved for many beach rocks in other areas. But there are occurrences where the cement is purely aragonitic with secondary filling of voids by calcite; in such cases the rock is intertidal in location and its cement of marine origin (Stoddard & Cann 1965). In Brazil, however, this type of beach rock has not been found.

Coral Reefs

Generally it is admitted that corals constitute an important part of the Brazilian reefs. However, it appeared that coral reefs of the Pacific type do not exist here (Mabesoone 1966). All reefs in which corals grow or grew, have a base of sandstone or sometimes another rock type cropping out on the sea floor. Where corals occur, there is also a great influence of algae which may grow at the seaward side of the reef, where the wave action is the strongest (fig. 28, after Laborel 1965a).

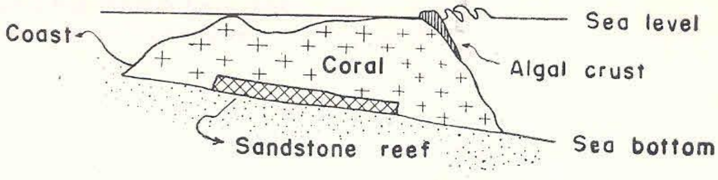

Fig. 28 — Section through coral reef building in northeastern Brazil (Laborel 1965a).
Corte através de um recife de coral no Nordeste brasileiro.

It is again Branner (1904) who gave a description of the coral "reefs" as a whole. Their occurrences are also mentioned in table X. It appears that also corals occur up to the Amazon area, but that they do not constitute reefs there. The coral cover is often thin, especially in the nearshore zone. Where they occur farther from the coast, such as near Cape São Roque and the Abrolhos group, they are thicker and might attain sometimes tenths of meters at their outer edges. It seems that many reefs have reached their upward limit of growth. They are now dead or grow only laterally (fig. 29). The dead reef rock apparently converts into dolomite. No recent coral reefs elevated above tide-level are known in the investigated area.

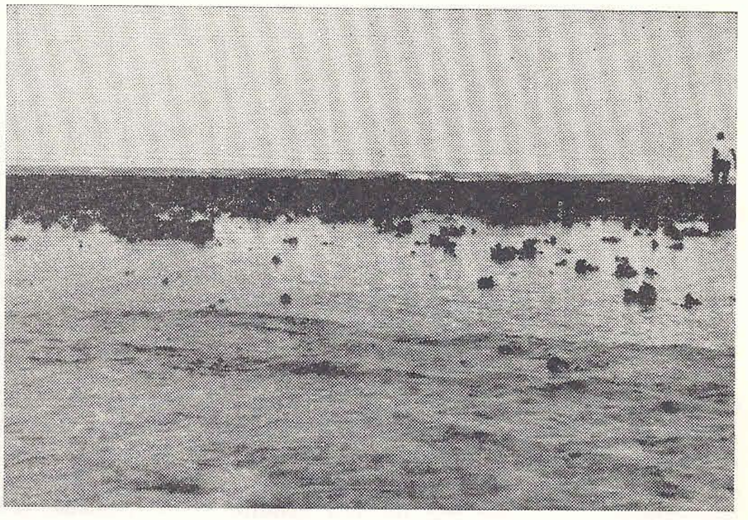

Fig. 29 — Coral reef, Tamandaré Bay (Pernambuco State; photo A. C. Rebouças).
Recife de coral, Baía de Tamandaré (PE).

The corals have been determined since early times as, for instance, by Rathbun (1879), Verril (1868) and Greely (in Branner 1904, pp. 266-274). Very recently, Laborel (1967b) dedicated a thesis to this subject.

The Abrolhos archipelago, situated at the southern limit of the investigated area at 17°58'S 38°42'W (fig. 30), has since long attracted the attention, particularly because of its

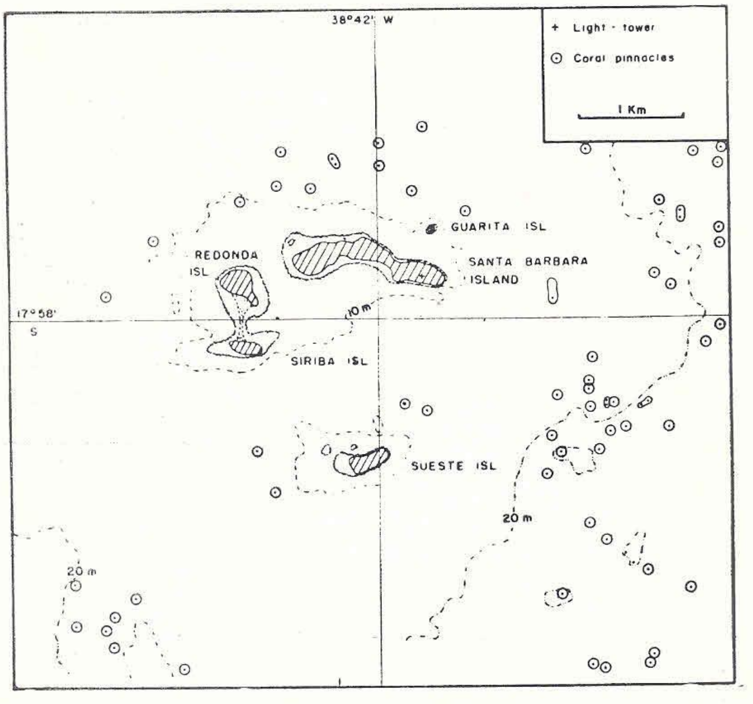

Fig. 30 — Map of Abrolhos archipelago.
Mapa do arquipélago dos Abrolhos.

dangerous position in the route of the coastal navegation. One of the first nautical charts of this area was made by a French expedition under the guidance of Admiral Mouchez in 1861 (Câmara 1942b). The curious fact is that this map gives also the character of the sea bottom around these islands, being fine sand, shells and Madreporia fragments. The islands themselves are composed of corals which at five places rise above sea level.

Hartt (1870), cited by Branner 1904), gives a fairly complete description of this reef complex. The base of the islands is constituted of sandstones, shales and trap, dipping aproximately N-NW with an angle of 10-15°. On these rocks grow the corals, chiefly madreporians. The environment is very favorable, with not too deep waters on a broad shelf. On top of the reefs other marine organisms are found, especially calcareous algae. The organic reef limestones are very hard and not easy to break with a hammer; they also suffer attack of the surf. Around the islands, but chiefly at the eastern side, coral pinnacles, often living, rise steeply from a depth of 20 m to 1-3 m below the sea level, causing an extremely irregular bottom topography and being thus dangerous for the navegation. The bottom sediment appears, after recent studies (see Chapter 3), to be chiefly composed of algal detritus with fragments of other organisms in smaller amounts.

In 1861 the Brazilian government installed a light-tower on the Santa Bárbara island. On the occasion of the centenary of the building of this tower, Linhares (1961) completed the description of the Abrolhos group environment. The main island, on which the light-tower was built, possesses two beaches, one sandy at the S part, the other gravelly at the N side. The climate is dry, and only a poor vegetation with some coconut trees exists on the islands. The water surrounding the group is clear, with depths visible up to 15 m.

DUNES

Alongside great parts of the coast, especially where sandy beaches are frequent, also dunes are found. These may attain at some places considerable heights, even up to 100 m.

Detailed studies, however, do still not exist. Bigarella (personal communication) began with the study of the cross-stratification, chiefly of the older dunes. The results have not yet been published, but the general impression is that in the various series the crossi-bedding coincides with actual prevailing wind direction.

Only recently, Corrêa (1968) and R. S. Andrade (1968), students of the School of Geology of the Federal University of Pernambuco, mapped the coastal areas S and N of the city of Natal (Rio Grande do Norte State), including the there frequently occurring dunes (fig. 31). The authors came to the following results, based on field and laboratory studies. The dunes constitute extensive cordons with a SE-NW direction, and can reach some 10 km landward. Two types are clearly

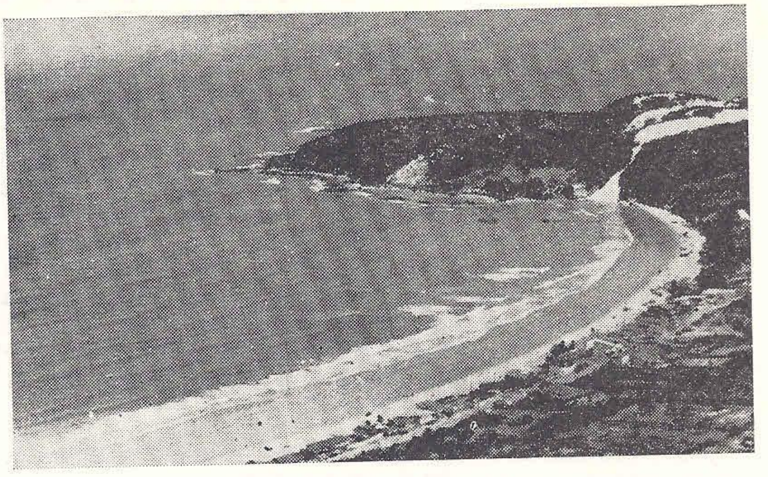

Fig. 31 — Dunes at Ponta Negra (Rio Grande do Norte State).
Dunas na Ponta Negra, Natal (RN).

distinguished: the fixed ones and the moving ones (fig. 8). The fixed dunes are generally covered with vegetation and are composed of yellowish to reddish sands; they are the oldest dunes, although it is not yet known if they represent more than one generation. The more recent moving dunes, without any vegetation, occur in a narrow strip along the coast. These are normally composed of actual beach sand, as prove the grain size and sand grain analyses. They are constituted of almost white sands and cover sometimes the older, dark coloured dunes. At some places the older dunes are being reactivated, losing their vegetation cover. These recent dunes move fairly rapidly, sometimes covering houses which are found in their way.

The disposition of the dunes is parallel to the dominant wind direction coming from the SE, which is also the actual direction. The older dunes may have a direction somewhat different from the recent ones, but this is only a few degrees. They are thus possibly due to a period in which reigned a climate more or less equal to the present one, which is rather dry. The vegetation cover may have come up during a more period. Their red colour is probably of secondary origin.

The dunes situated more southward of the investigated area, are at moment being studied by the Anthropological Institute of the Federal University of Rio Grande do Norte.

The dunes of other areas, especially that of the coast of the Maranhão State, where extensive dune fields occur, have still to be investigated.

Recently, Morais & Souza (1971) finished a study in some detail on the dunes in the area of Fortaleza (capital of Ceará State). These authors found that the dune sands are chiefly composed of quartz with minor amounts of feldspar. In the fine fractions the heavy minerals may constitute a considerable quantity. The sands are fine to medium sized ($Md\phi = 1,1\text{-}3,2\phi$) and well sorted ($Qd\phi = 0.30$). Some of the bigger dunes show a neat wedge-shaped cross-bedding with a 30° dip and a 50°NE direction, that is the prevailing wind direction of the region. Ripple marks are frequent at the surface. Most dunes have not been fixed by vegetation and in this way contribute to a certain filling-up of salt pans and the Mucuripe harbour of Fortaleza city.

GEOMORPHOLOGY

Introduction

Various studies on the gemorphology of the coastal area have been made, especially for the eastern coast. General problems have been treated by Tricart (1959, 1960) and Tricart & Cailleux (1965, pp. 105-144), whereas a study in detail on the Itamaracá island (Pernambuco State) has been published by Andrade (1955). On the northern coast hardly any data exist.

The eastern Brazilian coast in the investigated area, especially between Abrolhos and Recife, shows great contrasts between the abundance of accumulation forms and the relative rarity of living cliffs and abrasion forms. This phenomenon seems to be characteristic for the more humid tropical climate zone. In this way, Tricart (1969, 1960) examines the following features: (1) the erosion of rocky coasts; (2) the deposition of accumulation forms; (3) the paleoclimatic and tectonic oscillations involved in the littoral morphogenesis. This scheme will also serve as the base for this subtitle.

Erosional features

Generalities. — The rock outcrops alongside the Brazilian coast consist of two different types: the crystalline cliffs and the detrital sediment cliffs which both have their influence on the erosional features.

The outsrops of crystalline rocks are chiefly of metamorphic rocks belonging to the Precambrian basement, locally impregnated by more recent igneous rocks of Middle-Createaceous age. An example of a cape constituted of granite is Cape Santo Agostinho (Pernambuco State). The crystalline rocks, however, possess often a fairly thick weathering cover of sandy to clayey material not much different from the proper sediment of the area.

The majority of the "dead" cliffs consists of sediments belonging to the Cenozoic Barreiras Group. These show an alteration of sands, clays and gravels, locally consolidated to ferruginous sandstones (see paragraph on Sandstone Reefs). Particularly the coast between Cape São Roque and Salvador shows such cliffs; an example is that of Cabo Branco (Paraiba), almost the eastern point of South America (fig. 32).

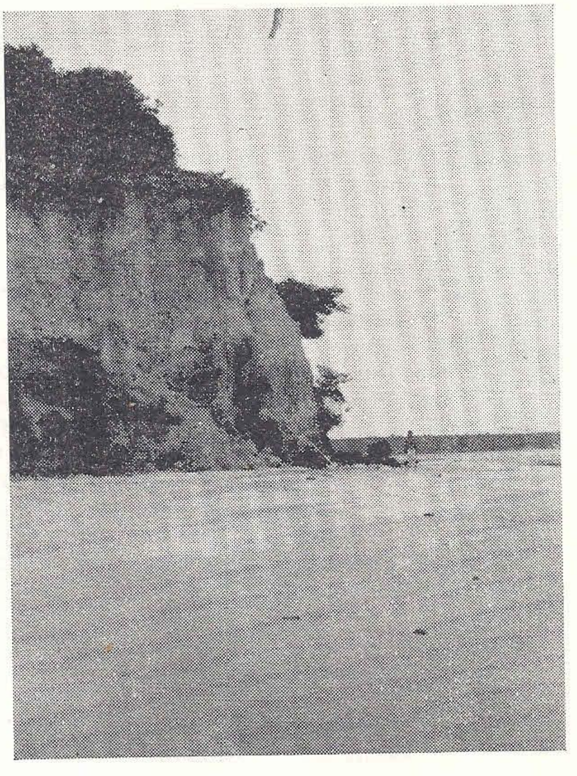

Fig. 32 — Cabo Branco, Barreiras cliff (Paraíba State).
Cabo Branco, falésia de Barreiras (PB).

In the beaches and also offshore occur the sandstone reefs, already described. Many times they protect the sandy shore from abrasion, although they are themselves subject to strong wave attack.

The most important parts for erosion are thus the surface formations, being sedimentary or weathering products, both reacting upon it in more or less the same way.

Erosion of loose deposits. — As has been already said, the major part of the cliffs is dead, not more under direct attack of the waves and currents. They are covered with vegetation and show sandy beaches at their foot. However, this vegetation which causes a deep chemical weathering, never comes lower than the spring-tide line. This means that there is always a part of the cliff on which the sea may attack, especially during the high tides and stormy weather in winter (July-August).

Once the sediments are thoroughly wetted by the heavy tropical rains of that season, the whole cliff may easily slide down. But generally these movements are slow, braked only by the vegetation cover. Certain rocks, however, which show an abrupt transition between fresh rock and clayey weathering cover, produce often more catastrophic landslides.

The eroded material is transported towards the sea by waves and tidal currents. The quantity of this material is but small. Its grain size falls in the sand and clay fractions, whereas hardly any pebbles are present. Anyhow, the greater blocks fallen at the foot of the cliffs do also not produce many pebbles due to the chemical tropical weathering. Therefore, pebbly beaches are rarely found in the investigated area.

Attack of the hard rocks. — Abrasion of hard rocks hardly occurs, because the present sand is too fine for acting as abrading agente. Where rocky capes exist, the sand is often absent, washed away by the waves. Where, on the contrary, sand is abundant, it covers the hard rocks and protects these from abrasion. This means that abrasion platforms do not develop actually and that the existing ones had their origin under other conditions. The attack of the hard rock is thus caused by other processes.

The first of these is the biological action. This phenomenon is most intensive in the foreshore zone, where numerous algae and sea urchins live. The algae penetrate with their tentacles between the rocks and cause their desaggregation. The sea urchin action is more important, especially in the more friable rocks such as the reef sandstones. At the Cape Santo Agostinho such excavations can be found in the granites at a level higher than high tide, indicating a higher stand of the sea some time ago.

The desaggregation by salt action affects the littoral zone immediately above the medium high-water level. In the investigated area this phenomenon is the more important due to the insolation with high evaporation. The salt spray penetrates in the rock pores, and when the water evaporates, the salt crystallizes and exercises a pressure on the rock. In this way it widens the apertures and finally desaggregates the rock. The salt may even react with some minerals, as for instance, the micas in micaschits.

The breakers on the coast are not so frequent that the water cannot evaporate totally until the next wetting. Therefore, small platforms develop in the hard rocks slightly above the high-tide level. The salt crystallization impedes the growth of vegetations so that the rock remains uncovered. The formation of such flats is limited to homogeneous rocks, because in heterogeneous or in those cut by diaclases they cannot be formed.

Accumulation forms

The accumulation forms on the northern and northeastern Brazilian coast consist chiefly of fine material such as sands and muds. As has already been explained, the desaggregation processes do not produce pebbles, so that only sand and clay is supplied to the shore.

The clays are taken in suspension by the waves and are transported to the greater oceanic depths. The clays found in the littoral area are always of terrigenous origin and sedimented at quiet places, especially mangrove swamps, due to the brackish conditions and to the sieving out by tree roots. The composition of these clays in always kaolinite because of the tropical weathering.

The sands are transported alongside the coast line, often over long distances. There they may form long sandy beaches composed of medium to fine sized sand. Between the rock capes, in the small bays, the accumulated beach sands are generally coarser. The fineness of many beach sands is often caused by the tropical weathering processes which make the quartz to break into pieces when the iron oxides in its cleavage planes become dissolved. Besides these, the quartz sand is also provided by the Barreiras cliffs and by the rivers. Especially the latter provided a large quanty of sandy material transported as a consequence of the soil erosion in the interior. This sand settles at the mouth of these rivers in banks, as is the case, for instance, with the São Francisco river (fig. 13), helping in this way to widen the coastal plain. Where the rivers do not provide sand to the sea, they embouch in estuaries with muddy deposits in which rapidly develop the mangrove swamps. This means that the enormous quantity of sandy sediments actually found alongside the coast of almost the entire investigated area, is of older origin.

Tricart (1959, 1960) points still to the feature of the beach rock as an example of a more ancient formation. This author suggests that they might have formed at the end of the period of sand accumulation, and that therefore their datation is of great importance for the reconstitution of the littoral morphogenesis.

Morphogenetic periods

Introduction. — The paleogeographical reconstitution of the coastal development is fairly difficult due to the rapid changes common of the intertropical zone. Also, the Quaternary stratigraphy of Brazil is all but unknown. In this way, Tricart (1959, 1960) begins its consideration with the actual modeling.

Fixation of the littoral barriers. — The chief element in this process in the beach. Herefore, also papers of other authors can be used, especially those by Andrade (1955), van Andel & Laborel (1964) and Mabesoone (1964).

Recently, some absolute age determinations were made. For instance at Piedade beach, behind the Oceanographical Institute, two lines of sandstone reefs occur. The first crops out in the proper beach, and the second at some distance in the offshore zone but only at low tide (fig. 25). A determination on the shells of this second reef revealed an age of 5.900±300 years (samples LJ 1367 — La Jolla Radiocarbon Laboratory; van Andel, written communication). Other determinations at the Gaibú beach (32 on fig. 23) of some reefs situated between 2,20 and 3,40 m above the present sea level, provided ages of 3660 — 1190 years ago (van Andel & Laborel 1964). Unfortunately, no age determinations of the more friable reef sandstone exposed in the beach were made. These data do not coincide very well with the established curves of recent sea level rise, as for instance that of Shepard (1936b). The coastal development seems to be more complicated.

At Rio Vermelho (Salvador, Bahia), the sandstone covers an ancient conglomearte cemented with iron oxides. As actually no pebbles are found at the beaches, this conglomerate must represent an ancient period with drier (semi-arid?) climates. A similar feature is found at Pontal dos Ilhéus (Bahia). This lead Tricart to the supposition that the beach rocks date from the Dunkerquian, characterizing the maximum of the Flandrian transgression.

The combination of the following processes caused then the enormous deposition of sand barriers alongside the coast. First, the abrasion of the platform during the transgression, under a warm and humid climate, more os less the same as the present. This abrasion occurred on latosols formed during a preceeding regression period. Secondly, the erosion of the Barreiras Group formations which reached farther seaward formerly. Third, the direct attack of the fresh rock during the transgression, under a climate with a pronounced dry season which facilitated the formation of sand. And fourth, the major sand supply by the rivers. All this sand built the actual beaches and the dunes which are now fixed by vegetation.

This refers only to the recently found sand accumlation. The coast, however, shows a polycyclical development which implicates also a consideration of the pre-Flandrian evolution.

Pre-Flandrian coast development. — Alongside the coast various ancient terrace levels can be found, as at Ilhéus and Salvador (Tricart 1959, 1960) and at the Itamaracá island (Andrade 1955). These phenomena have been chiefly explained by glacio-custatic control, although there exist also indications of tectonic activity.

(1) Terrâces and rias near Ilhéus (Bahia). Somewhat N of this city the Itaipe river embouches into the ocean. This river drains for a great part a region with Barreiras Group deposits; it transports thus a large quantity of material which is brought into the sea in a southerly direction. The barrier formed in this way, closes completely an ancient ria. In it a delta has been built, already begun in the Dunkerquian. The higher parts of this delta are not more submerged, indicating a sea level stand 1,0-1,5 m higher than the present one. This area is covered with a dense marsh vegetation.

S of the river mouth one finds pre-Flandrian deposits, at some sites even 7-8 m above the inundation plain. The sediments are clayey sands with a few small quartz pebbles, apparently of the same type as the Barreiras deposits so that their distinction becomes difficult. Near the coast, terraces can be found, one at 2 m, another at 1 m above the present sea level. More landward a level of 5-6 m occurs. However, a more exact datation of the successive periods is not possible due to the absence of exact topographical mapping.

(2) Ancient formations at Salvador. South of the Rio Vermelho beach exists a small bay in which ancient formations are found, exposed in the cliff. One finds: at the base a pebbly deposit deeply altered into a latosol, laying directly upon a gnaiss, with a maximum thickness of 2,40 m; at the top, cutting off the latosol, an irregularly cemented ironsandstone which dips towards the sea, with some intercalations of gray clay. This littoral series represents evidently a drier climate than at present. The pebbles of the lower bed are typical representations of a deposit at the foot of a cliff. The ironsandstones with their dip of 25° are interpreted as the seaward side of an ancient dune on top of an ancient beach. That beach indicates a sea level of some meters higher than the actual, whereas the dune points to one somewhat lower. It is quite possible that this indicates the pre-Flandrian regression, because Flandrian beach rock covers the dune ironsandstone.

An analogous situation is found at the beach N of the Barra fortification. Here one finds below the beach rock also a red coloured ironsandstone with eolian characteristics.

Thus, there must have existed before the pre-Flandrian regression a dry climate with strong mechanical action. A glacio-eustatic interpretation, however, is almost impossible because of the tectonic deformation suffered by this region during the Quaternary.

(3) Itamaracá island. Our knowledge of this island is due to the work of Andrade (1955) who studied the polycyclical coast and the littoral deposits.

The island is supposed to be a somewhat basculated block of the chiefly calcareous sedimentary coastal belt of the Pernambuco State. Still affected is the Paleocene Maria Farinha Formation, whereas the younger Cenozoic Barreiras Group sediments cover the whole disconformably. This means that the tectonic movement was at least pre-Barreiras and post--Paleocene. Ancient beach levels are met with at 7-8 m and 2-3 m above the present sea level.

Andrade (1955) adopts the glacial-control theory but attributes the various levels to the last glaciation phase (Würm).

In this case, the ancient beaches and terraces of 7-8 m should represent the Würm III-phase (pre-Flandrian regression), and that of 2-3 m the "Little Ice Age" (Dunkerquian), interrupted by the post-glacial optimum (Flandrian transgression). During the regression phase the sea level should have been 7-8 m below the present one as should be shown by two submarine valleys which flow together and continue alongside the actual reef line, after the bathymetrical charts of the area.

To the island shore hardly any terrigenous material is supplied. The only process which exercises some influence, is the wave action together with the currents. It causes only a certain reworking of the sandy beach and offshore material. No beach is presently formed in this area.

The author divides the island coast into three parts: Forno de Cal beach (8), Pilar terrace (near 6, 7) and Lance dos Cações beach and terrace (without number on fig. 23). The first beach is an accumulation zone, a progreeding beach with a reef zone. Behind it exists a series of moving dunes which cover and uncover from time to time mangrove swamps and small coastal lagoons. The Pilar terrace is a coastal part which regrades; some streets of the village of Pilar have been cut by erosion. The beach is only a narrow zone. At the northermost point the Maria Farinha limestone crops out in the beach as a "reef". At the other side of the estuary of the small Jaguaribe river, the beach and terrace of Lance dos Cações are found, a good example of a recent beach at the foot of a Holocene terrace. This latter phenomenon is frequent in the whole coastal area of the States of Pernambuco and Paraíba.

(4) Maceió. A more general description of the morphological feature in the area of the city of Maceió (capital of the Alagoas State) gave Lima (1961). This author adopts the theory of glacial control as expressed by Andrade (1955), and applies it to the beach and terrace levels there, because the phenomena are almost the same as those found on the Itamaracá island. The only difference exists in the fact of occurrence of the Mundaú and Manguaba lagoons, drowned river valleys separated from the ocean by barrier beaches. Lima attributes the formation of these lagoons to the Flandrian transgression, possibly increased by a slight tectonic subsidence of the area. In the Dunkerquian period the barrier should have developed.

(5) Tectonic deformations. As Tricart (1959, 1960) already pointed out, the generally supposed "stable" Brazilian shield suffered tectonic deformations as late as in the Quaternary. This author could confirm it at three different places: near Salvador, near Ituberá between Salvador and Ilhéus and near

Ilhéus. Near Salvador there exists a fault which must have been active in recent times and cut an abrasion terrace. In the Ituberá region the interior plateau constitutes a rectilinear escarpment falling steeply over some 100 m of the height difference. The rivers have not cut their valleys in this escarpment yet and the most important one shows water-falls. Also here, there must have been fairly recent tectonism. Similar phenomena can be found near Ilhéus where one may suppose a flexure rather than a fault.

In the other areas of the Brazilian northeast coast detailed investigations have not yet been made. But the geophysical studies effectuated by Rand (1967) which still continue, point to this recent fault action in the whole area. This explains also the fairly steep slope (4-20°) of the continental slope in this region, as well as the narrowness of the shelf.

General conclusion

The data mentioned above show that the coastal area of northern and northeastern Brazil presents many interesting features. One may verify the coastal development in a humid tropical area, with few cliffs and no pebbly beaches. It is also

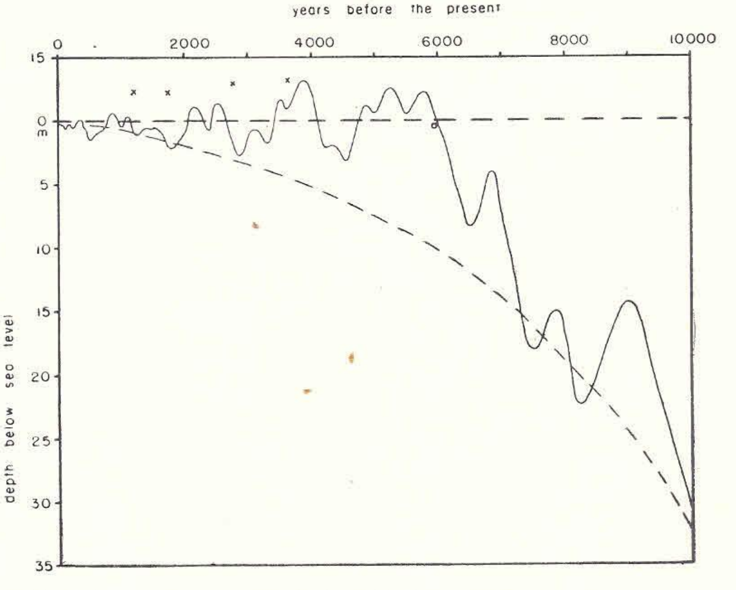

Fig. 33 — Curves of rising sea level, applied to Brazilian examples.
Curvas da subida do nível do mar, aplicadas a exemplos do Brasil.

possible to reconstitute the climatic oscilations during the post-Flandrian period. However, the Quaternary tectonic deformations do not permit exact datings of erosional and depositional features, and make it difficult to apply the glacial-control theory in this area.

Figure 33 compares the known C-14 datings with the curves on recent sea level rise of Fairbridge (1961) and Shepard (1963b). One sees that the data coincide more with the theory of fluctuating sea level of the first author than with that of a constantly rising level of the second. To similar conclusions came van Andel & Laborel (1964) and also Bigarella (1965) for southern Brazil. The dated samples from Gaibú (x on fig. 33), however, are all somewhat too high for the Fairbridge-curve; only that of Piedade (o. on fig. 33), falls almost upon it. The data are still too few to make certain correlations, and therefore a study in much more detail is required for a better explantion and for a consideration of eventual recent tectonic events.

3. CONTINENTAL SHELF ENVIRONMENT

INTRODUCTION

In this chapter the present knowledge on shelf topography and bottom sediment has been resumed. A map on the scale 1: 4.000.000 of the sedimentary facies distribution has been added.

Almost nothing but general knowledge has been published up to present date, in various international review articles. These indicate a "calcareous" shelf sediment" in the entire area between the Amazon mouth and the Abrolhos archipelago, and "terrigenous sediment" on the shelf N of the mouth. A further subdivision was never given because no data were available.

The only publication which gives some detailed information on the area near the Amazon mouth is that of Ottmann (1959). Besides this, the report of the R. V. "Tôkô Maru" (1958), written in japanese, and therefore not easily acessible, figured a facies map of the shelf bottom between São Luiz and the Amazon river influence area. Another tentative for a map appeared in the "Atlas Nacional do Brasil" (Botelho 1966), dividing the Brazilian shelf deposits in not exact grain size terms. But all these maps give a fairly good impression of the environment. This confirmation can be made, based on the extended surveys, some of which in more detail, since 1966, especially by the various research vessels of SUDENE and the Brazilian Navy (Mabesoone & Tinoco 1967; Coutinho & Morais 1968, Kempf, Coutinho & Morais 1968, 1970; Kempf, Mabesoone & Tinoco 1970). There could be included even the preliminary results of the expedition "Geomar I", on the base of the summaries presented by Pomerancblum & Costa (1970) and Marchesini Santos & Carvalho (1970).

So we have actually a better knowledge of the shelf between Cape Orange and the Abrolhos archipelago, although not in detail, but enough for a base for further studies.

TOPOGRAPHY

Not much is known about the topography of the continental shelf of the investigated area. A detailed bathymetric survey does not exist, and also magnetometric or seismic studies which could provide a genetic interpretation of the Brazilian shelf have not been made. In this way, it is only possible to trace the submarine relief in a very general way, without entering in details.

The first known survey is that published on the nautical charts of the coast, edited by the DHN of the Brazilian Navy. These maps delimit the shelf area and give a great number of depth measurements. However, on the strip nearer to the coast, where many so-called "reefs" occur, the depth information is scare, with the exception of harbour entrances. Only recently, the discovering of oil on the continental platform off the States of Alagoas and Sergipe, took Petrobrás to the execution of echobathymetric, magnetometric and seismic investigations, more actualized and in greater detail.

There exist also some depth measurements of the sections made by the various oceanographical research vessels during their cruises in the area. Particularly, the R. V. "Almirante Saldanha" on its cruise 35 (Operation North-Northeast I) between Recife and Cape Orange provided some interesting general data. Also off the city of Recife and off the States of Alagoas and Sergipe the surveys of the shelf area gave also bathymetrical results. Figure 34 (after Kempf, Coutinho & Morais 1970; Kempf, Mabesoone & Tinoco 1970; Cavalcanti & others 1967) presents a number of depth sections through the shelf area between Cape Orange and Sergipe State. They show more or less the extent of the shelf in the investigated area. More southward no reliable data exist for giving also sections of this area.

Concerning the Amazon mouth, Freitas (1967) explained that the northern entrance of the river is due to rapid changes which make the ship traffic dangerous. So the nautical char has to be adapted from time to time. In 1966 the Hidrogr. V. "Canopus" of the Brazilian Navy had to be urgently directed towards this area because of the depth changes noted at certain places since 1958. For instance, the axis of the Canal Grande do Curuá through which the actual ship trafic passes, showed in

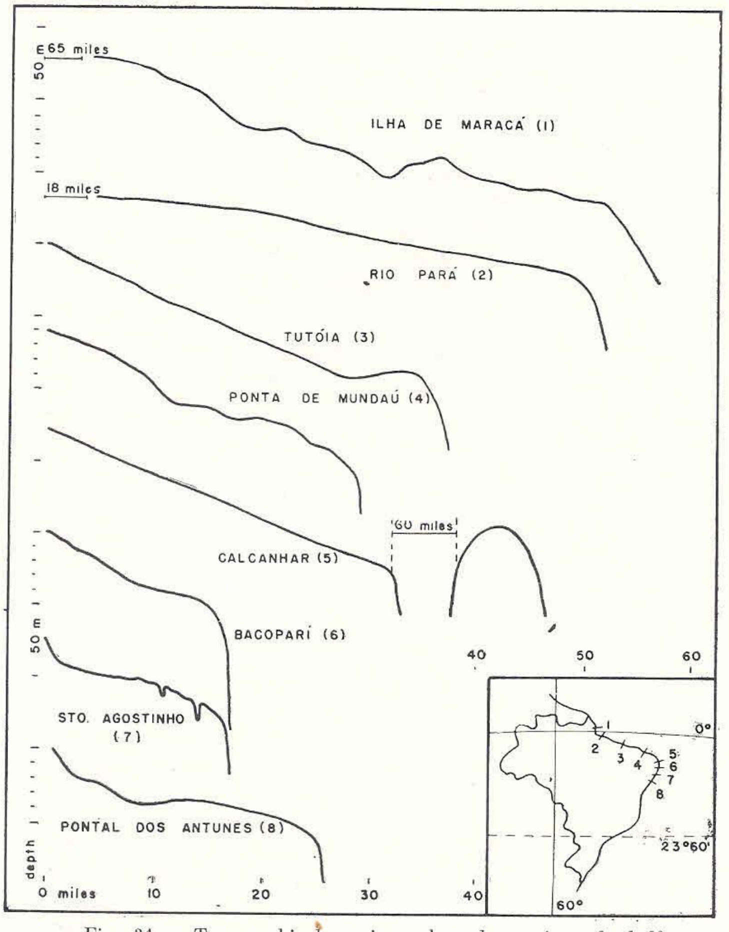

Fig. 34 — Topographical sections through continental shelf.
Perfís topográficos da plataforma continental.

1966 a depth of 1 m and less. This enormous river influence makes a constant vigilance on depth changes indispensable.

The Amazon region possesses the widest shelf, attaining about 150 miles, with a very slight slope. From this area the shelf width decreases to eastward. South of Cape São Roque the continental platform is only about 25 miles wide and near Recife its narrowest parts are not wider than 18 miles. The outer limit is always abrupt in the whole region, with the break occurring at the depth between 60 and 80 m. Only N of the Pará river the slope is very slight and the break found at depths grater than 80 m. The extent of the shelf is well represented by the isobath of 20 m, which is found at a distance of 60 miles from the coast near Cape Norte and at less than 5 miles off Recife.

A series of submerged points and banks exist alongside the shelf off the States of Ceará and Rio Grande do Norte, constituting a very rough relief. Its origin seems to be related with vulcanic phenomena; the banks belong to the same ridge on which the oceanic islands Rocas and Fernando de Noronha are built. The sediments on the highest banks are the same as those found at shelf edge.

A morphologically interesting feature of the shelf bottom is the existence of "waving-bottoms", occurring from São Luis in a NW direction. However, they have not been studied yet in detail. The ridges are crists of coarse quartz sand, attaining height differences of 10 m between top and bottom. It is still an open question, whether these ridges are related to the dunes existing at the coast, whether they might be even fossil dunes.

The topographically best known part of the shelf is that off Alagoas and Sergipe (Cavalcanti & others 1967; Zembruscki 1968). North of the São Francisco river mouth the shelf is relatively flat with depths between 25 and 45 m. After Zembruscki (1968), there exists on the platform off Alagoas a bifurcating gully of about 20 km length, 4 km wide and 30 m deep, with directions coinciding with the coastal lagoons Mundaú and Manguaba. The shelf becomes narrower towards the river mouth, where a canyon exists. Southward the shelf becomes more irregular with small canyons and calcareous points.

Kempf, Mabesoone & Tinoco (1970) presented a detailed bathymetrical mapping of the area off Recife, between Olinda and Cape Santo Agostinho. The authors divided the shelf into three parts: the littoral zone with reefs, causing interesting topographical features; a zone between the isobaths of 10 and 40 m without accidents; a zone below 40 m with longitudinal shaped depressions with depths of about 70 m and small elevations. The break is very obvious, at about 70 m, whereas the slope has an incliation of about 7° up to a depth of 500 m. It seems to be related with faulting.

South of Sergipe State the data are too scarce to give some sections. The only interesting phenomenon in that area is the occurrence of the narrowest part of the whole shelf, near Cape Troma Grande at the city of Itacaré (Bahia State), where it is only 5 miles wide. More towards S the shelf widens again, especially near the city of Belmonte and at the Abrolhos Group.

With these data it was impossible to classify the shelf in one of the groups proposed by Shepard (1963a).

SEDIMENTARY FACIES

Introduction

The study of the samples collected from the shelf bottom, chiefly by dredging (fig. 35), enabled the distinction of a number of sedimentary facies types. Their variations are chiefly due to their composition. The grain size distributions are much less decisive, because they depend not only on the distribution by currents but also on the deposition of recent material and on mixing with ancient deposits. As it has been proved by Mabesoone & Tinoco (1967), it is extremely difficult in the case of such sediments, which part is due to current deposition, which to local accumulation or organisms, and which to older deposits. Therefore, the grain size distribution is only used if necessary, for instance, in distinguishing some subfacies.

The recognized sedimentary facies types are:

(1) littoral facies;
(2) mud facies;
(3) biodetrital facies;
(4) algal facies;
(5) mixed facies.

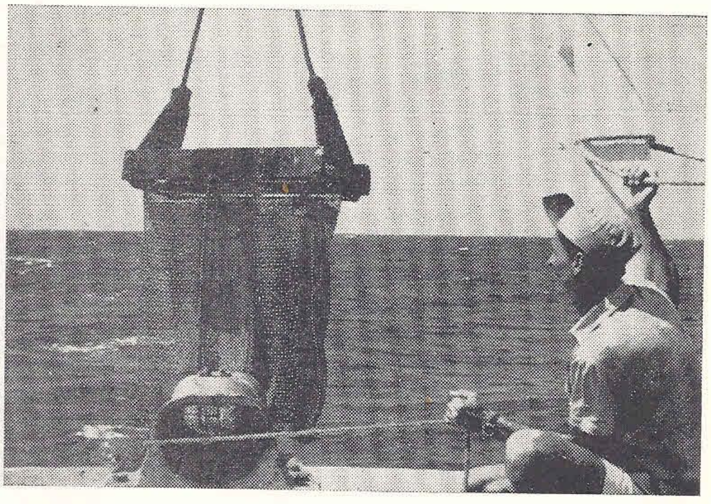

Fig. 35 — Dredge, R.V. "'Almirante Saldanha" (photo J. F. da Cruz).
Draga do N.Oc. "Almirante Saldanha".

A number of these can be subdivided, particularly where detailed studies have been effectuated.

The various facies types are not always sharply limited; in certain areas mixed types can be mapped. The criterium of containing more than 50-60% of a certain component determined in general the denomination, whereas more or less equal proportions over a large area were considered as mixed.

Littoral facies

Generalities. — This near-shore sedimentary facies type is the most complex one encountered. It is composed not only of terrigenous clastic material, such as quartz grains, but contains often a high to dominating quantity of organisms. The investigation of the sublittoral are off Recife (Kempf, Mabesoone & Tinoco, 1970) showed a highly complex area with a rapid subfacies change, sometimes even over a few meters. Besides beach sands, sandstone reefs and local mud areas, were found biogenic accumulations of corals, calcareous algae and other organisms (fig. 36). However, only a detailed mapping makes such a subdivision possible. And often the research vessels have difficulties to take samples from depths below 20 m in the near-shore area. Therefore, in the general consideration, these types have been grouped into one facies: the littoral.

It is fairly easy to recognize at first sight which facies has been brought up by the sampling device. But a more defined

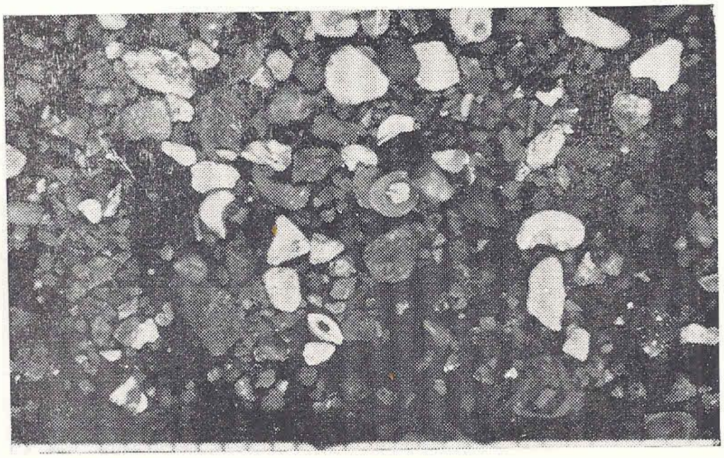

Fig. 36 — Biodetrital facies, Recife harbour (photo Coutinho 1961).
Fácies biodetrítica, pôrto do Recife.

subdivision can only be obtained by microscopical investigation in the laboratory.

Sandy subfacies. — This subfacies is generally composed of a high quantity of quartz grains; depending from the size they are angular to well-rounded with a vitreous to glossy surface character. Pitted and frosted grains occur more rarely. The deposit is sandy in size, well to moderately sorted and negatively skewed.

The biogenic fraction may make up a considerable part of this subfacies, but it never dominates. It is composed of fragments of pelecypods and gastropod shells, some calcareous algae, foraminifera and not more recognizable broken fragments. The *Archaias* and miliolids of great size dominate; when the sands are fine, *Amphistegina* and the smaller miliolids are found.

This subfacies occurs generally in areas not deeper than 20 m. Where it occurs at greater depths, it may be an ancient deposit.

Muddy subfacies. — At some quiet places, near the mouth of small rivers, even ancient ones, and between the reefs, an accumulation of fine-grained silty to clayey deposits may occur. The quantity of sand size material in such sediments varies between 2 and 25%. The remainder is composed chiefly of clay size fraction whereas more silt occurs in waters of lower salinity.

The clay size fraction is generally of terrigenous origin. Its mineralogical composition shows a dominance of kaolinite with minor quantities of illite and montmorillonite. The is due to the type of weathering in the source area and the relatively rapid sedimentation which did not permit the neoformation of other clay minerals.

The sand fraction is constituted of fine angular, not-worn quartz grains. The organisms show foraminifera, particularly of the following families: Miliolidae, Rotalidae, Elphidiidae and Bolivinidae. The species are of small size with a very thin, almost transparent, test.

Reef subfacies. — It is generally known that at the coast of northeastern Brazil beach rock ("sandstone reef") features are abundant . These beach rocks have been considered separately in Chapter 2. They occur not only in the proper beach, but also in the offshore zone where they can become exposed at low tide or remain always submerged. These submerged rocks are often too hard to be broken by the common sampling devices, that is why it seems to exist a "hard ground" at such places.

On the seaward side of the beach rock ridges, where the wave action is strong, growth of calcareous algae, corals and vermetids can be abundant (Laborel 1965a, Laborel & Kempf 1967). These organisms, however, do never constitute reefs of their own, but they may contribute with their debris to the finer sediments accumulated at the foot of the reefs. This is reason why a reef subfacies has been distinguished, showing a very mixed deposit composed of various components, clastic as well as biodetrital.

Other subfacies. — At a few places one can find also other organisms dominating in the sediment. Of these, foraminifera and bryozoans may be mentioned. They occur often at the outer side of the littoral, facies and constitute a transition to other facies types. Their occurrence zones being rather narrow, they are not easily mappable.

Mud facies

This facies covers extensive areas on the shelf north of the Amazon river mouth, and a smaller area south of that of the São Francisco river. The material is of terrigenous provenance supplied by the proper streams. Where the water is still of low salinity, the sediments are more silty, whereas farther from the mouth the material becomes chiefly clayey. The sand fraction is generally insignificant. In the Amazon influence area the muddy deposits are almost without micro-organisms. Near the São Francisco mouth the sediment shows foraminifera in its sand fraction.

There occur also some isolated spots within the shelf area where terrigenous mud has been found. These patches seem to have no relation with either the littoral facies or river influence. They occur generally at somewhat deeper sites where clay size material may accumulate. In the fine sand fractions abundant miliolids are found. On the general map these mud occurrences cannot be figured due to their small extension.

In front of the other rivers, the mud facies does generally not constitute a separate area on the platform. The material settles within the range of the littoral facies with which it is mixed. In this case such a type falls within a subfacies of the littoral environment. This occurs, for instance, at the mouth of the Capibaribe river.

Biodetrital facies

This facies type shows sandy to muddy sediments, composed of dominantly fragments of organisms and generally with an almost absence of quartz. The mud fraction may attain some 40%, chiefly of terrigenous origin, ocurring near the river mouths but transported over a certain distance. The non-terrigenous part is constituted of fine white calcareous mud which is always recognizable. This calcareous mud has been chiefly derived from biochemically disaggregated skeletal fragments as, for instance, calcareous algae (Mabesoone & Tinoco 1967) However, also fine silt size aragonite needles can sometimes be determined. The high salinity of the waters which favours its supersaturation with calcium carbonate, may also cause a certain chemical precipitation.

The determinable organisms are foraminifera, bryozoans, ostracodes, and more rarely pelecypods and gastropods. The bulk of this fraction is composed of broken, often not more recognizable fragments. Among the foraminifera dominates *Amphistegina*.

There may occur a certain constituent which nevertheless does not dominate, but which may be very conspicuous (25-50%). We may mention bryozoans, calcareous algae, and corals. Such deposits could be considered as subfacies, and they have been mentioned where they occupy an area of representable size.

Marchesini Santos & Carvalho (1970) divided this facies, in the Amazon region, into two subfacies. The first is the normal one, within the quartz sand bottom, with a great number of fragments and whole exemplars of benthonic foraminifera, dissociated bivalve shells, sessil organisms, bryozoans, and incrusting calcareous algae. The other subfacies is that nearer to the shelf edge with foraminifera normal for the depth of the environment and other organisms with worn tests, certainly of older origin.

Algal facies

One of the most curious facies types on the open shelf is that composed almost entirely (more than 90%) of calcareous algae. Although in fact belonging to the biodetrital facies, its abundance and great extension permit a separate consideration and mapping.

The most often occurring genera are *Lithothamnion*, *Lithophyllum* and *Halimeda*. The first two genera are present as a mixture of pebble-size ramificated and smaller fragments chiefly of *Lithothamnion*. On the bottom occur often aggregates of algae of boulder size; these may even dominate at some sites. At other places they may constitute crusts which could often not be broken by the sampling devices. But some samples came to surface and could be studied, showing the aspects of an incipient limestone formation (see Chapter 6). In the open spaces, fragments and other organisms accumulate.

On the contrary, *Halimeda* is very delicate in its forms. It lives in the present-day warmer seas in quiet water, especially lagoons, at depths between 0 and 50 m. The calcareous stems generally disappear into the fine fractions because of their rapid desintegration. But at some places, under favorable circumstances, these stems remain as a coarse sediment, constituting then pure *Halimeda*-sands (fig. 37). The frequent

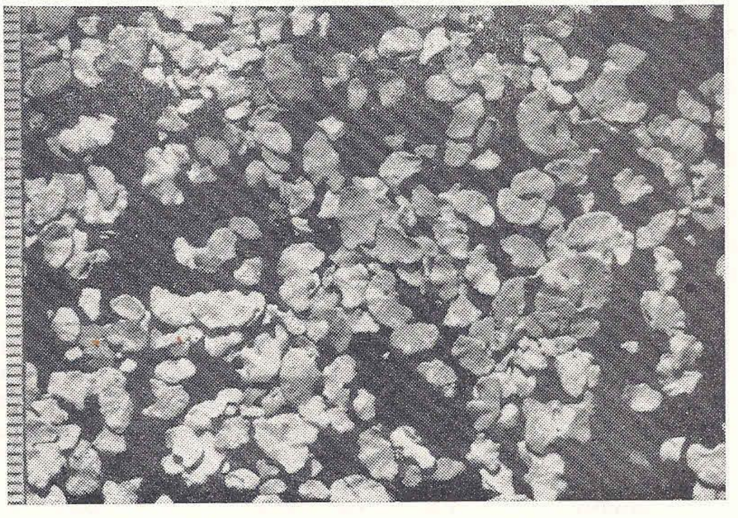

Fig. 37 — *Halimeda sand* (photo A. C. Rebouças).
Areia de *Halimeda*.

occurrences of such *Halimeda* deposits on the open shelf, even up to the self edge in northeastern Brazil, suggest that this area is a rather quiet environment, but also that part of the deposite may be fossil.

The finer material retained between the open spaces is composed of the common organisms of the area, for instance foraminifera of the genus *Archaias*. The mud size material is constituted of fine calcareous dust, possibly attrition fragments of the proper algal remains.

Mixed facies

Where two facies types show more or less equal proportions, they have been considered as mixed. These have been mapped only where the mixtures occupy extensive areas on the shelf, or where detailed investigations have been presented on smaller scale maps. In this way two common types can be distinguished.

Mixed facies of terrigenous and biodetrital material. — Occurs in wide areas, particularly where the quartz sandy littoral zone is also wide. Such a zone passes gradually into the facies of biodetrital material, so that a fairly wide strip of mixing may exist. The quartz grains possess the same character as those of the more landward littoral facies, whereas the biogenic material is constituted of fragments of various types of organisms.

Between the littoral zone and the more outer algal facies a mixing zone does also occur. But there it is often too narrow for mapping. Only in areas where detailed studies have been carried out, such a mixed facies could be figured as, for instances, off the city of Recife (fig. 40).

Mixed facies of biodetrital material and coarse algal fragments. — Covering large areas of the shelf bottom, especially in northern Brazil, this sedimentary facies is characterized by a fine fraction (sand) composed of organogenous fragments and a coarse fraction (gravel) of calcareous algae. Curiously, in the sand fraction the algae fragments do not dominate, but may constitute a great part (up to 40%) In this case the algal fragments are chiefly of *Lithothamnion* and *Lithophyllum*, just as the boulder-size concretions, whereas *Halimeda* is completely absent. This mixed zone is found, where the pure algal facies tends to disappear, in the direction of the Amazon mouth.

Age of the sediments

It is generally known that many sediments covering the shallow sea floor, have been deposited under other environmental conditions than the present ones (Emery 1968, van Andel 1967). Such sediments are called "relic". It is found that large platforms with many calcarenites are relic.

In the foregoing were already mentioned some features which could point to the fact that also in the investigated area, relic sediments are frequent. For instance, an irregular grain size distribution, a very wide zone of littoral sandy deposits, *Halimeda* stems at greater depths, are some arguments in favour of it.

The recognition of calcareous relic facies in hand specimens is very difficult; often laboratory analyses have to provide the final decision. There exist a number of criteria for this: (1) colour — the deposit has no more white colour; (2) calcareous algae — *Halimeda* found below a depth of 50 m must be dead; (3) no more aragonite; (4) shells occurring at greater depths; (5) C-14 datings. In the investigated area no such datings exist, but on a number of samples some of the other criteria can be applied.

The dredged samples thought to be relic material were determined by the following facts. First, their occurrence in areas where other facies types prevail, for instance, organogenous material in a littoral sandy zone. Secondly, their colours are often grayish and their fragments broken, worn and rounded Thirdly, the occurrence of *Halimeda* and molluskan shells at depths greater than normal. Particularly these shells prove to be good indicators; they appear as worn exemplars or with incrustations of other organisms. The white *Halimeda*-stems, however, would suggest a recent age, but their occurrence at depths of about 70-80 m cannot be of recent times. This can be confirmed by the smaller organisms between these stems. For instance, the foraminifera are often worn, evidently already fossil (I. M. Tinoco, personal communication). Furthermore, at two places within the algal facies, sediments have been dredged up consisting almost entirely of more or less worn exemplars of the foraminifer *Amphistegina radiata* forma *tumida;* such a deposit cannot be of recent age but has to be either an accumulation of these tests during a long time or a result of a longtime slow sedimentation (Tinoco 1968). The age, however, cannot be determined. The foraminiferal fauna indicates only a Quarternary age. Another argument is the actual fauna. M. Kempf (personal communication) noted that the bottom fauna at depths below 40 m is different from that at shallower depths, independent of the bottom sediment character. It is too doubtful, with only these scarce data available, to correlate the sedimentation with the sea level rise since the past few thousand years.

The wide zone of quartz sand littoral facies, chiefly off the coasts of Piauí, Maranhão and eastern Pará States, gives also the impression of a zone of relic sediment. Actually, no river, not even the Parnaiba, provides much sand to the shelf. Then for instance, the extensive Parnaiba delta must been built during other circumstances, when the river carried more coarse material thus having a greater runoff.

Anyhow, due to the many uncertainties, no area of relic sediments could be mapped. This makes the problem to be very complex so that a good deal of more detailed work is required to enable the drawing of some decisive conclusions.

FACIES DISTRIBUTION ON THE SHELF

Introduction

The general facies distribution has been presented on the annexed map. The scale of his map, 1 : 4.000.000, did not permit to subdivide these facies, especially because of the narrow shelf width off the northeastern coast. Therefore, where such subdivisions are known, more detailed maps on a smaller scale have been added.

For the interpretation and consideration of these facies in the investigated area, four parts can be distinguished:

(1) from the Amazon mouth northward to Cape Orange;
(2) between the Amazon and the Parnaiba river delta;
(3) from the Parnaiba river to the mouth of the São Francisco river;
(4) from the São Francisco river southward to the Abrolhos archipelago.

Of these parts the fourth is less well known; here still no detailed investigations have been made.

The few areas of which a more detailed map can be given, are the Amazon mouth (Tôkô-Maru 1958; Ottmann 1959; Kempf, Coutinho & Morais 1968, 1971; Coutinho & Morais 1970), off the city of Recife (Kempf, Mabesoone & Tinoco 1970), off the States of Alagoas and Sergipe (Mabesoone & Tinoco 1967) including the mouth of the São Francisco river (Coutinho 1970b).

A small scale map of the stations where samples have been taken, cannot be given. The great number of cruises of different vessels, and the still greater number of samples taken, make such a map impossible. Therefore, it may be referred to the original publications. When describing the various shelf parts, reference will be made to these different sources.

Generalities. — Fairly complete investigations in front of the Amazon mouth and northward to Cape Orange have been made in 1956-57 by the Japanese R.V. "Tôkô-Maru" (Tôkô--Maru 1958) and by the Brazilian R.V. "Almirante Saldanha" in 1958 (Ottmann 1959) and again in 1967 and 1968 (Coutinho & Morais 1970; Kempf, Coutinho & Morais 1968, 1970). Oceanographical data have been published by the Tôkô-Maru (1958) and by Moreira da Silva (1959). The geomorphological features have been considered by Pimienta (1959). The shelf area in which the river influence is felt, is rather extensive so that a separate paragraph may be dedicated to it.

The river mouth is known under various names such as Amazon Estuary and Mouths of the Amazon. The best denomination, however, seems to be the Brazilian term "Golfão Amazônica" or Amazon Gulf. In this gulf and on the adjacent shelf the Amazon and Tapajós rivers deposit a great part of their load, although a fairly high percentage is taken by the ocean currents and transported alongside the Guyana coast, even partly deposited there.

Oceanography. — The data known have been given by the Tôkô-Maru cruise (1958), by Moreira da Silva (1959) and recently by the cruises of the "Almirante Saldanha" (some data already published). Current reasurements have been scarcely made, but it is known that the South Equatorial Current passes the river mouth in the direction of the Guyanas. It causes the sediment-loaded runoff to curve towards NW. This is confirmed by the salinity patterns. The temperatures are high, varying between 26 and 28°C. For detailed maps may be referred to the original publications.

The R.V. "Tôkô-Maru" made also some determinations of the water transparency in meters. Figure 38 gives the results. One sees evidence of a lower transparency where the river influence is highest, but in the whole shelf are the transparency values are low almost never below 10 m. This means that the suspended river mud occupies a fairly broad area seaward.

Sediments. — The data published by the various reports are all in agreement. Figure 39 presents the facies types found at the bottom surface in the river mouth area. Also here becomes evident the tendency of sediment transport with longshore current. In the two principal river branches (Amazon and Pará) chiefly well-rounded quartz grains are met with. N of the Marajó island a fluvial mud facies occurs which continues

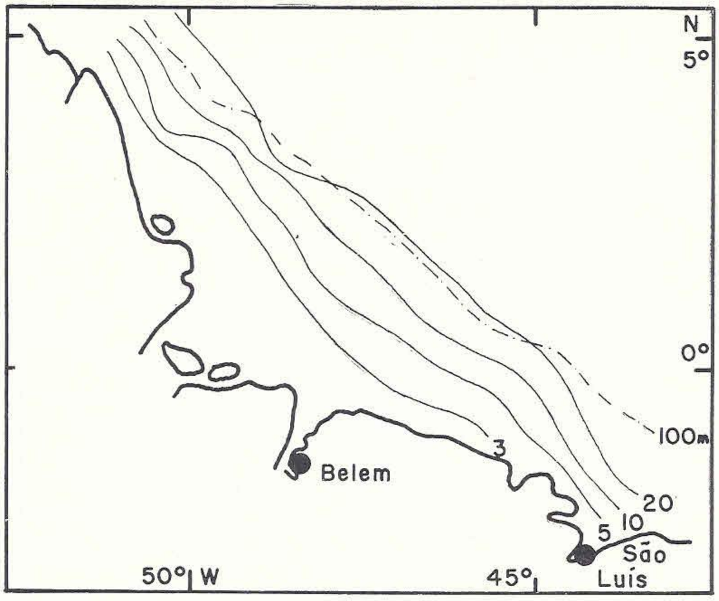

Fig. 38 — Water transparency in meters, Amazon mouth (Tôkô-Maru 1958).
Transparência da água em metros, foz do Amazonas.

northward. Although Ottmann (1959) does not give analytical data, he suggests that the major part of this mud consists of clay size material. However, the somewhat lower salinity values in the western part of this mud area could indicate the sediment there being more silty. Alongside the Amapá coast the mud zone continues although the sand percentage increases. This sand shows besides rounded, glossy quartz grains a very few fragments of organisms. This almost sterile sediment points to a rapid deposition.

Coutinho (personal communication) studied the mineralogy of the clay fraction of the mud. Generally one supposes that the river, coming from an equatorial area, has a great quantity of kaolinite in its clay (see for instance, Bakker 1963). But it appeared that the clay size fraction is almost entirely composed of the minerals of the montmorillonite group with nontronite as the dominant constituent. Actually, the chemistry of the fine fraction is being studied. On the contrary, Caillaux (1970), studying the mud samples taken by the expedition "Geomar I", determined the clay mineral composition as being equal

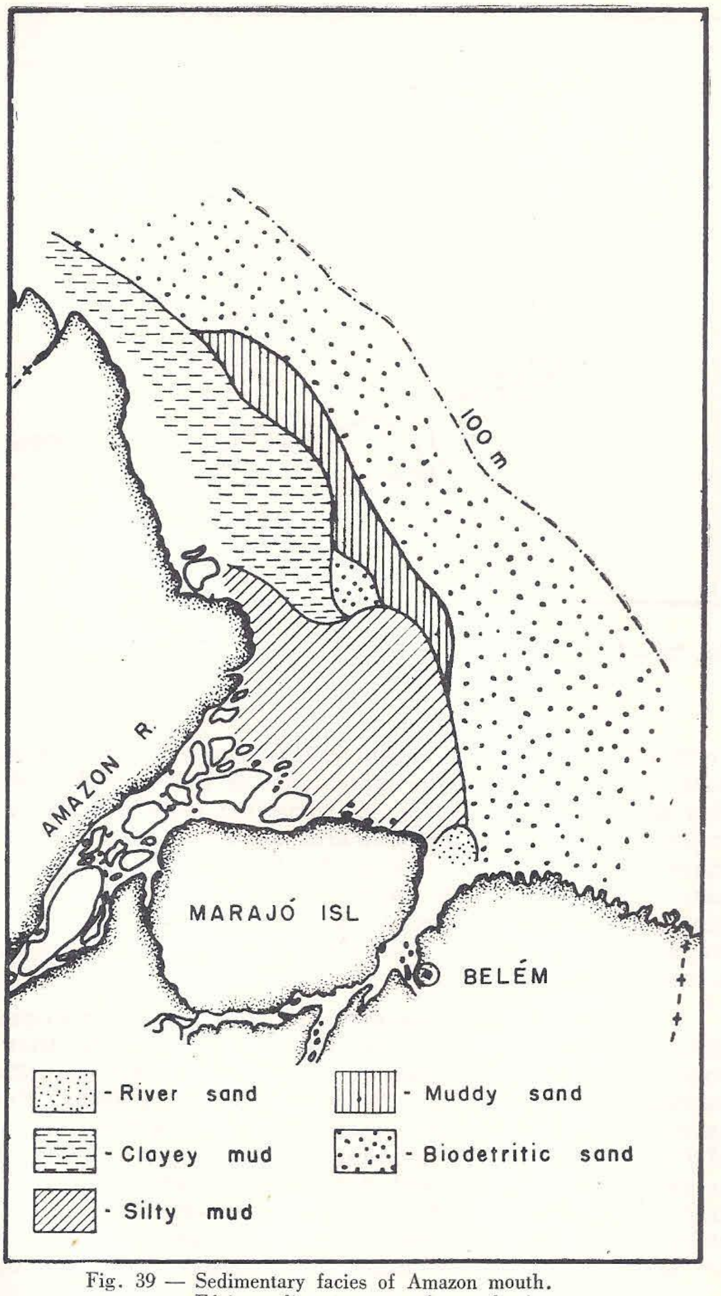

Fig. 39 — Sedimentary facies of Amazon mouth.
Fácies sedimentares em frente do Amazonas.

quantities of kaolinite and illite, with only minor amounts of montmorillonites. The reasons for this anomaly in both studies has not yet been detected.

In front of the mud area, a mixed fluvial-biodetrital material is found. This facies type shows besides the quartz sand and mud of fluvial origin, fragments of the common organisms found at the shelf. These are, for instance, bryozoans, serpulid worms, foraminifera, various mollusks and ostracodes. It can be seen that, although the general disposition of this facies is directed with the longshore current, it also occurs somewhat more eastward. This is certainly due to other rivers which are not very important but carry a rather great quantity of material to the ocean. However, a part of the fluvial fraction in that area could be fossil. A sandy littoral-terrigenous facies, as commonly occurs alongside the coast, cannot be detected in the Amapá region because of thorough mixing with the fluvial mud.

The remainder of the shelf, where almost no more river influence is noted in the bottom sediment, is covered with the biodetrital facies. It is composed of the organisms mentioned before. In this area no algal facies so common at the north-eastern coast is found. The survey of the Tôkô-Maru (1958) proved the occurrence of coral at the outer shelf area, at some places. These corals are not present in the form of reefs but as solitary individuals. The data published in the mentioned report give always a mixture with "sand" which may be of organogenous origin, meaning that the coral never dominates.

The study of the microfauna, particularly of the foraminifera, effectuated by Tinoco (1959), shows the presence of the common benthonic species together with a certain number of planktonic ones. These latter must have been supplied to the shelf area by the longshore current. In Chapter 5 the determined species are mentioned.

Actually, the Amazon river is filling up its estuary and building a delta on the shelf (Russell 1958). So one may suppose that the fluvial and mixed sedimentary facies in front of the river and towards the NW are recent formations. It appears that it is an area of rapid sedimentation, because the deposit is almost without any organogenous fragment. The mixed facies found more towards the NE came chiefly from the numerous small rivers which embouch into the ocean between the Amazon mouth and São Luis in the State of Maranhão. But it suggests also that a part of it represents the remnant of an ancient delta at least with respect to its fraction of fluvial origin (Pimienta 1959).

Amazon to Parnaiba delta

Generalities. — This shelf part of northern Brazil was until recently one of the less well known areas. No detailed studies existed there, and the stations at which sediment was collected were relatively few. The area was sampled by only one research vessel, the "Tôkô-Maru", and that only between the Amazon mouth and São Luis. Finally, the Brazilian "Almirante Saldanha", in summer 1967 on its cruise 35, completed the sampling also of the still unknown shelf parts. Taking together these data, one has now a clear idea of the bottom sediment character (Kempf, Coutinho & Morais 1968, 1970).

In this area the shelf becomes gradually narrower from W to E. In the W part it borders an area with a more or less humid tropical to equatorial climate, whereas towards E the climate at the coast becomes more semi-arid. This has its influence on the river supply and consequently on the shelf bottom sedimentary facies, as explained below.

Oceanography. — Most of the data on salinity and temperature were obtained by the cruises of the "Tôkô-Maru" and "Almirante Saldanha", to which detailed reports may be referred here.

The surface temperatures measured in the area are remarkably uniform, about 26°C with differences of less than 1°. The same uniformity exists with respect to the salinity; all determined values turn around 36°/oo with differences of less than 1°/oo.

Current measurements have not been made. But also in this area the fairly strong South Equatorial Current exercises its influence. This can clearly be concluded from the sediment pattern; all material supplied to the ocean settles in a westward direction.

Sediments. — Three facies types are found in this area: littoral, biodetrital and algal, whereas wide zones of mixed types are common.

The zone in which the littoral facies covers the shelf bottom, is also rather wide. W of the Parnaiba river delta the deposits are chiefly sandy, whereas nearer to the coast they become somewhat more muddy. The sand size fraction is composed of rounded, glossy quartz grains giving a yellowish beach-like aspect to the sediment. The biogenic fraction constitutes only a few percent of the total sample and is chiefly composed of foraminifera, ostracodes, bryozonas, mollusks and broken fragments.

The sand fraction of the samples dredged up by the Geomar I — expedition, has been studied by Pomerancblum & Costa (1970). The grain size characteristics may be summarized as follows: (1) the grain size distribution is unimodal; (2) median and mode values are very anomalous for the environment as well as among the proper sediments. Heavy mineral analyses showed only a few local variations; the common association is composed of staurolite, zircon, tourmaline and kyanite. Only towards NW hornblende increases in percentage, whereas there appear hypersthene, andalusite, basaltic hornblende and augite in the association. The authors came to the conclusion that the sediments are mature, transported to the shelf by only one agent, suffering only a partial reworking; two different rock types, of crystalline origin, contributed to the heavy mineral assemblages. One may add that these data indicate a relic sediment.

Based on the biological composition of these deposits, even a supposed ancient coast-line could be traced (Marchesini Santos & Carvalho 1970).

The Parnaiba river built a large delta on the shelf in front of its mouth. As the river transported much sandy material, the submarine delta part is almost entirely sandy. The sand is medium to fine grained with not-worn quartz grains; its aspect in the sample is of a fine, gray sand, thus showing a difference with the sandy sediments more to W. The current pattern causes the material to be deposited in a westerly direction. This is not only noticeable in the proper delta form (Chapter 2, fig. 12), but also in the occurrence of the fluvial material on the shelf. The sediment is chiefly composed of quartz; only a few biogenic fragments are met with. Another conspicuous feature is the occurrence of a recent calcareous sandstone in this area; its probable origin will be considered in Chapter 6.

The remainder of the continental shelf between the Amazon Gulf and the Parnaiba delta has a biodetrital bottom sediment with algal gravel. It occurs from the littoral facies zone to the shelf break. The deposit shows sand-size fragments or whole organisms, generally belonging to the common groups; a great part of the deposit is composed of broken fragments not more recognizable. Algae dominate only at one place which means that this facies type is of minor importance here.

The wide extension of the sandy zone causes also a wide zone with mixed deposits composed of quartz and biodetritic fragments. It is found between the littoral facies and the mixed biodetrital-algal facies. It is also determined at two places nearer to the coast where it occupies a special place; most probably these deposits are relic.

Parnaiba delta to São Francisco river

Generalities. — The separate distinction of this shelf area is chiefly based upon the better knowledge of this part than of that more southward. It is also characterized by the dominant ocurrence of the algal facies in this area.

The platform is narrow, from 40 to 28 miles between Parnaiba and Cape São Roque and from 25 to 18 miles southward to the São Francisco river mouth.

The investigations here have been made by the vessels "Akaroa" and "Canopus" (SUDENE), "Taurus" and "Almirante Saldanha" (Brazilian Navy), "Calypso" (France), besides some samples taken by an unknown vessel of the DHN (Diretoria Hidrografia Naval). There exist also two areas mapped in detail. The first is that in front of the city of Recife, made by a small vessel hired by the Oceanographical Institute of the Federal University of Pernambuco and by SUDENE, and completed at the greater depths by Hidr. V. "Taurus". The second is the northern part of the region sampled by the "Akaroa", that is off the Alagoas State; this latter study continues also more to southward off the Serigpe State.

The shelf is bordered by the so-called Barreiras cliff coast (Chapter 2), and has a semi-arid climate between Fortaleza and the region N of Natal, and a tropical seasonally humid climate in the other parts.

Oceanography. — Besides the general oceanographical data, there exist more detailed studies in the Recife (Cavalcanti & Kempf 1970) and Alagoas-Sergipe (Cavalcanti & others 1967) areas. Temperatures are more or less the same as in the shelf area W of Parnaiba. They turn around 26°C at the surface; near the bottom they become hardly lower, with averages of 25,5°C. The salinity values in the whole area turn around 36°/oo, also more or less equal to those W of Parnaiba.

The ocean currents are more complex (fig. 4). The Atlantic South Equatorial Current which approaches the Brazillian coast near its northeastern point, bifurcates forming a northern branch — the South Equatorial Current — going towards W, and a southern branch — the Brazil Current — going towards S. The shelf between Cape São Roque and Parnaiba is under the influence of the northern branch, the same as the other shelf parts more westward. The shelf S of Cape São Roque, however, is not so much influenced by the Brazil Current. This branch remains out of the narrow platform area during the major part of the year, causing a kind of counter-current which flows northward (compare fig. 4). Although no current measurements were made, its existence is shown by the deviation of the river mouths towards N, especially those of the Capibaribe, Paraíba do Norte and Potengí, and the major part of the smaller rivers. Only off Alagoas the influence of the Brazil Current becomes more pronounced.

Sediments. — The most conspicuous element in this area is the algal bottom facies. It is found between the Parnaiba delta and Cape São Roque at the shelf outside the zone where the littoral facies deposits occur. From Cape São Roque to the São Francisco river mouth it occupies almost the whole shelf, because the littoral zone is there very narrow. The greater part of the algal zone is composed of fragments of *Lithothamnion*, but at various places the bottom sediment is constituted of *Halimeda* sand. Where these places have a considerable size, they have been marked on the map. The whole zone of occurrence gives the impression of being one giant organic reef area. Why such an area is found here at the open ocean, is still a problem. Especially the friable *Halimeda* fragments do generally not occur on open shelves. But one may think in a weak current action at these places, at least at the time of formation of the deposit. However, algal reefs grow exactly where the waves are strong. Therefore one may think about a not so recent age for this facies type, although the pure white colour of the sediment would be an argument against this supposition.

The biodetrital facies is found only at a few places, particularly at the shelf edge. It is chiefly composed of fragments of organisms in which algae are abundant but never in quantites over 50%.

The littoral facies occupies a rather wider zone at the northern coast. It is composed of medium-fine quartz sand with minor quantites of organisms. In front of the Jaguaribe river, in the E of the Ceará State, the quartz grains are somewhat coarser, supplied by the river. The number of samples is too small for an exact delimination of the area of river influence here. Alongside the eastern coast the littoral zone is much narrower. Generally quartz sands make up a great deal of the sediments.

Kempf (1970a, b) completed recently the more detailed investigations to the region of Itamaracá island, and along the whole platform off Pernambuco State. The results confirm the general pattern established for the area. It was noted that between reef zone and beach, the muddy subfacies of the littoral facies bottom occurs fairly frequently in the whole area.

Area off Recife. — The area in front of the city of Recife has been mapped in detail, with a special subdivision of the littoral facies (fig. 40, after Kempf, Mabesoone & Tinoco 1970). There can be distinguished three subfacies within the littoral zone, besides the algal facies at depths below 20 m and a small transition zone.

The greater part of the littoral area is occupied by the quartz sand subfacies, in which more or less rounded medium to coarse quartz sands dominate. The material becomes finer more seaward, with an increasing quantity of biodetrital material composed of fragments of the region's common animals. The foraminiferal fauna is poor, with dominance of worn thick skeletons of *Archaias, Amphistegina* and miliolids.

The reef subfacies occurs in a narrow zone near the beach. It shows a hard substratum of beach rock on which grew or still are growing calcareous algae and also some corals. At the foot of the reef and in its transverse channels, accumulate biodetrital material eroded from the centre. Among the foraminifera the miliolids are the most abundant, followed by *Amphistegina* and some rotalids.

Mud is found at three different places, of which the zone between beach and reef is the most important. The fine material is of terrigenous origin with a certain quantity of fine quartz sand and biodetrital sand. The mud has also a high content of organic matter, giving a strong smell of H_2S to the sample. The microfauna is composed of thin, fragile tests of rotalids (*Ammonia, Discorbis*), miliolids (*Triloculina, Quinqueloculina*), and elphidids.

More seaward, generally below 20 m, the common algal facies of the shelf is found with characteristics as described before. Between this and the littoral facies, a narrow zone of mixed sediments occur.

Area off Alagoas. — The area off the Alagoas State, sampled by the "Akaroa" (Mabesoone & Tinoco 1967), gives an impression how the sedimentary facies are distributed on the shelf, when mapped in some more detail (fig. 41).

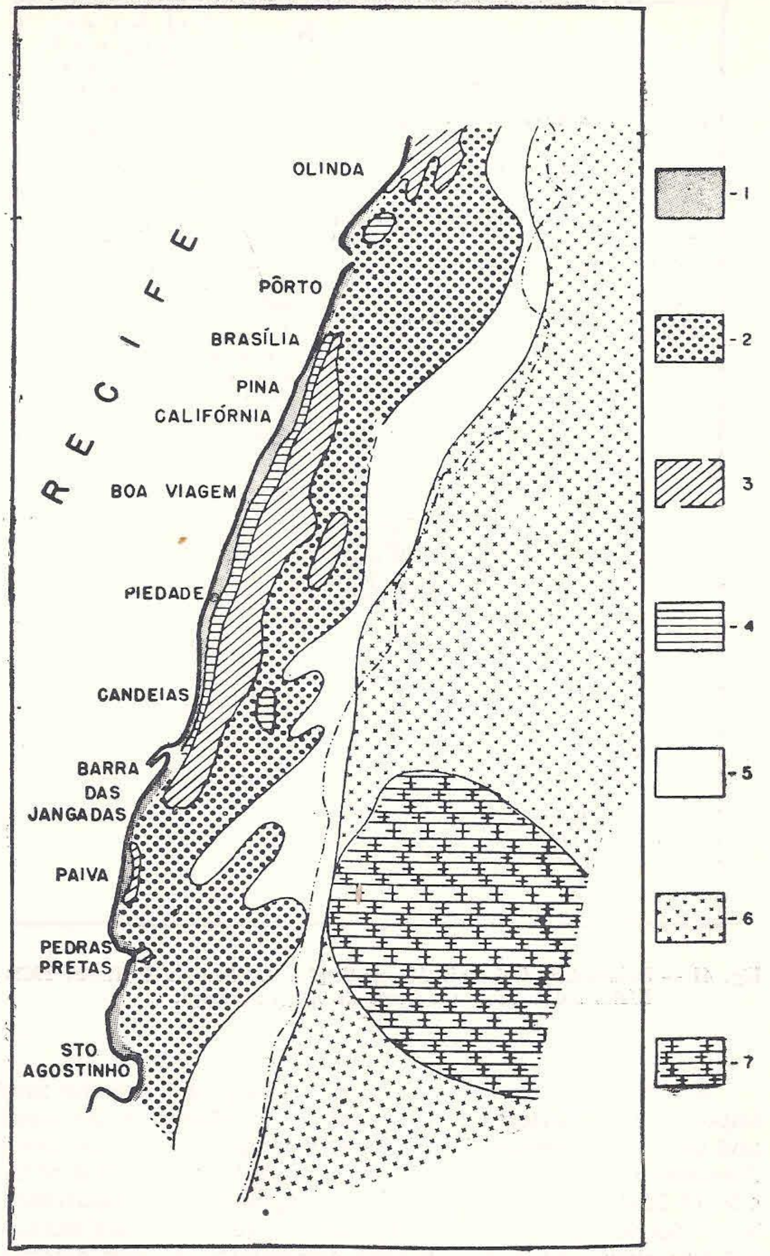

Fig. 40 — Sedimentary facies off Recife, detail (Kempf, Mabesoone & Tinoco 1969).
Fácies sedimentares em frente do Recife, detalhes.

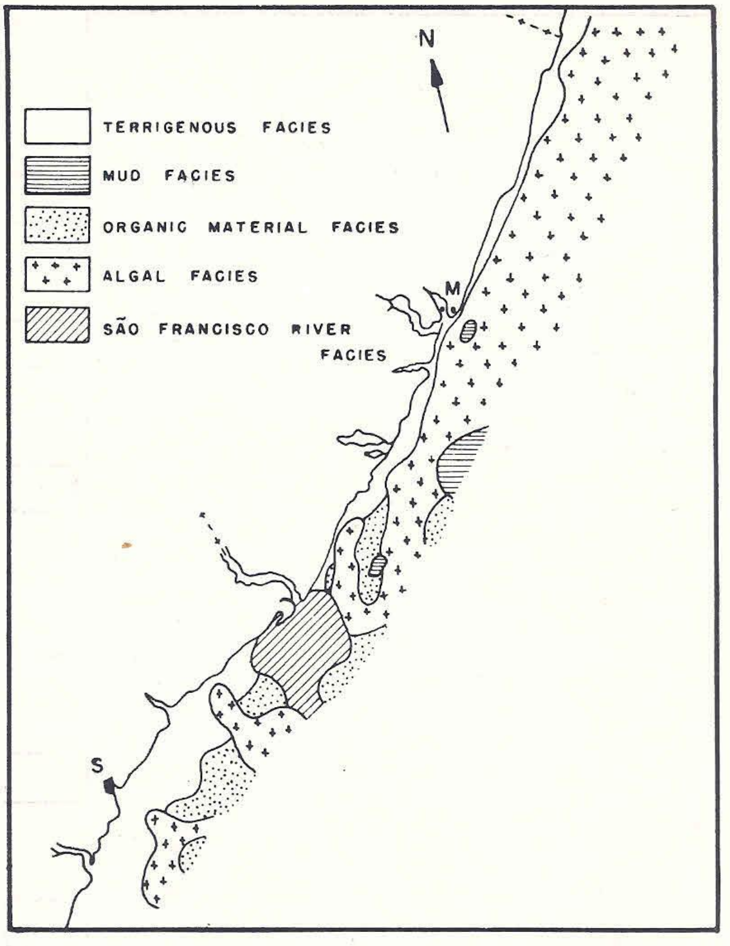

Fig. 41 — Sedimentary facies off Alagoas-Sergipe (Mabesoone & Tinoco 1967).
Fácies sedimentares em frente de Alagoas-Sergipe.

North of the São Francisco river two facies are the most important: the littoral in a narrow zone alongside the coast, and the algal covering almost the rest of the shelf. In the north extensive areas with *Halimeda* sands were found. Only S of the city of Maceió the biodetrital facies appears, two occurrences being found at the shelf edge. Mud is found at two isolated patches, deposited due to special circumstances, only detected because of the detailed mapping. The third mud occurrence is below the shelf edge at the upper part of the slope, although still at shallow depths (about 100 m).

The facies becoming more varied near the São Francisco river mouth, may be the consequence of the river influence. It is often found that the algal facies does not well develop where muddy river waters come into the sea.

São Francisco river to Abrolhos

Generalities. — This shelf part is still for the greater part unknown. Only a few expeditions have taken some samples at localities near harbours or interesting points, leaving almost open the space between. Available data are of the R.V. "Calypso" (Forest 1966) and "Almirante Saldanha" (Operação Leste I; data still unpublished). Only off Sergipe, in the northernmost part of the area, the "Akaroa" made a more detailed investigation, whereas the São Francisco river mouth is fairly well known (Coutinho 1970b). The scarce data made it impossible to trace with certainty the limits between the different facies types so that these have been marked on the map as "inferred".

The platform remains narrow between the São Francisco river and the southern part of the Bahia State (5-45 miles). Only between Belmonte and Santa Cruz Cabrália it shows a sudden extension from 40 to 150 miles. Then it becomes narrower again (about 50-60 miles) to widen near the Abrolhos group up to about 250 miles and more. In this area also a number of shallow banks off the shelf occur, until yet not studied.

The coast is characterized by. Barreiras cliffs and other more or less steep slopes with a clayey weathering cover. The climate is humid tropical with a rainy season in summer (Chapter 2, fig. 4).

Oceanographical data are also scarce. But even these have not yet been published. Also those of the "Almirante Saldanha" did, until now, not come into our hands. But one may suppose that due to the warm Brasil Current, temperatures and salinity show values in the same range as those found more northward.

Sediments. — Initially, it was thought that S of São Francisco river mouth, the dominance of the algal facies would decrease (see, for instance, the operation "Akaroa"; Mabesoone & Tinoco 1967). The river influence on the shelf are off Sergipe is still noticeable, so that there the algae could not well develop. Up to more or less the city of Aracaju the biodetrital facies with a high mud content dominates. But more towards S the algal facies dominates again in almost the entire area. Even in the interior of the Todos-os-Santos Bay, near the city of Salvador (Bahia State), algal debris cover the bottom (Chapter 2). The littoral facies zone in the whole area is narrow, as is the case with the area more northward. Locally, within the algal facies, some other organisms may dominate, such as bryozoans and even corals; in such cases these occurrence have been mentioned on the general map.

Where the shelf widens, especially at the borders and at greater depths (below 50-60 m), the biodetrital facies is more abundant. The facies type seems to be dominant at greater depths. Where it occurs at shallower depths, there must be a certain cause for its existance, as is the case with the São Francisco influence area.

Around the islets and rock points of the Abrolhos group, the bottom surface facies is also algal. Coral fragments constitute only a minor amount of the whole sediment. This does suppose that the so-called "coral reefs" of Abrolhos posses a similar substratum as the other coral occurrences in the whole investigated area.

In this area, Martins & Villwock (1969) made also some preliminary investigations. The results of these authors confirm the general pattern of the region. Kempf (1971) collected all scattered data from the various publications about the area. His interpretations were used for the confection of the map. Actually the shelf off Bahia State is being studied in more detail.

São Francisco river mouth. — This area has been studied in detail, first by the "Akaroa" (Mabesoone & Tinoco 1967), and later by the "Ilha de Itamaracá II" of the Fisheries Division of SUDENE (Coutinho 1970b). The data provided by both expeditions do not cover each other exactly. A map of the area has, been presented in figure 42.

At the shelf north of the river mouth the common, gravel--sized algal facies dominates, and south of it a mixture of terrigenous, algal and biodetrital, sand-size material.

The central area covered with muddy sediments is rather extensive, although the greater part of the fine material brought by the river settles in its canyon and at greater depths in a delta-like accumulation on the continental slope. Coutinho distinguishes two types of different size within these muddy deposits: very silty clay and silty clay. The first type is the more commonly occurring in a central band in front of the river

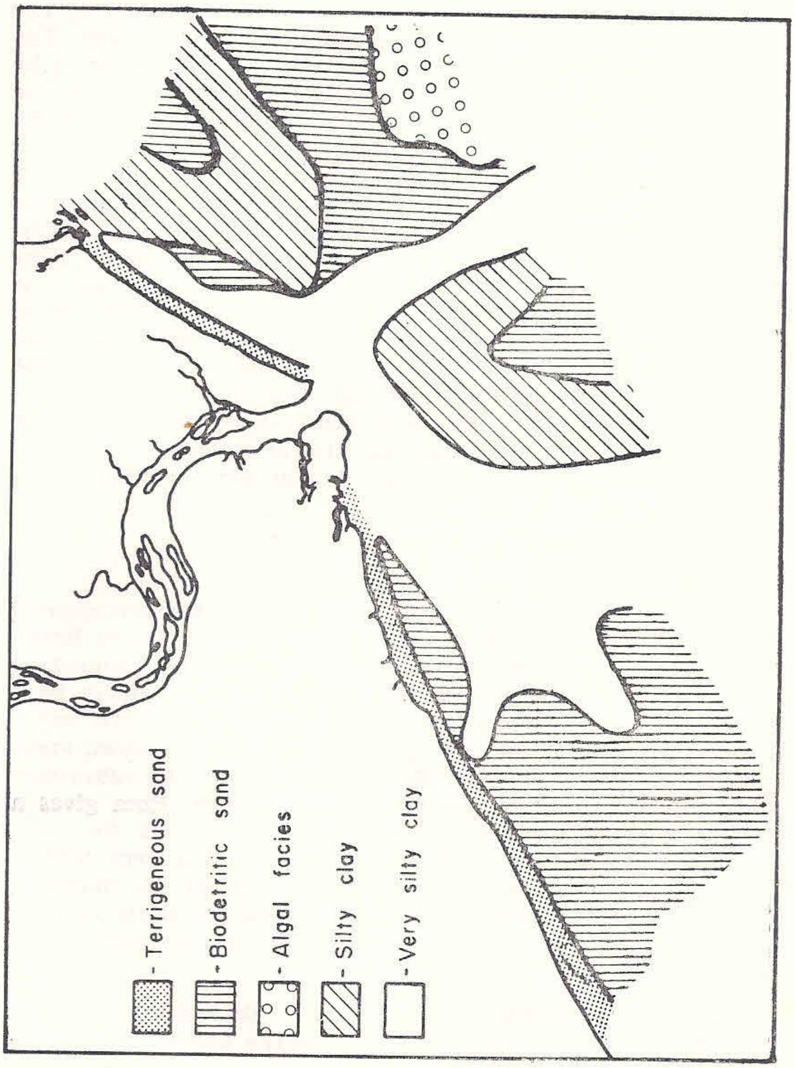

Fig. 42 — Sedimentary facies off São Francisco mouth, detail (Coutinho 1970b).
Fácies sedimentares em frente do São Francisco, detalhe.

mouth, being the bulk transported towards SW due to the longshore current. The other type occupies the head of the canyon and its northeastern slope. In the canyon itself a constant turbidity current mixes thoroughly all available material, with a dominance in the fine sizes. The distribution of the silt fraction is due to the water salinity which is very low near the river mouth, causing the deposit to be more silty. The scarcity of biogenic fragments is thought by the author to be the consequence of a direct or indirect adverse effect of the rapid sediment supply to the shelf on the development of the fauna.

Area off Sergipe. — The area off the State off Sergipe, also sampled by the "Akaroa" (Mabesoone & Tinoco 1967), showed an important influence of the São Francisco river mouth just in the north (fig. 41). The facies distribution is more irregular, and most samples, although still belonging to the algal or biodetrital facies, possesses a rather high percentage of mud (up to 30%). Because of this the occurrence of the algal facies remains restrited. Only where the river influence is not more sensible, to the S of the mapped area, the algae become abundant again. Also the littoral facies zone off Sergipe is wider, with muddy sands, due in part to other rivers embouching in this region.

Subsurface

The subsurface of the continental shelf in the investigated area remains almost unknown. Only recently, Petróleo Brasileiro S.A. initiated chiefly seismic studies off the sedimentary basins on the continent, in search for oil. Two papers have been published thusfar (Fonsêca 1967; Rosa 1967). The paper of Fonsêca explains, by comparison of other well-known areas such as the Mississippi and Niger deltas, where the subsurface of the shelf is most favourable for oil reserves. Rosa gives a map of the Brazilian shelf with some sections off the sedimentary coastal strips. These sections reveal a very faulted shelf subsurface in many areas, especially off the States of Maranhão (Barreirinhas basin), Rio Grande do Norte — Pernambuco, Alagoas — Sergipe, and Bahia (continuation of Recôncavo basin).

In a recent communication, Fonsêca * showed some profiles made at the Amazon mouth, in front of the Barreirinhas basin

* Eng. José Ignácio Fonsêca of Petrobrás: conference about "Oil exploration on the continental shelf of Brazil", held at the 4th Symposium on the Geology of Northeastern Brazil, Recife 1968.

(E of São Luis do Maranhão), and in the area off Bahia State between Mucuri and Abrolhos. The most probable structures in which oil can be expected are: (1) thick Mesozoic-Tertiary deltaic deposits (Amazon); (2) reefs; (3) salt domes (Sergipe).

In the Amazon area the more prospective deltaic sediments are found on the shelf area. The structures shown by aeromagnetometric profiles show a great complexity, possibly even the existence of a reef at a distance of 100 km from the coast with a possible thickness of 6000 m .

Off the Barreirinhas basin, the crystalline basement is found at a depth between 6000 and 7000 m, which means an enormous sedimentary sequence in that area. The thickest series occurs, where the surface sediment map shows the influence of the Parnaiba river in a delta.

Off the States of Rio Grande do Norte, Paraiba and Pernambuco, the seismic explorations are still being carried out, with no results available yet.

The more prospective areas occur off Sergipe and Alagoas where at moment oil has been discovered. The São Francisco river possesses almost no delta, but the Vaza-Barris shows a better prospect. Off the Sergipe coast the oil is accumulated in salt dome structures.

The submarine gravimetrical studies off Bahia show minima in the Mucuri-Caravelas and Belmont-Pôrto Seguro areas, maybe due to the presence of salt too.

Whereas the studies have still not been finished, more detailed information cannot be given for the moment.

CONTINENTAL SLOPE

Although this volume is dedicated to the shallow marine geology of the investigated area, the various expeditions took sometimes samples from the continental slope as well. This slope begins more or lesse at a depth of about 100 m what is still relatively shallow. There are places where the occurs even at 70 m. The slope itself had a fairly high angle, particlarly at the northeast coast, becoming only more normal below a depth of 500 m (Kempf, Mabesoone & Tinoco 1970).

Within this environment, from which the São Francisco river canyon was excluded, various types of sediments have been collected as, for instance, recent limestones, sands composed of biogenic fragments, muds and algae.

The recent limestones and organogenous sands constitute really the same facies, being the first no more than a cemented form of the second. They are composed of various fragments and a great percentage of planktonic foraminifera of which can be mentioned: *Globigerinoides rubra, G. sacculifera, G. conglubata, Globorotalia menardii* (forma *typica* and f. *tumida*), *Dentalina, Frondicularia, Robulus*, and the agglutinated forms *Textularia, Gaudryina* and *Reophax* (Mabesoone & Tinoco 1967).

The muds are composed of terrigenous clay and a small sand size fraction, consisting almost entirely of planktonic foraminifera and some pteropod fragments.

At some places, for instance near Recife, where the slope begins at 70 m, the common algal facies of the shelf has been found.

It was, however, impossible to figure these slope facies types on the general map. But on figure 43 the localities and sediment character have been presented.

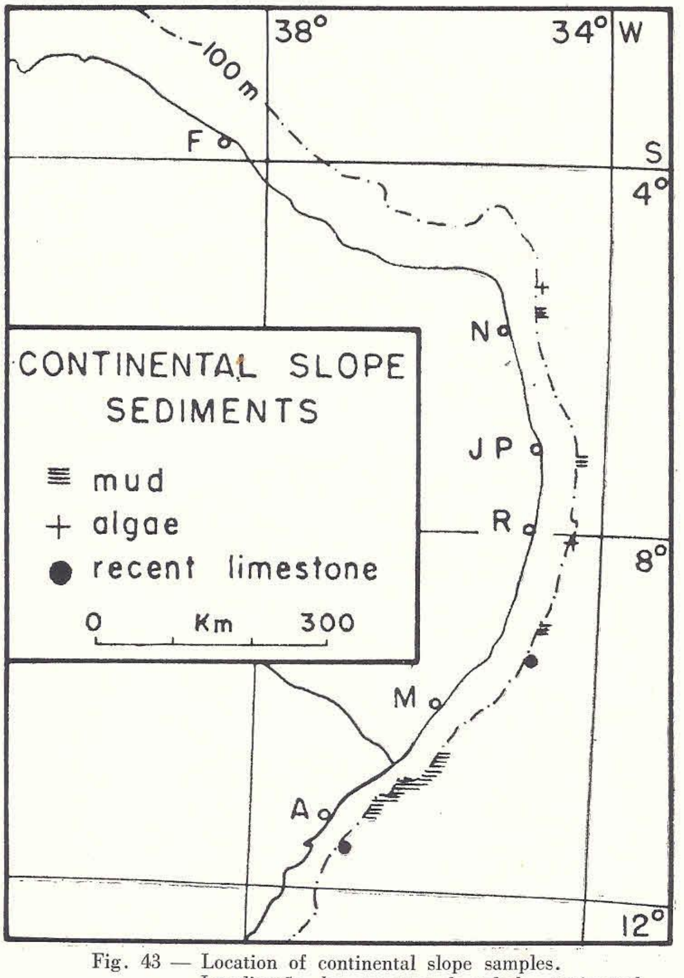

Fig. 43 — Location of continental slope samples.
Localização das amostras do talude continental.

4. OCEANIC ISLANDS AND BANKS OFF THE SHELF

INTRODUCTION

Brazil possesses a number of oceanic islands in the South Atlantic. These are: the archipelago of Fernando de Noronha, the so-called Rocas "atoll" and the St. Peter and Paul's Rocks. The islands of Trindade and the Martin Vaz group are situated far more southward, and because of that are not considered here.

An excellent description of the present knowledge on these islands has been given by Soares (1964). However, the shallow marine geology of their shelves is still not well known. Some information on the Rocas "atoll" has been published by Andrade (1960), Ottmann (1963), Ribas (1966) and Tinoco (1967). The Fernando de Noronha archipelago counts with the monography of Almeida (1958), who mentions also some littoral and near-shore features. Only in 1967 the R.V. "Almirante Saldanha" of the Brazilian Navy on its cruise 35 took some samples on the both islands.

The St. Peter and Paul's Rocks, volcanic rock points emerging from the ocean surface, have been recently visited by two cruises of the Woods Hole Oceanographic Institution, first by the R.V. "Chain" — cruise 35 (at March 18, 1963) and secondly by the R.V. "Atlantis II" — cruise 20 (March 19-22, 1966). Preliminary reports have been published in the review "Oceanus" of this institution (1963, 1966).

There occur also a number of banks off the shelf area of the northern coast more or less between Cape São Roque and Fortaleza. These banks rise steeply from abyssal depths to shallow depths often less than 40 m. Their exact location as well as their size are not well known, and therefore their figuration the nautical charts is only provisionally.

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FERNANDO DE NORONHA

Generalities. — The archipelago of Fernando de Noronha (fig. 44), being a Federal Territory of Brazil, covers an area of 18,4 sq.km. It is situated some 345 km from the northeastern coast of the country. The principal island, that of Fernando de Noronha, constitutes 91% of the total area. The other island of reasonable size, Ilha Rata, has a surface of 80.000 sq. m. The rest of the area consists of 17 very small islands.

The group is, after Almeida (1958), all what remained of a vast volcanic construction, of a long and complicated history, the base of which rests at a depth of 4000 m on the ocean floor (fig. 45). Is is composed of at least 14 different types of

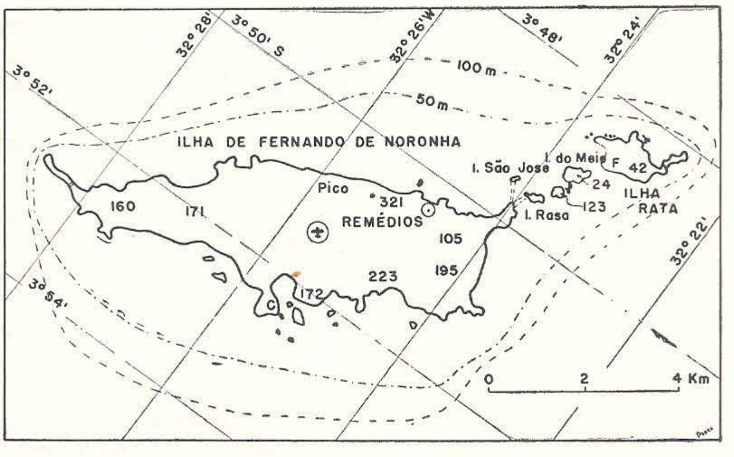

Fig. 44 — Fernando de Noronha.

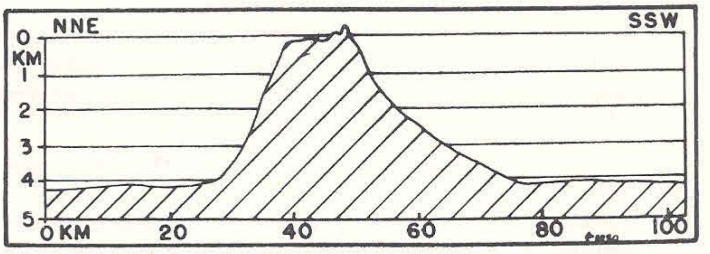

Fig. 45 — Section through the Fernando de Noronha building.
Perfil do edifício de Fernando de Noronha.

ultrabasic and intermediate igneous rock. The age of this volcanism is about 2-12 millions of years (absolute age determination, Geochronological Laboratory of São Paulo University). Although the principal island is of volcanic origin, its relief is not very marked, with the exception of the Pico, the landmark of the archipelago which is a giant rock pile attaining a height of 321 m above sea level. The relief forms are chiefly structural.

The geology of the islands has been defined by Almeida (1958): Fernando de Noronha is a volcanic archipelago constituted of a substratum of pyroclastic rocks, cut by a great variety of alkaline igneous rocks which, after long hiatus, have been covered by flows of alkaline basaltic lavas of two fundamental types. The sediments occurring on the islands are a few deposits of littoral, eolian and marine origin.

These sedimentary rocks cover areas not greater than 7,5% of the archipelago. They have been formed when the volcanic base was already much eroded. Two types of sediments can be distinguished. The first consists of ancient marine deposits, actually in elevated position, and of ancient dunes transformed into eolianites. The second type comprises the recent sediments of the small river valleys and the coastal area. Among these have to be mentioned dunes, conglomeratic and sandy beach deposits, organic reefs and guano.

Ancient sediments. — Besides a few fluvial deposits in the small river valleys, the ancient sediments are all of marine or littoral origin, due to the variation of the sea level. Almeida (1958) distinguishes three types: the Caracas Sandstone, marine limestones and conglomeratic terrace deposits.

The Caracas Sandstone crops out on the pricipal island, at the Caracas Point (C on fig. 44) and at a few other places. Major exposures occur on the Rata island (F, fig. 44) and two smaller islands (Ilha do Meio, Ilha Rasa). They dip towards the southeast, showing a neat cross-bedding of the eolian type. Macroscopically they are light creme coloured rocks, of a fine sandy texture. In thin sections, they show a composition of grains of organogenous material, especially fragments of coralline algae (Corallinaceae) with nice examples of *Amphiroa.* The other fragments are composed of molluskan shells, foraminiferal tests and rests of echinoderms, bryozoans and other marine organisms. Only a few heavy minerals of the island's volcanic rocks have been determined in the sandstones. The deposits are clearly cemented dunes, thus eolianites, as noted already by Branner (1889, 1890).

The marine limestones occur in a very restricted area, E of the village of Remedios. They constitute a very thin cover on the volcanic underground. They are horizontally bedded and contain pebbles of the volcanic rocks. The calcareous grains are of Corallinaceae algae, bryozoan colonies, pelecypod shells, crustacean carapaces and foraminifera. Notable is the absence of any fragment of *Lithothamnion* so common in the deposits of more recent age.

Terrace conglomerates are found at various sites of the chief island. They occur only on top or near the sea cliffs, being therefore of marine origin. This is confirmed by the high degree of roundness of the pebbles. Sometimes a matrix of calcareous sandstone can be detected.

Recent sediments. — The recent deposits of the archipelago consist of beach and dune sands, talus debris, algal reefs, guano, and platform sediments.

At various places on the principal island occur beaches. However, their sands are composed of calcareous organisms, because there is no quartz on the island. The fragments are those common organisms of this area, such as calcareous algae, bryozoans, tubes of worms, crustaceans, echinoderms, mollusks, and foraminifera. The grain size distribution is common of that of other medium-fine beach sands. In some samples heavy minerals occur, but in a fairly modest quantity, chiefly augite, hornblende, olivine, magnetite and iron oxides. The light fraction shows fragments of phonolite, chalcedony and orthoclase. The pebbly beaches, on the contrary, have a dominance of rock fragments occurring on the island. This type of deposits constitutes the major part of the tombolos which attach the islands of São José and do Meio to Fernando de Noronha. The forms of pebbles and cobbles depend on the nature of the rocks, but all show a strong marine shaping. At some places the beach sediments have been cemented by a calcareous cement causing the formation of hard conglomerates; this process is still continuing.

Active dunes occur on the principal island, moving under the action of the trade winds. The dunes are chiefly composed of calcareous grains from the adjacent beaches or from eroded parts of the Caracas Sandstone. The grain size composition of the sediments is very similar to that of the beach sands, only the first being somewhat finer. A short transport causes the dune sediments still to possess the grain character of the adjacent beach.

The talus debris reach only at a few places the sea. where they been deposited at the foot of the cliffs. However, their character is still that of landslides without any marine reshaping.

The reefs which exist on Fernando de Noronha are not composed of corals, but of calcareous algae of the genus *Lithothamnion*. Also calcareous structures of vermes and other organisms contribute to the reef formation. The reefs grow chiefly at the windward SE side of the island, under constant wave action. They form fringing and barrier like occurrences. The seaward side of these reefs show steep slopes which may attain heights of some meters. The structures are cut by fissures and canals trough which sea water is constatly running. The calcareous rock is porous at the surface, but at some depth it is extremely hard due to diagenetical cementation. All observed reefs on the archipelago are recent and living.

The Caracas Sandstone of the southern part of the Rata island has a cover of excrements of sea birds, now occurring as guano with a medium P_2O_5 content of 19,6%.

Origin of the littoral sediments. — The *Lithothamnion* reefs constitute notable elements of the archipelago littoral environment. They exist only in the southern and eastern parts where the trade-winds cause strong movement of waves. They do not appear at the northern lee side, in calm waters and near the rock points. In this way such reefs are excellent climate indicators.

Fernando de Noronha is situated in the middle of the South Equatorial Current which causes transportation of material towards W. The waves resulting from the trades and the currents deslocate detrital material alongside the beaches. This results, for instance, in the occurrence of pebbles of nepheline basanite with xenolithes of olivine at the beaches of the Fernando de Noronha island because such rocks crop out at the São José island and some nearby rock points.

The shallow depth and the nature of the island platform brings the coastal area within the reach of the wave action. At the southern windward side the transported material is coarse. Therefore, at this coast the beach deposits are coarse, even pebbly, with a strong dip. At the northern side the beaches are more sandy with a smaller slope, due to a more longshore current.

The island Fernando de Noronha it attached to the islands of São José and Rosa by real tombolos, partially exposed at low tide. These tombolos are composed of small pebbles and have been built on an igneous basement. The high energy of currents and waves impedes the accumulation of a sandy matrix, so that the tombolos remain nearly always submerged.

The intense and persistent winds are thus the cause of the accumulation of littoral dunes at the southern beaches. Where they have been built near extensive sandy beaches, they may cover a fairly large surface and reach heights of about 10 m. At one place, E of Remedios the dunes are directly derived from erosion products of ancient cemented dunes.

The Caracas Sandstone has been interpreted by comparing its character with recent phenomena. The structures point to a ESE wind of high intensity, sufficient for the accumulation of important dunes. It could have been the proper trade-winds which at that time (Pleistocene) suffered slight modifications. The sandstone material is constituted of lime fragments of marine origin coming from the island shelf, passing through beaches and accumulating into dunes. The sea level was lower, proved by the occurrence of the sandstones actually submerged. Such a lower sea level stand facilitated the access of the winds to the platform detritus. A diagenetical cementation made from the dune sands eolianites.

Island platform. — The shallow marine platform deposits have not been studied by Almeida (1958). But Ottmann (1959) mentions a sample of that area collected at a depth of 58 m (n.º 352). It is composed of chiefly algal fragments belonging to the genera *Lithothamnion* and *Halimeda*. Furthermore, there occur the other common marine organisms of the region. A list of foraminifera determined has been given by Tinoco (1959), who emphazises the abundance and size (2 mm) of *Amphistegina lessonii* var. *conica*.

The R.V. "Almirante Saldanha" — cruise 35, effectuated some dredgings on the island platform in October 1967. The composition of the samples has been mentioned in table XI (after Kempf, Coutinho & Morais 1968, 1969). One sees that algae dominate in all samples except one. Furthermore, foraminifera occur frequently, whereas sometimes planktonic forms are present (samples 1667B, 1667C). Based on these samples one may conclude that the platform around Fernando de Noronha has a cover of sediments belonging to the algal facies described in Chapter 3. At some places the facies may become organogenous with dominance of other organism, generally found at a greater distance from the coast.

Table XI — Data on samples collected on the plataform of the oceanic island and banks off the shelf by the R.V. "Almirante Saldanha"
Dados sôbre as amostras coletadas na plataforma das ilhas oceânicas e dos bancos pelo N.Oc. 'Almirante Saldanha".

Rocas:			Depth	
1662A	3°53,8' S	33°46,6' W	25 m	algal crust
1662B	3°50,3'	33°45,6'	47	algal sand with pebbles
1663A	3°49,6'	33°49,2'	53	algal sand with pebbles
1663B	3°52,2'	33°50,8'	95	fine, withe algal sand
1663C	3°51,8'	33°46,4'	60	*Halimeda* sand
Fernando de Noronha:				
1667A	3°50,7'	32°28,1'	65	foraminiferal sand
1667B	3°50,8'	32°27,5'	55	algal sand
1667C	3°50,0'	32°24,3'	26	algal sand
1668A	3°53,0'	32°37,2'	90	coarse algal sand
banks off the northern shelf				
1682	3°45,0'	35°06.5'	61	coarse *Halimeda* sand
1682A	idem		61	*Halimeda* sand
1684	3°59,5'	35°53,7'	75	algal crust
1684A	idem		140	coarse algal sand
1684B	idem		73	caorse algal sand
1701	1°47,0'	37°57,0'	57	coarse *Halimeda* sand
1701A	idem		57	algal gravel
1701B	idem		87	coarse foraminiferal sand
1705	2°12,0'	38°19,0'	80	algal gravel

Because of the lack of quartz, a terrigenous facies near the coast must not exist. At other places possible hard grounds of igneous rocks can be found; terrace-like flats of tuffs are exposed at spring low tide.

The topography of the shelf is not well known. Almeida (1958) mentions some 200 soundings irregularly distributed with vague indications of the bottom character, effectuated by the Brazilian Navy in 1938. So, many of the marine processes which occurred and occur still in this area, cannot be properly explained. Figure 46 shows a section through the island and its platform. The latter appears to be much more extensive than the island surface.

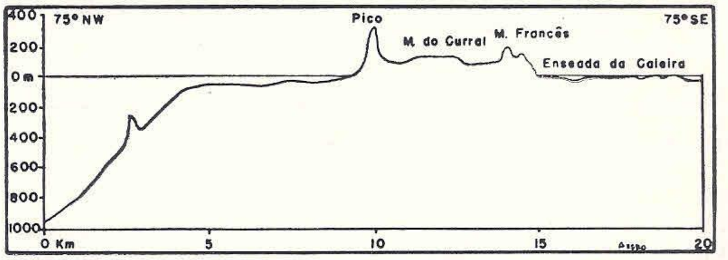

Fig. 46 — Island of Fernando de Noronha and its platform.
Ilha e plataforma de Fernando de Noronha.

At many cliffs the bottom is apparently steep, impeding the existence of a surf zone and causing big oscillation waves to attack the rocks with high energy. In this way various tunnels are formed; the Rata island shows one of 20 m length within the reef zone.

Morphology. — The many terrace-like features of the islands are chiefly due to lava flows and not to marine shaping. However, on oceanic islands the waves may exercise their influence to rather high levels.

There are indications of three higher and one lower sea level. The first higher stand must have been some 40 m above the recent one, developing the central plain under semi-arid climatic conditions.

Another level is supposed at about 12 m above the actual one. It is proved by the ancient limestones with *Amphiroa*, E of the village of Remedios. Also at other places some small remainders of beach deposits are met with.

Later, a level of about 1 m caused the accumulation of coarse gravels and beach sands with fragments of *Lithophyllum*, foraminifera, gastropods, etc.

The Caracas Sandstone which covers at some places these ancient deposits, developed at a sea level of about 6 m lower than at present. This is the youngest one of the successive series.

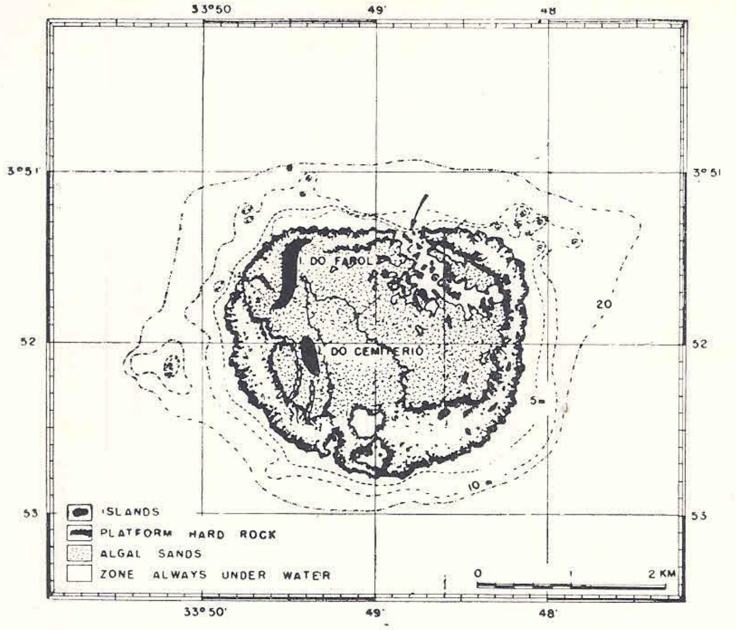

Fig. 47 — Rocas.

It is quite impossible to correlate these various oscillations with the Pleistocene glacial periods. They are certainly due to eustatic movements, but the archipelago is in isostatic disequilibrium which does not permit the supposition of stability with reference to the eustatic levels.

ROCAS

Generalities. — The so-called Rocas "atoll" is situated at 3°52'S, 33°49'W, off the coast of the State of Rio Grande do Norte (fig. 47). Its surface is about 7,2 sq.km. and its height attains not even 3 m. The small island, however, constitutes a peculiar feature in the Atlantic Ocean, being its only "atoll", at least after its shape. Its form is ring-like, with a medium diameter of 1600 m, and with an inner lagoon. Rocas differs from the atolls of the Pacific Ocean because of its constitution, being built by calcareous algae and not corals. The island has been studied by various authors from different points of view, such as geomorphology (Andrade 1960), sediments (Ottmann 1963), foraminifera (Ribas 1966, Tinoco 1967), and in a general descriptive way (Soares 1964).

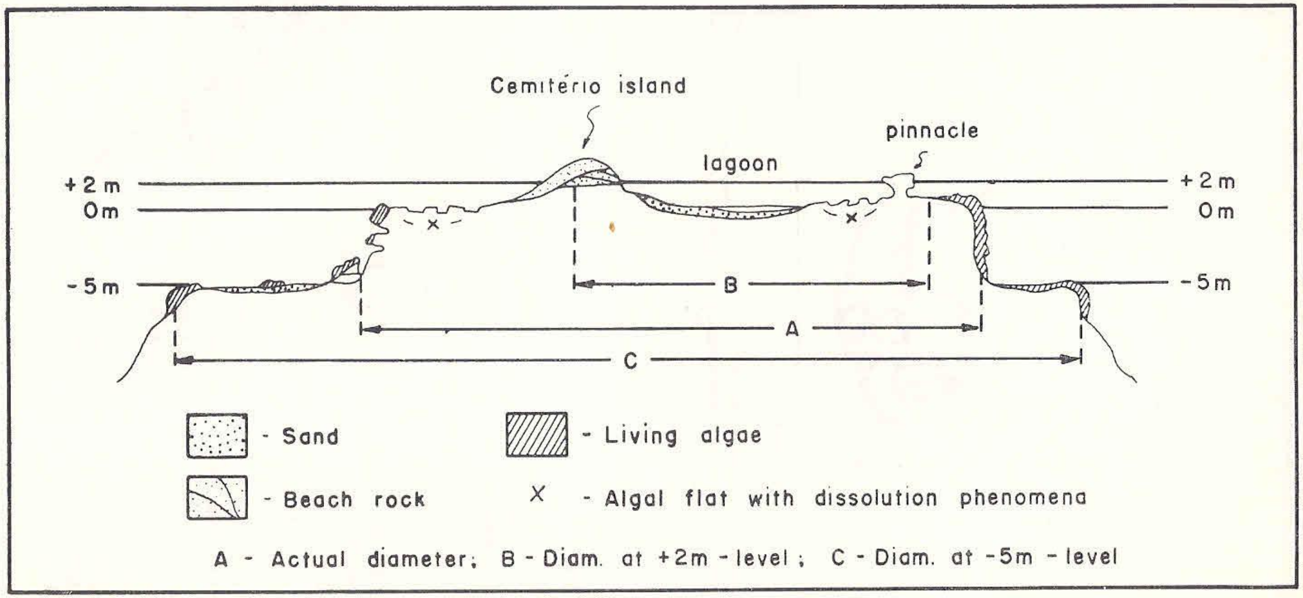

Fig. 48 — Cross-section through Rocas-"atoll" Ottmann 1963).
Perfil através do ""atol" das Rocas.

The base on which the island has been built, forms part of a branch of volcanic rocks which comes from the Mid-Atlantic Ridge and on which also the Fernando de Noronha archipelago is situated. This branch is almost entirely submarine and the islands are mere accidents of it. The Rocas mount rises steeply with escarpments of about 700 m.

Sediments. — The sediments of the Rocas-atoll have been studied by Ottmann (1963). The two islands, — Ilha do Farol and Ilha do Cemetério —, are constituted of lime sands with more or less rounded grains. The beach sands are composed of fragments of calcareous algae, with only a few other organisms. The sediments are rather coarse with 60% of particles greater than 2 mm and only 10-15% of silt and clay size material.

The Ilha do Cemetério shows also a bank of beach rock with a median diameter of 300 microns and with well-rounded grains. Its layers show cross-stratification.

In the lagoon occur organogenous sands of very different sizes. In the area of the strongest tidal influence, they are coarse, in the centre of the lagoon they are much finer. All deposits are entirely calcareous. A cross-section is shown in figure 48.

Cruise 35 of the R.V. — "Almirante Saldanha" took a few samples from the island platform. The results are also mentioned in table XI. Here the algal facies is again dominant, farther from the island the organogenous facies occurs.

Microfauna. — The organisms of the beach sands are, besides the algae, coral and bryozoan fragments, plates and spines of echinoids and foraminifera. In the lagoon, coral fragments and molluskan shells are more abundant.

The algal species are chiefly of the genera *Halimeda, Jania* and *Amphiroa*.

The foraminifera have been determined by Ribas (1966) and by Tinoco (1967) The most important species are *Textularia agglutinans, Archaias angulatus, Heterostegina suborbicularis, Amphistegina radiata* and *Homotrema rubra*. The samples of Tinoco were taken in 1961 and those of Ribas in 1964. The authors determined besides these five species, a great number of others which are different from place to place. The association, however, is the common one of northeastern Brazil (Boltovskoy 1965).

Variations of the sea level. — After Andrade (1960) one can draw some interesting conclusions on the more recent sea level changes from the algal reefs.

The residual forms are chiefly pinnacles at the eastern side of the reef. They rise some 3-4 above the flat and are evidently remainders of an ancient algal wall. All blocs are composed of dead algae. They point to a sea level of about 2,5 m higher than the actual.. Also the beach rock may point to such a level. In its present position it cannot be cemented by infiltrating sea water, but only by a higher level.

The submarine morphology shows that at the eastern side attacked by the sea, the living algae form an abrupt nip of 5-6 m, a type of terrace. At the lee side in the W the beach is separated, at low tide, from the sea by an extensive flat of dead algae. Here no nip occurs. Below the sea level begins the flat sand of the terrace, reaching up to the big slope. This terrace could have been formed during the latest Quaternary regression phase, the "antecedent platform" of Andrade (1960).

Conclusions. — The origin and evolution of the Rocas-"atoll" has been resumed in a number of conclusions by Ottmann (1963).

The "atoll" is not a coralline atoll of the Pacific Ocean type, but an algal reef. Therefore it should not be termed as "atoll", but as a circular algal-reef built on an abrasion platform.

Its form is apparently due to the rapid growth of the algae at the windward side, whereas the detritus constitutes the rest of the ring.

The Rocas-"atoll" proves the existence of a sea level some 2,5 m higher than the actual, in the tropical South Atlantic, which is supposed to have existed some 2-3000 years ago.

ST. PETER AND PAUL'S ROCKS

The small rocks come to surface at 0°56'N 29°22'W. They are composed of ultrabasic igneous rocks rich in olivine and constitute a miniature archipelago of some five bigger and ten smaller rock points (fig. 49, after Soares 1964). The major island has a size of 100 x 50 m and rises some 20 m above sea level. They are the ruins of a volcanic cone of the Mid--Atlantic Ridge. A geographical and bathymetrical report has also been written by Tressler, Bershad & Berninghausen (1956)

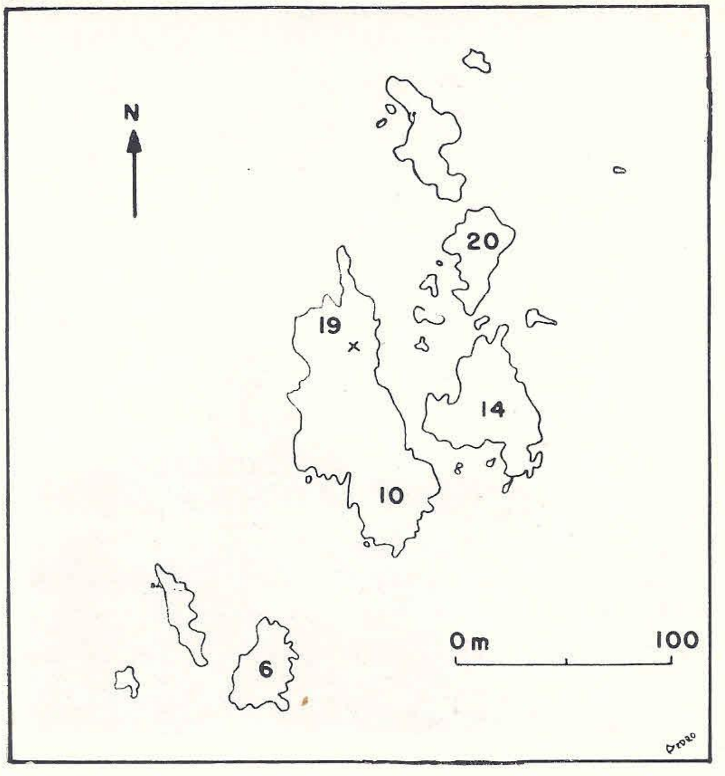

Fig. 49 — St. Peter and Paul Rocks (numbers are heights in meters).
Penedos de S. Pedro e S. Paulo (números são altitudes em metros).

There are no beaches, and the various blocks rise steeply from greater depths.

Because of the inacessibility (fig. 50) only a few studies of its shallow marine zone have been made; it is known that at a distance of 200 m of this group the depths are only some 180 m.

The only inhabitants are sea-birds which caused all rocks to have a thin cover of guano. This product interacts with the weathering material of the igneous rocks.

Recently, after the two expeditions of the R.V. "Chain" in 1963 and the R.V. "Atlantis II" in 1966 (fig. 51), some preliminary results have been published and more definitive papers are already coming out.

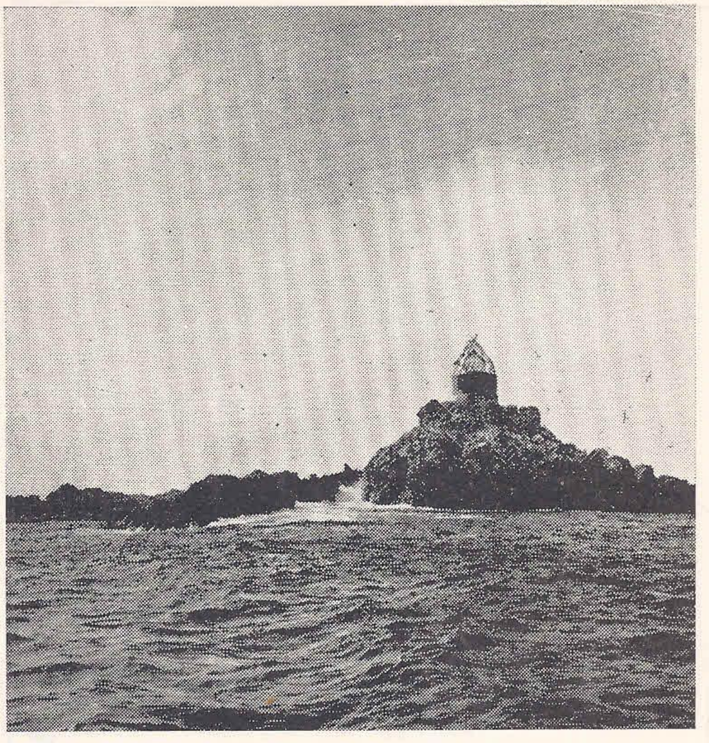

Fig. 50 — St. Peter and Paul Rocks; more landing party at left in rubber boat (photo Mr. Jan Hahn, with kind permission).
Penedos de S. Pedro e S. Paulo; observe a equipe de desembarque à esquerda numa lancha de borracha.

Bathymetrical investigations showed the rocks to come to surface close to the point where the axis of the Mid--Atlantic Ridge changes its NW-SE direction between about 10°N and the Equator to E-W through an angle of 120°. The rocks must thus be closely related with the transverse faulting of the Ridge. Below the sea surface the bottom is irregular and steep to N and S of the axis. To W and E shallower zones have a greater extension (Thompson 1966).

The Rocks are composed of ultrabasic rocks, rich in magnesium, low in silica and alkalies. The most abundant mineral is olivine more than 50% forsteritic. The Rocks are similar in composition and mineralogy, chiefly spinel peridotite, to the dense rocks of the upper Earth's mantle. These have been

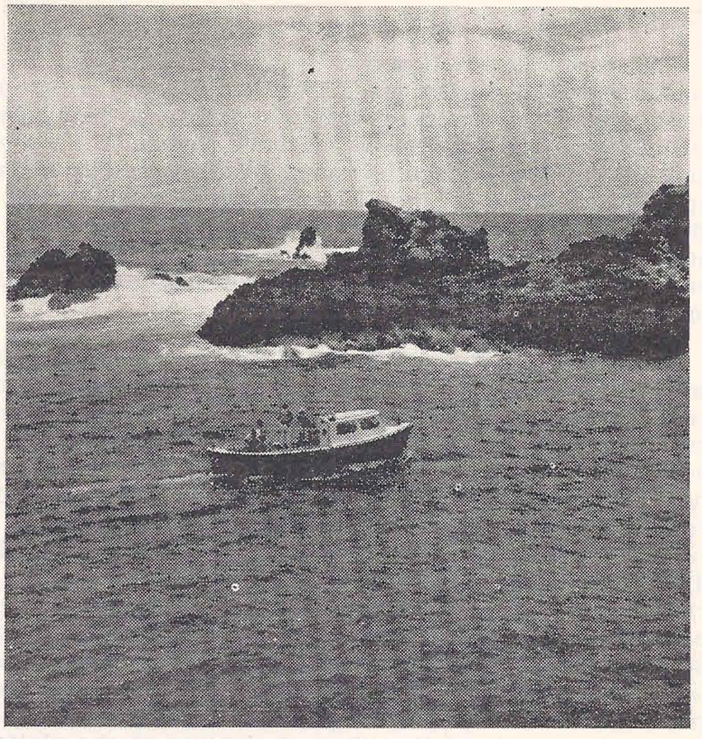

Fig. 51 — St. Peter and Paul Rocks; landing party of R.V. "Atlantis II" (photo Mr. Jan Hahn, with kind permission).
Penedos de S. Pedro e S. Paulo; equipe de desembarque do N.Oc. "Atlantis II" do Woods Hole Oceanographic Institution.

upthrusted. The original plutonic rocks which composed the islands have been thoroughly mylonitized, supposed to have occurred during the initial movements which did lift them up above sea level. Age determinations by Sr-87/86 showed the mylonization and metamorphism to have taken place not more than 500 million and not less than 50 million years ago. Recent studies discovered another rock type, similar to the rare nepheline teschenites, constituting 30% of the surface of the SE islet; they have also been metamorphozed and mylonitized (Melson 1966). St. Paul's Rocks are often postulated to be an exposure of the sub-oceanic mantle; they consist, however, of a wider variety of rocks then previously recognized. It is supposed that these crystallized at different mantle levels, and were later incorporated and mylonitized in a hot but solid intrusion (Melson & others 1967).

The constant wave action causes a salt spray on the exposed rocks. The salts precipitated by evaporation are only partly washed away by subsequent rain, so that chiefly calcium carbonate, in part as aragonite, remains. These carbonates have filled up the numerous diaclases and are actually exposed as small walls on the eroded parts of the softer peridotites. The carbonates also cemented loose fragments and shells into breccias and conglomerates. As a secondary mineral occurs apatite as the most abundant phosphate, remained from the weathered guano (Melson 1966).

The rough bottom of the St. Paul's area made dredging for underwater samples difficult. But it appeared that at most places only hard ground occurs and that no recent sediments are present (Dr. V. T. Bowen, written communication). But corals have been collected, showing a great number of species and also of individuals; they represent a typical oceanic island assemblage as demonstrated by preliminary studies. The sponges indicate many affinities with those found at the Brazillian continental coast, which cannot be said for the echinoderms, crustaceans and shell fish. Ancient sediments showed these fishes to be more abundant in the past. Some submarine beach conglomerates dredged in 1963 from several hundred meters from the slope, showed surface deposits of Pleistocene foraminifera. These deposits have not been covered, indicating a relative physical stability of the platform. Another problem is that bird and fish populations appear to have much changed since the 19th century visits by the "Beagle" (Ch. Darwin) and "Challenger" (Bowen 1966).

The age of the sediments exposed in the Mid-Atlantic Ridge, determined by fossils, is helpful in reconstituting the successive phases of uplift and volcanic activity. However, the high relief and the seismic activity cause often a mixing of the fauna, affecting, the foraminifera in particular.

The St. Paul's Rocks showed a great variety of hardened sediments, of which an interesting type is the phosphatized ultramafic conglomerate from the slope. This rock must have a Pleistocene age. The planktonic foraminifera appear to be homogeneous and contain abundant *Globorotalia truncatulinoides*, a Quartenary index species. Only the dredged conglomerates show these foraminifera in their matrix; an identical conglomerate now exposed above sea level does not contain foraminifera, only shell fragments (Cifelli 1966).

At more abyssal depths two important features were encountered. First, the occurrence of an alkali olivine basalt, dredged from a depth between 2000 and 3000 m (Melson & others 1967). Secondly, the finding of lithified carbonates, composed of consolidated oozes, coarsely crystalline limestones and even dolomitic limestones, also from abyssal depths; these have been dated by their fossils as Miocene to Pleistocene (Thompson & others 1968).

BANKS OFF THE NORTHERN SHELF

The banks which are situated off the shelf between Cape São Roque and Fortaleza have been partially sampled by the vessels "Canopus" and "Almirante Saldanha". Their bottom shows without exception the algal facies as described in Chapter 3. The sediment is generally composed of fragments from sand to boulder size of calcareous algae, chiefly *Lithothamnion*. In the smaller sizes foraminifera and bryozoans can be found. At greater depths, belows 70 m, the algae content decreases so that the facies is of a more mixed type, similar to the biodetrital facies described before. The whole sediment seems to be of recent age. The studied banks are mentioned on the general map.

It is still unknown which rock type constitutes the basement of these banks. But it is supposed that they might be the same as those of the Rocas-"atoll' and Fernando de Noronha.

5. FAUNA IN SEDIMENT

INTRODUCTION

In this chapter we will mention in lists the fauna determined in the bottom deposits. Only a few groups have been studied: foraminifera (Boltovskoy & Lena 1966; Closs & Barbarena 1960; Narchi 1956, 1963a, b; Ribas 1966; Tinoco 1958, 1959, 1967), bryozoans (Barbosa 1964), echinoderms (Brito 1962), mollusks (Campos e Silva 1966; Mendonça 1966; Kempf & Matthews 1968), and corals (Laborel 1967a, b). Generally, the mentioned forms are dead, but also living exemplars were found; no publication mentions which exemplars were living. Where possible, we will also give a summary of the principal conclusions drawn from these lists by the various authors. Especially about the foraminifera (Tinoco 1968) and the corals (Laborel 1967a, b) interesting observations could be made. Recently, Kempf (1970c) published some observations on the benthic bionomy of the shelf area, considering the relation between fauna and bottom sediment.

FORAMINIFERA

List of foraminifera determined in the investigated area:

1 — Praia da Barra, Salvador, Bahia: Closs & Barbarena
2 — Rocas: Ribas
3 — Rocas: Tinoco
4 — Fernando de Noronha, sample 352: Tinoco
5 — Amazon mouth: Tinoco
6 — Various publications: Narchi
7 — Pernambuco: Boltovskoy & Lena
8 — Quaternary, Olinda, Pernambuco: Tinoco.

Benthonic foraminifera	1	2	3	4	5	6	7	8
Astrorhizidae								
Crithionina pisum hispida							x	
Saccamminidae								
Psammosphaerinae								
Psammosphera bowmanni							x	
P. fallax							x	
P. fusca							x	
Saccammininae								
Saccammina atlantica					x		x	
Pelosininae								
Technitella atlantica							x	
T. hystrix							x	
T. legumen						x		
Hyperamminidae								
Hyperammininae								
Hyperammina calcilega							x	
Jaculella acuta						x		
Reophacidae								
Reophacinae								
Reophax arayensis							x	
R. curtus					x			
R. scorpius				x	x			
Lituolidae								
Haplophragminiinae								
Haplophragmoides conglobatus						x		
Ammoscalaria calcarea						x		
Textulariidae								
Spiroplectamminae								
Spiroplectotammina floridana					x			
Textulariinae								
Textularia agglutinans		x	x	x			x	x
T. candeiana forma typica		x					x	
T. candeiana forma fungiformis							x	
T. conica					x		x	
T. corrugata						x		
T. gramen		x				x	x	x
T. kerimbaensis							x	
T. lateralis					x			
T. luculenta						x		
Bigerina irregularis					x	x		
B. nodosaria							x	
B. textularioides						x	x	
Verneuilinidae								
Gaudryina pseudoturris						x		
Valvulinidae								

	1	2	3	4	5	6	7	8
Valvulininae								
Valvulina oviedoiana				x			x	
Clavulina angularis		x		x				
C. parisiensis						x		
C. tricarinata						x	x	x
Eggerellinae								
Liebusella soldanii						x		
Miliolidae								
Quinqueloculina alabamensis							x	
Q. angulata forma typica							x	
Q. angulata forma derbyi							x	x
Q. angulata forma undosa		x					x	
Q. atlantica							x	
Q. bradyana					x			
Q. candeiana		x						x
Q. crassa forma subcuneata								x
Q. cultrata					x			
Q. exsculpata							x	
Q. groenlandia					x			
Q. horrida					x	x		
Q. implexa								x
Q. kerimbatica							x	
Q. lamarckiana					x	x	x	x
Q. linneiana							x	
Q. microcostata							x	
Q. moynensis							x	
Q. parkeri		x					x	x
Q. philippinensis							x	
Q. planciana							x	
Q. poeyana							x	
Q. polygona forma typica					x		x	x
Q. polygona forma subpolygona							x	
Q. punctulata		x						
Q. pricei				x				x
Q. sabulosa							x	
Q. seminulum forma typica			x			x	x	x
Q. seminulum forma anguste-oralis							x	
Q. sulcata							x	
Q. tricarinata						x	x	
Q. tribulata							x	
Q. vulgaris					x			
Milionella oblonga						x		
M. suborbicularis					x		x	
M. subrotunda forma typica							x	
M. sobrotunda forma labiosa					x		x	

	1	2	3	4	5	6	7	8
Dentostomina enoplostoma forma typica							x	
D. enoplostoma forma aguayoi							x	
D. enoplostoma forma bermudiana							x	
Massilina crenata							x	
M. pernambucensis							x	x
Spiroloculina antillarum	x	x				x	x	x
S. caduca						x	x	
S. dorsata							x	
S. esperula					x			
S. mosesi							x	x
S. planulata					x			
S. profunda	x						x	x
S. tenuis								x
Sigmoilina asperuta						x		
S. sulpoeyana								x
Articulina antillarum							x	
A. atlantica							x	
A. multilocularis	x					x	x	x
A. pacifica						x		
A. paucicostata							x	
A. sagra							x	
Tubinella funalis					x		x	x
T. inornata								x
Hauerina bradyi								x
H. ornatissima							x	
H. pacifica							x	
Schlumbergerina alveoliniformis							x	
Triloculina baldai							x	
T. bertheliana	x						x	
T. cultrata							x	
T. cylindrica							x	
T. gracilis var. brasiliensis							x	x
T. laevigata							x	
T. linneiana	x						x	x
T. oblonga					x	x	x	x
T. planciana			x				x	x
T. reticulata forma typica							x	
T. reticulata forma antillarum							x	
T. reticulata forma bicarinata	x		x				x	
T. reticulata forma carinata				x			x	
T. reticulata forma sagra							x	
T. rotunda							x	
T. sommeri	x	x						x
T. terquemiana							x	
T. tortuosa							x	

	1	2	3	4	5	6	7	8
T. transversestriata							x	
T. tricarinata		x					x	x
T. trigonula					x		x	
Triloculinella lutea		x					x	x
Flintina crassatina					x			
Pyrgo cromata		x			x			
P. depressa forma carinata		x			x		x	
P. depressa forma dehiscens							x	
P. denticulata forma caudata		x						
P. elongata			x					
P. murrhina					x			
P. patagonica			x					
P. ringens							x	
P. subsphaerica		x	x		x	x		x
P. tainanensis							x	
Ophthalmidiidae								
Cornospirinae								
Cornuspira involvens					x		x	x
C. planorbis					x		x	
Cornuspiramia antillarum							x	
Nodophthalmidiinae								
Nodobaculariella cassis					x		x	
Ophthalmidiinae								
Wiesnerella auriculata							x	
Nubeculariinae								
Rhizonubecula adherens							x	
Fischerinidae								
Fischerina helix					x		x	
Trochamminidae								
Trochammininae								
Trochammina advena							x	
T. heloglandica							x	
T. inflata							x	
T. ochracea forma typica							x	
T. ochracea forma membranosa							x	
T. stellata							x	
Carterina spiculotesta							x	
Placopsilinidae								
Placopsilininae								
Placopsila cenomana							x	
P. confusa						x		
Nodosariidae								
Robulus limbosus chiriguanoi							x	
R. rotulatus					x			x
R. rotulatus forma typica		x						

	1	2	3	4	5	6	7	8
Marginulina planulata					x			
M. semiluta					x			
Dentalina filiformis					x			
D. communis							x	
Lagenidae								
Lagena laevis forma perlucida							x	
L. striata								x
L. stridatopunctata							x	
Fissurina lacunata							x	
F. laevigata								x
F. lagenoides							x	
F. marginata								x
F. orbignyana							x	
F. perfurata							x	
F. pulchella							x	
F. quadricostulata							x	
F. semimarginata		x						
F. stewartii								x
F. subglubosa							x	
F. tricostulata							x	
Parafissurina lateralis							x	
Oolina caudigera							x	
O. inornata							x	
O. variata							x	
Polymorphinidae								
Polymorphininae								
Guttulina lactea							x	
G. trilocularis							x	
Globulina caribea							x	
Glandulina rotundata forma typica							x	
G. rotundata forma elliptica							x	
G. vitrea							x	
Sigmomorphina williamsoni							x	
Nonionidae								
Nonion affinis							x	x
N. grateloupi		x			x		x	x
N. scaphum						x		
Nonionella atlantica					x			
N. auricula							x	
Pseudononion japonicum							x	
Elphidium advenum						x	x	
E. alvarezianum							x	x
E. discoidale			x		x		x	x
E. galvestonense					x		x	x
E. incertum								x

	1	2	3	4	5	6	7	8
E. poeyanum							x	
E. sagrum	x					x	x	x
E. selseyense							x	
Camerinidae								
Camerininae								
Heterostegina depressa	x	x	x	x	x		x	x
Peneroplidae								
Spirolininae								
Peneroplis bradyi			x				x	x
P. carinatus	x		x			x		x
P. discoideus	x						x	
P. pertusus forma typica						x	x	x
P. pertusus forma arietina	x						x	
P. proteus forma typica	x		x	x		x	x	x
P. proteus forma laevigata							x	
Archaiasinae								
Archaias angulatus	x	x	x			x	x	x
Orbitolitinae								
Marginopora vertebralis	x		x			x	x	
Alveolinellidae								
Borelis pulchra	x		x	x		x	x	
Buliminінae								
Turrriluninae								
Buliminella milletti							x	
B. parallela							x	x
Bulimininae								
Bulimina marginata					x			
Virgulininae								
Virgulina compressa					x			
V. pontoni							x	
Bolivina compacta							x	x
B. dottiana							x	
B. fragilis					x			
B. limonensis							x	
B. pulchella forma typica							x	
B. pulchella forma primitiva							x	x
B. rhomboidalis							x	
B. striulata							x	
B. tortuosa							x	x
Loxostomum limbatum	x						x	x
Bifarina advena							x	
Rectobolivina euzebioi								x
Reussellinae								
Reussella atlantica					x			
R. spinulosa	x						x	x

	1	2	3	4	5	6	7	8
Chrysalidinella dimorpha			x				x	
Uvigerininae								
Uvigerina auberiana					x			
U. auberiana var. laevis								x
Siphogenerina duartei								x
S. raphana							x	x
S. roxoi								x
Angulogerina jamaicensis							x	
Rotaliidae								
Spirillininae								
Spirillina densepunctata							x	
S. denticulo-granulata							x	
S. limbata var. denticulata								x
S. ornata							x	
S. revertens							x	
S. vivpara							x	x
Turrispirillininae								
Planispirilina denticulata			x					
Discorbinae								
Patellina corrugata							x	x
Discorbis concina								x
D. granulosus							x	
D. incrustatus							x	
D. mira	x		x				x	x
D. parisiensis								x
D. parkerae							x	x
D. peruvianus					x		x	x
D. pustulata								x
D. stachi							x	
D. terquemi							x	x
D. torrei							x	
Glabratella globosa							x	x
G. pileolus							x	
G. pulvinata							x	
Gyroidina neosoldanii							x	
Rotaliinae								
Eponudes antillarum				x	x		x	
E. repandus								x
Rotalia beccarii							x	x
R. becarii parkinsoniana							x	
R. cubensis							x	
Ammonia catesbyanus var. tepida								x
A. venusta								x
Siphonininae								
Poroeponides lateralis	x			x	x		x	

	1	2	3	4	5	6	7	8
Siphonina reticulata	x				x		x	x
Siphoninoides echinatus							x	
Siphoninella soluta							x	
Bagginінae								
Cancris sagra					x		x	
Baggina indica							x	
Amphisteginidae								
Amphistegina lessonii forma typica	x	x	x		x		x	x
A. lessonii forma conica		x	x				x	
Cymbaloporidae								
Tretomphalus bulloides							x	x
T. clarus							x	
Cassidulinidae								
Cassidulininae								
Cushmanella brownii							x	
Cassidulina subglobosa					x			x
Chilostomellidae								
Allomorphininae								x
Allomorphina lamegoi								x
Sphaeroidininae								
Sphaeroidina bulloides					x	x		x
Planktonic foraminifera (1)								
Globigerinidae								
Globigerininae								
Globigerina bulloides					x	x		x
G. eggeri				x	x	x		
G. inflata					x	x		
G. rubescens							x	
G. trilobus					x			
Globigerinoides conglobatus					x		x	
G. ruber					x	x	x	
G. sacculiferus			x		x	x		
G. trilobus		x			x	x	x	x
Globigerinella equilateralis					x			
Orbulininae								
Orbulina universa				x	x	x		
Pulleniatininae								
Pulleniata obliquiloculata				x	x			
Globorotaliidae								
Globorotalia menardii					x	x		
G. scitulata								x

(1) In the samples of the coast and the shelf, planktonic foraminifera occur only in small quantities, but they are always present.

	1	2	3	4	5	6	7	8
G. tumida					x	x		
Anomalinidae								
Anomalininae								
Anomalinoides anomalinoides							x	
Planulina mera							x	
Cibicidinae								
Cibicides aknerianus							x	x
C. candei							x	
C. concentricus					x			
C. floridanus					x			
C. miocenicus							x	
C. pseudoungerianus							x	x
C. refulgens								x
C. variabilis							x	x
Dyocibicides perforata							x	
Planorbulinidae								
Planorbulina acervalis		x					x	
P. larvata							x	
P. mediterranensis							x	x
Acervulina inhaerens				x				x
Gypsina globulus forma typica							x	
G. globulus forma discus							x	
G. globulus forma vesicularis		x		x			x	
Homotremidae								
Homotrema rubra				x			x	

Foraminiferal distribution in the littoral zone

Boltovskoy & Lena (1966) made a complete studdy of the foraminifera collected in the beach environment near Recife between the Pilar beach (Itamaracá island — 7 on fig. 23) and Suape (S of Cape Sto. Agostinho, 35). The distinguished species have been mentioned in the list.

The authors came to the following conclusions:

(1) The fauna is typical for the littoral zone for low latitude, proved by the great number of *Elphidium*, presence of *Rotalia becarii* and great *Quinqueloculina*. The great diversion of many species is a consequence of the variable ecological conditions of the zone.

(2) The presence of *Archaias, Amphistegina, Borelis, Homotrema, Heterostegina, Spiroloculina,* as well as *Elphidium sagum, E. poeyanum, Siphogenerina raphanus, Marginopora vertebralis* and others, give the fauna a very tropical aspect.

(3) The specific assemblage proves that the area belongs to the West-Indian zoogeographical province .

(4) Frequent occurrence of planktonic foraminifera (*Globigerinoides ruber, G. trilobus, G. conglobatus, Globigerina rubescens*) may be due to the narrowness of the shelf and the fact that the South Equatorial Current bifurcates in this area.

(5) The fauna is recent, although some species up to now considered as fossil, have been met with. Compared with the Quaternary fauna of Olinda (Tinoco 1958), one may conclude that both faunas are identical.

Foraminiferal distribution on the shelf

Generalities. — The paper of Tinoco (1968) is based on the study of 586 samples collected by the various research vessels between the parallels 3°N and 11°50'S, as well as from the oceanic island platforms and the banks off the northern shelf area. Where detailed sediment studies exist (off Recife and Alagoas-Sergipe), the faunal study could also be carried out in more detail.

In the biodetrital fraction of the sediment samples were considered besides the foraminifera, also ostracodes, bryozoans, mollusks of small size, and algal fragments. The study of these groups has not been finished yet. Also the foraminiferal study could not be completed due to the abundance of material. In the first phase (Tinoco 1968), the microfossils were classified after their families, with species identification only those which were abundant in the samples.

Relation between bottom character and foraminiferal fauna. — Based on the facies distribution mentioned in Chapter 3 and on the annexed map, the most important foraminifera determined were:

(1) sandy littoral facies — with a poor fauna, with worn and yellow skeletons of *Archaias angulatus, Triloculina* sp., *Quinqueloculina* spp. and *Amphistegina radiata;*

(2) mud facies — in the Amazon river influence area almost sterile sediments with a few exemplars of *Triloculina;* at the São Francisco river mouth, *Ammonia beccarii, Elphidium* and *Bolivina;* in the mud subfacies of the Recife coast, small, thin and transparent tests of *Ammonia beccarii* vars. *Discorbis* aff. *parisiensis, Elphidium discoidale* and *Elphidium* sp.;

(3) biodetrital facies — in which dominate *Amphistegina, Arcaias,* miliolids rotalids and textularids, with a great number of species;

(4) algal facies — rich in *Archaias angulatus, Amphistegina radiata* forma *typica* and *tumida,* miliolids and textularids, whereas rotalids are rare but always present with *Poroeponides lateralis* and *Discorbis mira*.

Samples from greater depths of the continental slope showed a great number of planktonic foraminifera besides numerous benthonic species. Big exemplars of *Textulariella, Liebusella, Reophax, Dentalina, Frondicularia* and *Robulus* were determined. In the São Francisco canyon, at a depth of 300 m, were found a great number of *Bulimina marginata* vars. and *Eponides* cf. *regularis*.

Analysis of microfauna. — The biogeographical province of the West-Indies or Caribbean extends from the Gulf of Mexico to about the parallel of 33°S and, after Boltovskoy (1965, p. 102) already at 23°S to 32-33°S a certain faunal change occurs, sufficient for distinguishing a South-Brazilian subprovince.

The microfauna of foraminifera N of 23°S is composed, up to the present, of 406 forms whereas S of this parallel 392 forms are found, of which 217 are present in both. This permits the two regions to be grouped into one province, whereas species common and typical in only one region enables the division into two subprovinces.

The most abundant species found N of 23°S are *Amphistegina radiata, Archaias angulatus,* various species of *Peneroplis* and miliolids which are absent south of this parallel.

The existing vast bibliography about the foraminifera occurring N of 4° N shows a general similarity between its fauna and that of northern and northeastern Brazil, although some species, among which the well developed *Amphistegina radiata* forma *tumida,* one of the most important in the latter area, is completely absent north of that parallel.

The association *Amphistegina radiata* forma *typica, Archaias angulatus* and *Peneroplis* spp. become only common in the Caribbean since the Miocene. In the layers of that age at the Marajó island and in the Pirabas Formation (Miocene, N. Brazil), *Amphistegina radiata* forma *tumida* is very characteristic and abundant. This fact, as well as the absence of this form N of 4° N, suggest a distinction as subprovince for northern and northeastern Brazil. A further confirmation has still to be made.

Foraminiferal distribution on oceanic banks and islands

Tinoco (1970), continuing his studies on the microfauna of foraminifera in the investigated area, considered also the assemblages on the banks off the shelf and the oceanic islands Rocas and Fernando de Noronha. In the samples collected at these places, 50 species of benthonic foraminifera were determined and 7 planktonic ones. For the purpose of ecological studies, and quantitative and qualitative composition related to depth and substratum, these species were grouped into five types: (I) planktonic forms, (II) benthonic forms with agglutinated tests, (III) benthonic forms with perforated calcareous tests, (IV) benthonic forms with non-perforated calcareous tests, nd (V) calcareous forms of large size.

In the greater part of the samples taken from depths greater than 50 m and composed of algal bottoms, the foraminifera of group V dominate, with *Amphistegina radiata* forma *tumida* and *Peneroplis* spp. Even samples constituted entirely of *Amphistegina* tests were found.

In two samples, from 55 and 25 m depth respectively, composed of muddy sand and sand, the representatives of group II increase in number, with *Bigerina nodosaria* and *Textularia candeiana*, of which the latter also occurs in other bottom types.

The forms of group III are rare and irregularly distributed, exception made for *Poroeponides lateralis*, present in almost every sample.

Group IV, represented almost entirely by miliolids, is that of the major species diversity (25), although not in a considerable number.

The concentration of planktonic forms is relatively greater on the banks than on the island platforms. *Globorotalia menardii* and *Globigerina trilobus* are the most frequent species.

BRYOZOANS

Barbosa (1964) gave a list of bryozoans determined in a number of samples taken in the investigated area until that time. Because it is a resuming paper, we can mention in the list only the species and the sample in which they were found. The author could use the following sampling localities:

1 — "S. Norseman" 1877, station 348 — 12°48'S 38°W — 49 m;
2 — South Atlantic, station 122 — 9°5'S 34°50°W — 630 m, red mud (slope);

3 — Barra de Serinhaem (Pernambuco State) — depth up tot 17 m;
4 — Fernando de Noronha — encrusting shells;
5 — South Atlantic, off Bahia — 18-75 m;
6 — North Atlantic, station 109 — 0°55'N 29°22'W — off St. Paul rocks, shallow water;
7 — "Coll. Rathbun" 1876, Todos-os-Santos Bay;
8 — North Atlantic, station 106 — 1°47'N 24°26'W — 320 m, globigerina ooze (slope?);
9 — littoral Recife (Pernambuco);
10 — "Albatross", station 2758 — 6°59'30"S 34°47'W — 36 m;
11 — littoral Fortaleza (Ceará).

List of bryozoans:

Adenoidae	
Adeona bipartita	1
A. heckeli	1
Adeonella distoma var. imperforata	2
Trigonopora tuberosum	10
T. unguiculatum	1
Aeteidae	
Aetea anguina	3
A. recta	4
Arachnopusiidae	
Exechonella brasiliensis	7
Bicellariellaidae	
Bicellariella glabra	5
B. navicularis	2
Bifaxariidae	
Bifaxaria corrugata	2
B. submucronata	2
Bugulidae	
Bugula versicolor	2
Kinestoskias pocillum	2
Buskiidae	
Buskia repens	3
Calleporidae	
Holoporella schubarti	3
Calloporidae	
Mollia elongata	1
Catenicellidae	
Catenicella diaphana	6
C. elegans	2
C. sacculata	2
Cellariidae	

Cellaria magnifica	2
C. imbellis?	5
C. mammilata var. atlantica	5
C. ridlwyi	4
Cheiloporinidae	
Tremoschizodina lata	1
Crepidacanthidae	
Mastigophorella dutertrei	4
M. pes-anseris	1
Cribrilinidae	
Cribrilaria innominata	1
Cribrilina radiata	4
Crisiidae	
Crisevia pseudosolena	3
Crisia holdsworthii	4
Diastoporidae	
Stomatopora major	2
Electridae	
Electra bellula	3
Epistomidae	
Synnotum aviculare	4
Exochellidae	
Escharoides costifera	3
Farciminariidae	
Farciminaria brasiliensis	2
F. delicatissima	8
F. gracilis	2
Nollia oculata	3, 5
Gigantoporidae	
Gephyrophora imperfecta	7
Hicksinidae	
Aplousina errans	1
Hippoporinidae	
Gemelliporina glabra	3, 5
G. ornatissima	1
Hippoporina cleidostoma	1
Hippothoidae	
Hippothoa divaricata	3
Membraniporidae	
Cupuladria monotrema	5
Membranipora tuberculata	9
Microporellidae	
Microporella violacea	4
Mimosellidae	
Mimosella verticillata	3
Mucronellidae	
Mucronella castanea	2, 5

Smittina areolata	1
S. tennuis ?	5
S. trispinosa	1
Nolellidae	
Nolella dilatata	3
Oncousoeciidae	
Proboscina robusta	7
Onychocellidae	
Smittipora antiqua	4
Pasktheidae	
Posythea eburnea	2
Petraliidae	
Hippopodina feegeensis	3
Plumatellidae	
Stolella agilis	11
Reteporidae	
Rhynchozoon (?) arborescens	7
Rhynchozoon bispinosa	4
R. verruculatum	1, 7
Schizoporellidae	
Cribella traingulata	7
Schizoporella trimorpha	1
S. unicornis	4
Stylopoma aurantiacum	9
Scrupocellariidae	
Scrupocellaria frondis	4
Steginoporellidae	
Siphonoporella granulosa	7
Steginoporella smitti	4
Tubucellariidae	
Tubucellaria opuntioides	6
Tubuliporidae	
Idmonea atlantica	3
Vesiculariidae	
Amathia brasiliensis	4
————	
Lepralia cleidostoma	4
L. depressa	4
L. pulcherrima	1

ECHINODERMS

List of echinoderms determined in the investigated area, after Brito (1962):

Ophiuroids	
Ophinoderma apressum	— common at coast of Salvador (Bahia) and Paraiba
O. cinereum	— whole area; common in Bahia
O. januarii	— whole area, not common
Ophionereis reticulata	— common from Bahia to S
Ophiotrix violacea	— common in Bahia
Ophiocoma echinata	— from Bahia to N; abundant in Todos-os-Santos Bay
Ophiozona impressa	— idem
Ophiomyxa flaccida	— common in Todos-os-Santos Bay
Ophiactis savignyi	— cosmopolitan
Asteroids	
Astrophyton costosum	— Bahia, rare
Coscinasterias tenuispina	— tropical Atlantic
Leptasterias hartii	— Bahia, rare
Echinaster spinulosum	— whole area
E. brasiliensis	— whole area; common in Bahia, Pernambuco
E. sentus	— whole area
E. echinophorus	— from Bahia to N; common in Paraiba, Pernambuco, Todos--os-Santos Bay, Abrolhos
Patiris stellifera	— tropical Atlantic
Linckia guildingii	— tropical seas; common in Pernambuco, Todos-os-Santos Bay, Abrolhos
Narcissia trigonaria	— Bahia
Oreaster reticulatus	— tropical Atlantic; common in Todos-os-Santos Bay, Abrolhos, Pernambuco
Goniaster americanus	— littoral N
Astropecten armatus brasiliensis	— whole area; common in Bahia, Fernando de Noronha
A. cingulatus	— whole area; common in Pernambuco
A. marginatus	— whole area
Tethyaster vestitus	— idem
Luidia senegalensis	— whole area; abundant in Todos--os-Santos Bay
L. clathrata	— whole area
L. doello-juradoi	— idem
L. alternata	— idem
Holothuroids	
Holothuria grisea	— tropical Atlantic

H. arenicola	— whole area; common in Bahia
Stichopus badionatus	— whole area
Phyllophorus seguroensis	— Pôrto Seguro (Bahia)
P. parvus	— whole area
Thyone pervicax	— Bahia
T. belli	— Abrolhos
T. (Sclerodactyla) brasiliensis	— Pernambuco, Todos-os-Santos Bay, Abrolhos
Thyonepsolus brasiliensis	— Pôrto Seguro
Trachythyone crassipela	— Salvador
Euthyonidiella dentata	— idem
Synaptula hydriformis	— whole area
Chiridota rotifera	— whole area; common in Abrolhos
Crinoids	
Tropimetra carinata	— tropical Atlantic; common in Todos-os-Santos Bay
Echinoids	
Cidaris tribuloides	— tropical Atlantic; common in Todos-os-Santos Bay
Arbacia lixula	— tropical Atlantic
Diadema antillarum	— Bahia
D. setosum	— tropical seas; Bahia, Fernando de Noronha
Astropyga sp.	— Bahia
Echinometra lucunter	— tropical Atlantic; common in Pernambuco, Salvador, Abrolhos
Lytechinus variegatus	— whole area; common in Bahia
Tripneustus ventricosus	— Fernando de Noronha; one of the most abundant of Salvador and Todos-os-Santos Bay
Clypeaster (Stolonoclypus) subdepressus	— whole area; common in Todos-os-Santos Bay
Encope emarginata	— whole area; common in Pôrto Seguro
Mellita quinquiesperforata latiambulacrea	— whole area
Leodia sexiesperforata	— whole area; common in Pernambuco and Bahia
Cassidulus infidus	— Bahia
Plagiobrissus grandis	— whole area, not very common
Moira atropos	— whole area

Observation: Almost nothing is known on the coast between Amapá and Rio Grande do Norte.

MOLLUSKS

Mollusks have been determined in the beaches and beach rocks of the Rio Grande do Norte State by Campos e Silva (1964) and Mendonça (1966). Later, Kempf & Matthews (1968) published a preliminary list of the mollusks found in the material collected by the R.V. "Almirante Saldanha" on its cruise 35. The area covers besides the shelf also the banks off the shelf and the oceanic islands. The authors gave only a list based on geographical occurrences which does not correspond with the nature of the bottom samples. In the following list, some of the administrative areas have been taken together, considering the general nature of the bottom deposit as presented on the annexed map. Conclusions have not yet been drawn.

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1 — Territory of Amapá and W of Pará river (Kempf & Matthews)
2 — E of Pará river, Maranhão and Piauí (Kempf & Matthews)
3 — Ceará, Rio Grande do Norte and Paraiba (Kempf & Matthews)
4 — Rocas (Kempf & Matthews)
5 — Fernando de Noronha (Kempf & Matthews)
6 — recent beach, Rio Grande do Norte (Campos e Silva, Mendonça)
7 — beach rock, Rio Grande do Norte (Campos e Silva, Mendonça)

	1	2	3	4	5	6	7
Lamellibranchia							
Nuculidae							
Nuculana cf. acuta	x	x					
N. cf. concentrica	x	x					
Yoldia cf. perprotracta	x	x					
Arcidae							
Arca zebra	x	x	x	x	x		
A. imbricata		x	x				
A. campechensis						x	x
A. umbonata						x	x
Barbatia candida	x	x	x				
B. cancellaria	x	x	x				
B. dominguensis	x	x	x	x	x		
Arcopsis adamsi		x	x				
Anadara baughmani	x	x					

	1	2	3	4	5	6	7
A. notabilis	x	x	x				
A. ovalis		x					
A. brasiliana	x	x				x	x
A. chemnitzi		x	x				
Glycymerididae							
Glycymeris decussata	x	x	x	x	x		
G. pectinata		x	x				
Mytilidae							
Modiolus americanus	x	x	x				
Modiolus sp.						x	
Botula fusca		x	x	x			
Lithophaga nigra		x	x				
L. bisulcata		x	x				
Pteriidae							
Pteria colymbus	x	x	x				
Pteria sp.							x
Pinctada radiata		x					
Pinnidae							
Pinna carnea					x		
Atryna seminuda	x	x	x	x			
Plicatulidae							
Plicatula gibbosa	x	x	x	x	x		
Pectinidae							
Amusium papyraceum	x						
Pecten ziczac	x	x	x		x		
P. cf. chazaliei		x	x				
Chlamys noronhensis	x	x	x	x	x		
C. nana		x					
Lyropecten nodosus	x	x	x				
Spondylidae							
Spondylus americanus	x	x	x	x	x		
Limidae							
Lima lima	x	x	x	x	x		
L. scabra	x	x	x	x			
Ostreidae							
Ostrea cristata		x	x				
Ostrea sp.						x	x
Diplodontidae							
Diplodonta punctata	x	x	x				
D. nucleiformis	x	x					
D. semiaspera	x						
Lucinidae							
Miltha childreni		x	x				
Lucina blanda	x	x	x				
L. aproximata							x

	1	2	3	4	5	6	7
Phacoides muricatus	x	x					
P. pectinatus						x	x
Codakia orbicularis			x				
C. pectinella	x	x					
C. costata			x				
Codakia sp.						x	x
Divaricella quadrisulcata		x	x	x			x
Chamidae							
Chama sinuosa		x	x				
C. macerophylla	x	x	x				
Pseudochama radians		x	x	x			
Echinochama arcinella		x	x				
Erycinidae							
Basterotia quadrata granatina		x	x				
Cardiidae							
Trachycardium magnum		x	x		x		
T. muricatum	x	x				x	x
Papyridea soleniformis		x	x				
P. semisulcata	x	x	x				
Trigonocardia antillarum	x	x					
Americardia media	x	x	x	x	x		
Laevicardium laevigatum	x	x	x				
L. pictum		x	x	x	x		
Microcardium tinctum	x	x					
Veneridae							
Antigona rigida	x	x	x				
A. cf. foresti	x	x					
Chione cancellata		x	x	x	x		
C. subrostrata	x	x					
C. cf. intrapurpurea	x	x	x				
Tivela fulminata		x					
T. mactroides						x	x
Pitar fulminata	x	x	x				
P. circinata							x
Gouldia cerina			x				
Callista eucymata		x	x		x		
Macrocallista maculata	x	x	x		x		
Dosinia concentrica		x					
Anomalocardia brasiliana						x	x
Tellinidae							
Strigilla pisiformis							x
Tellina brasiliana		x	x	x			
T. listeri		x	x	x	x		
T. radiata						x	x
T. similis			x				

	1	2	3	4	5	6	7
Macoma cf. tenta	x	x					
Semelidae							
Semele proficua	x						
S. purpurascens	x	x	x				
S. bellastriata	x	x	x		x		
S. cf. muculoides		x					
Solenidae							
Solecurtus cummingianus	x	x					
S. sanctaemarthae		x	x				
Mactridae							
Mactra petiti		x	x				
M. alata							x
Mulinia portoricensis			x				
M. branneri						x	x
Corbulidae							
Corbula cf. uruguagensis							x
Notocorbula operculata	x	x	x				
Gastrochaenidae							
Gastrochaena hians			x				
Pandoridae							
Pandora cf. bushiana	x	x					
Thraciidae							
Cyathodonta cf. semirugosa	x	x	x				
Verticordiidae							
Verticordia ornata	x	x					
Cuspidariidae							
Cardyomya perrostrata	x	x					
C. ornatissima	x	x					
Donacidae							
Donax striata						x	x
Iphigenia brasiliana							x
Psammobiidae							
Tagelus sp.						x	
Escafopoda							
Dentaliidae							
Dentalium sp.							x
Gastropoda							
Haliotidae							
Haliotis pourtalesii		x					
Trochidae							
Calliostoma bullisi		x					
C. gemmosum		x	x		x		
Turbinidae							
Turbo castanea		x					
T. canaliculatus	x	x	x	x	x		

	1	2	3	4	5	6	7
Turritellidae							
Turritella exoleta	x	x	x	x	x		
Architectonicidae							
Heliacus cylindricus					x		
H. perrieri					x		
Architectonica nobilis	x	x	x				
Philippia krebsi	x	x	x				
Modulidae							
Modulus modulus	x	x	x				
Cerithiidae							
Cerithium algicola						x	x
C. litteratum		x	x				
C. semiferrugineum		x	x				
Alaba incerta			x				
Triphoridae							
Triphora melanura	x	x	x				
T. ornata	x	x	x				
Epitoniidae							
Opalia pumilio			x		x		
Epitonium krebsii	x						
E. cf. denticulatum	x		x				
Hipponicidae							
Cheilea equestris		x	x		x		
Hipponix antiquatus			x		x		
Clyptraeidae							
Crepidula aculeata			x				
C. plana	x		x				
Crucibulum auricula			x				
Xenophoridae							
Xenophora conchyliophora		x	x		x		
Strombidae							
Strombus pugilis			x				
S. gallus			x		x		
S. raninus		x					
S. costatus		x					
S. goliath			x				
Eratoidae							
Trivia pediculus		x	x				
T. suffusa	x	x	x		x		
T. antillarum		x	x				
T. leucosphaera	x	x					
T. cf. nix	x		x				
Trivia sp.							x
Cypraeidae							
Cypraea cinerea	x	x	x				

	1	2	3	4	5	6	7
C. spurca acicularis	x	x	x	x	x		
C. surinamensis		x	x				
C. zebra						x	
Ovulidae							
Cyphoma signatum	x	x	x				
C. intermedium		x					
Naticidae							
Polinices lacteus		x	x				
P. uberinus	x	x					
Sinum perspectivum	x	x					
S. maculatum	x						
Natica canrena	x	x	x				
N. floridana			x				
N. marochiensis	x	x					
N. cayennensis	x	x					
Stigmaulax sulcata			x				
Cassididae							
Morum oniscus		x	x				
M. dennisoni			x		x		
M. mathhewsi		x	x				
Phalium granulatum	x	x					
Phalium sp.							x
Cassis tuberosa			x				
Cyperaecassis testiculus			x				
Cymatiidae							
Charonia variegata			x				
Cymatium caribbaeum		x	x				
C. vespaceum	x	x	x				
C. rubeculum occidentale		x					
C. femorale		x	x				
Distorsio clathrata	x						
D. macginty	x						
Bursidae							
Bursa thomae		x	x	x	x		
B. cubaniana	x	x	x				
B. corrugata			x				
B. spadicea	x	x					
Tonnidae							
Tonna galea	x						
T. maculosa			x				
Muricidae							
Murex pomum			x	x			
M. brevifrons	x	x					
M. antillarum		x					
M. recurvirostris rubidus	x	x					

	1	2	3	4	5	6	7
M. cellulosus		x	x				
M. macginty	x	x					
M. spectrum			x				
Drupa nodulosa			x				
D. didyma	x	x	x	x	x		
Thais haemastoma floridana		x					
T. rustica		x					
Aspella anceps		x					
Ocenebra intermedia					x		
Magilidae							
Coralliophila mansfieldi		x					
C. caribea			x				
Columbellidae							
Columbella mercatoria		x	x				
Anachis sparsa		x	x				
Buccinidae							
Engina turbinella		x	x				
Colubraria lanceolata		x	x				
Nassariidae							
Nassarius albus	x	x	x	x	x		
N. nanus		x	x	x			
Fasciolariidae							
Fasciolaria aurantiaca	x	x	x				
Latirus infundibulum	x		x				
L. brevicaudatus		x	x				
L. virginensis			x				
Leucozonia nassa		x	x	x			
Xancidae							
Xancus leviagatus		x	x				x
Vasum cassiforme			x				
Olividae							
Oliva reticularis	x	x	x	x	x		
Olivella nivea			x				
O. floralia	x	x	x				
Ancilla lienardi		x	x				
A. matthewsi	x	x	x		x		
Mitridae							
Mitra nodulosa			x				
M. barbadensis			x	x			
Pusia pulchella			x				
Volutidae							
Voluta ebraea		x	x				
Cancellariidae							
Cancellaria reticulata		x	x				
Marginelliidae							

	1	2	3	4	5	6	7
Marginella haematita		x	x	x			
M. lilacina	x	x	x				
M. matthewsi		x	x				
Hyalina albolineata		x	x				
H. avena			x				
Conidae							
Conus regius		x					
C. jaspideus	x	x	x		x		
C. daucus			x				
C. centurio	x	x	x				
C. dominicanus			x	x	x		
C. brasiliensis	x	x	x				
C. selenae	x	x	x				
C. yemanjae		x	x				
C. ranunculus		x	x				
C. cf. austini		x					
Terebridae							
Terebra taurina		x					
T. hastata		x	x		x		
T. dislocata		x	x				
T. protexta		x	x				
Turridae							
Polystira albida	x						
P. florencae	x	x	x				
Crassipira fuscescens		x	x		x		
Bullidae							
Bulla striata		x	x				
Bulla sp.							x
Aplysiidae							
Stylocheilus longicauda			x				
Dorididae							
Platydoris augustipes			x				
Rostanga byga			x				
Bornellidae							
Bornella calcarata			x				
Fissurellidae							
Diodora listeri							x
Neritidae							
Neritina sp.							x
Vermetidae							
Petaloconchus irregularis							x
Cephalopoda							
Lolliginidae							
Lolliguncula brevis		x					

	1	2	3	4	5	6	7
Octopodidae							
Octopus hummelinckii			x	x	x		

CORALS

On the Brazilian corals, after some work done in the 19th century by Branner (1904), Rathbun (1879) and Verril (1868), recently Laborel (1967a, b) published and excellent study. Besides giving a full description, this author considered also the environment and distribution. In the following list, copied from Laborel (1967b), are mentioned the species determined, without mentioning their rareness.

Localities:

1 — Abrolhos, back-reef
2 — Abrolhos, reef crest
3 — Abrolhos, seaward slope
4 — other reefs on loose or concretionary bottoms, between Ceará and Cabo Frio

	1	2	3	4
Scleractinia				
Sthephanocoenia michelini	x		x	x
Madracia decactis			x	x
M. asperula				x
M. scotiae				x
M. pharensis				x
Agaricia agaricites	x	x	x	
A. fragilis			x	x
Siderastrea stellata	x	x	x	x
Porites branneri	x	x	x	x
P. astreoides	x	x	x	
Favia gravida	x	x	x	
F. leptophylla	x		x	
Montastrea cavernosa	x	x	x	x
Astrangia brasiliensis	x		x	x
Phyllangia americana	x		x	
Meandrina brasiliensis	x		x	x
Mussismilia hartii	x		x	x
M. hispida	x		x	x
M. brasiliensis	x	x	x	

	1	2	3	4
Scolymia wellsii	x		x	x
Caryophyllia maculata				x
Deltocyathus italicus				x
Paracyathus sp.				x
Sphenotrochus auritus				x
Dasmosmilia lyonani				x
Solenosmilia variabilis				x
Stenocyathus vermiformis				x
Milleporina				
Millepora alcicornis	x	x	x	x
M. nitida	x		x	
M. cf. brasiliensis	x		x	x
Stylasterina				
Stylaster duchassaingi	x		x	
Zoantharia				
Palythoa sp.	x	x	x	
Zoanthus sp.	x	x	x	
Stolonifera				
Telesto riisei	x		x	
Holaxonia				
Phyllogorgia dilatata	x	x	x	x
Muriceopsis sulphurea	x	x	x	
Pseudopterogorgia sp.	x		x	x
Plexaurella dichotoma	x	x	x	x
P. grandiflora	x		x	
P. pumula	x		x	

Laborel (1967b) subdivided the Brazilian coral region into the following chief units:

(1) From French Guyana to São Luiz do Maranhão, that is in the whole Amazonian area, there do not exist known coral buildings and probably only a few isolated Madreporians; the whole region was therefore excluded from the study.

(2) From São Luis de Maranhão up to Mossoró (Rio Grande do Norte State) there are almost no reefs but only poor populations becoming scarcer towards north: this region was called the northern area of surface impoverishment.

(3) Around the curve of Cape São Roque appear the first great reefs which begin near Caiçara do Norte and reach up to Natal: reef group of Cape São Roque.

(4) The oceanic islands of Rocas and Fernando de Noronha.

(5) From Natal southward to the São Francisco river mouth, separated from the São Roque zone by a sandy area without reefs, occurs what is called the reef coast in which the beach rocks exercise a great influence on the coastal morphology.

(6) From the São Francisco river mouth to Bahia there are no coral formations, but the coast is important because it constitutes a large biological barrier.

(7) From Bahia to the Abrolhos archipelago occurs the centre of the coralline area with extensive reefs, thick and rich in populations.

(8) More towards south, the reefs disappear and one enters into the southern zone of impoverishment which reaches up to the city of Santos.

Laborel (1967a) observed that in the Brazilian fauna many West-Indian genera, such as *Acropora, Oculina, Diploria* and *Dichocoenia* are absent.

The species *Mussismilia hartii* is an important reef builder N of the São Francisco to Cabedelo. It is still abundant in Bahia, but not important in the reef formation. It occurs together with *Mussismilia brasiliensis*. It is rare in Rocas and Fernando de Noronha, where it grows, because of the surf, only in protected environments. The species *Mussismilia hispida* with its two subspecies is an important index in the investigated area: the subspecies *hispida* occurs only in the southern region and the subspecies *tenuisepta* in the northern area of occurrence (see table XII).

BENTHIC BIONOMY

Introduction. — The pioneer ecology studies of the N-NE Brazilian shelf are due to Kempf (1970c). This author emphasizes the relations between biological populations and the different substrata. The nuclear area is that off Recife, which provides a general scheme of population delimitation. The results can be applied to the rest of the shelf with the exception of the muddy bottoms near the Amazon mouth.

Nuclear area. — The Recife area shows the following bottom deposits, from the coast seaward (fig. 40): beach, mud,

Table XII — Areal distribution of the genus *Mussismilia*, after Laborel (1967a)
Distribuição geográfica do gênero *Mussismilia*, segundo Laborel (1967a)

			M. hispida	
	M. hartii	*M. brasiliensis*	*hispida*	*tenuisepta*
Rocas, Fernando de Noronha	dead only	—	—	—
Cape SãoRoque	rare	—	—	common
Cabedelo to Maceió	abundant, important builder	—	—	common
reefless region of São Francisco river				
Todos-os-Santos Bay to				
Caravelas	common	common	common	rare
Abrolhos	very abundant, not a builder	very abundant, the main builder	very common	—
reefless region of Rio Doce and colder waters				

reef, quartz sand, transition zone, calcareous algae. The beach zone was excluded in this study.

The mud bottom, located between the beach and the reef, is a fairly quiet zone. Due to its H_2S-content the deposit is not very suitable for benthic life. The sessile and sedentary invertebrates are limited to one representative of Gorgonacea, Scaphopoda, Pelecypoda, tubicole Polychaeta, and Ophuiridea, respectively. The vagile fauna has a few more species with Crustacea (shrimps and Portunidae) and some fishes (chiefly family Sciaenidae).

The reef zone shows lines parallel to the shore, often exposed at low tide. They are beach rocks, sometimes with a coral cover. Laborel (1967b; see anterior paragraph) described these corals and their way of ocurrence. The rest of that fauna is poor; only calcareous algae and some vermetides participate actively in the reef construction.

The quartz sand area occurs behind the reef, or where this with the mud channel is absent, immediately near the beach. Its composition of medium-coarse sand and coarse calcareous algal gravel, results in a dualism of the biological population. Among the relatively abundant flora may be mentioned the Melobesiae (Rhodophyceae and Corallinaceae) as small hard concretions, used as the substratum by the soft algae. The rather poor fauna shows three groups: (1) sand dwellers — Madreporaria, Pelecypoda, Echinoida and one representative of Cephalochordata —; (2) species living on blocks, not typical of this bottom — pelecypod *Plicatula gibbosa,* polychaete *Phragmatopoma* sp. and echinoid *Eucidaris tribuloides* —; (3) epiphitic forms, existing on soft algae, for instance Hydroida, Bryozoa and juvenile Serpulidae.

The transition between the quartz sand and calcareous algae zones, shows the mixed composition of both substrata. There occurs a settlement of calcareous algae on a sandy bottom.

The so-called zone of calcareous algae occupies the greater part of the shelf area. They are present as free-living and ramificated forms, like *Lithothamnium,* as well as concreted forms of gravel size. Within the open spaces a sandy fraction of fragmented biodetritic material and some white lime mud is found. Also some hard substratum was found, elevated slightly above the sea floor. The fauna in this zone is very rich in species numbers. The depths of occurrence are between 20 and 80-90 m (shelf break), to be subdivided into two different zones. The division is found at about 35-40 m depth, where the reef, quartz sand, transition zone, calcareous algae. The beach zone was excluded in this study.

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Locally, there occurs as a variation of the calcareous algal bottom, the so-called *Halimeda* sands, where the fragments of these calcified Chlorophyceae are dominant, chiefly in the infra-littoral zone with *Halimeda incrassata,* more rarely in the lower circa-littoral area with *H.* cf *tuna*. The biological population differs slightly from the former bottom type, with a decreasing content in Melobesiae and consequently less substratum for other algae.

The biodetritic material bottom, chiefly constituted of detrital calcareous material, is abundant near the shelf edge. Due to its position sampling of populations is difficult. The main biological characteristic is the absence of living algae. Other species are still present, whereas those of the continental slope become more frequent at greater depths.

Local variations. — On the shelf of Alagoas and Sergipe, the part N of the São Francisco river mouth is almost identical to the Recife area. On the Sergipe shelf, however, there exist two canyons, those of the São Francisco and Japaratuba rivers. Their muddy sediments cause the almost complete absence of calcareous algae, at least near the coast.

On the shelf of northern Brazil, the extension of the quartz sand bottom increases. Therefore, the calcareous algal bottoms occur farther downwards, generally beneath 40 m, decreasing their importance in a northwesterly direction. Most of the sub--recifal corals disappear. At some localities, the Melobesiae occur as blocks, with sponges as a cemeting material. The biodetritical bottom substitutes gradually the algal bottom, with the subsequent changes in biological populations. Bryozoans become more frequent, chiefly concretionary and ramificated forms.

In the Amazon area muddy bottoms become a dominant factor, with a characteristic fauna. Some components belong to the Guyana fauna, and reach here their southernmost occurrences (for instance: pelecypods *Yoldia* sp., *Trigonocardia antillarum;* gastropod *Bursa spadicea;* some crustaceans, etc.). The mud of shallow depths, less than 20 m, is very inconsistent and poor in macroscopic invertebrates.

Relic sediments. — The benthic bionomy proves that large areas of the northern and northeastern shelf are covered with relic sediments. For instance, the sandy bottoms between the Pará river and Ceará State are not in accordance with the present sedimentation conditions, a fact also proved by Marchesini Santos & Carvalho (1970). Also the lower part of the calcareous algae bottom shows more dead than living fragments; the Melobesiae developed certainly under more favourable conditions, such as better light penetration or shallower water depth. On the northern coast of Rio Grande do Norte State, and at the foot of Rocas island, the white and pure calcareous sands dreged up from depths between 60 and 90 m, are also not of recent age.

6. RECENT LIME AND SANDSTONES

INTRODUCTION

The tropical climate of the investigated area creates an environment well adapted for the formation of calcareous sediments. The temperatures are high (24-27°C) as is also the salinity (up to 37°/oo), so that the water may be saturated with dissolved calcium carbonates. On the bottom surface where the biodetrital and algal facies types occur, loose pebble and boulder-size fragments of cemented calcareous material was found, generally in the form of limestones. Where the bottom facies has a considerable quartz sand content, the cemented fragments tend to be sandstones.

Recently the study of these fragments was undertaken, and still some results are only partially known, mostly due to technical difficulties in the investigation. One of the problems is whether these fragments are modern or not, because it is generally known that "there is a general absence of lithification on modern (Holocene) carbonate sediments" (Taft 1967). Therefore we will speak in the following description of "recent" lime and sandstones.

These recent lime and sandstones have been found: (1) in the littoral zone, especially the beach area, and (2) on the shelf and slope. Figure 54 gives the localities in the latter area, where samples have been dredged up. The beach rocks which have already been considered in Chapter 2, have been excluded here. The results of the recent limestone study have been published by Mabesoone (1968, 1971a, b); these papers serve as the base for the next consideration.

LITTORAL ENVIRONMENT

Area of occurrence. — The Piedade beach, behind the Oceanographical Institute, served as the type area for the study of these recent limestones in the littoral environment. One can but find similar phenomena at other beaches of northeastern Brazil, especially where also beach rock and other "reefs" occur.

In the foreshore area near the low-tide level, fragments of recent limestones accumulate, chiefly in winter (June-August) during stormy high tides. For instance, in July 1966 were determined on 1 m^2 in that area, besides abundant beach rock fragments, algal and vermetid limestones and coral fragments (table XIII). Just these few types can be found. It is also pe-

Table XIII — Frequency of limestone fragments on 1 m^2 of beach and petrographic description of some representative samples
Freqüência de fragmentos calcários em 1 m^2 de praia e descrição petrográfica de algumas amostras representativas.

	A	B
Piedade beach	4 — 7,4%	4 — 4,8%
coarse beach rock	11 — 20,4	23 — 27,3
fine beach rock	2 — 3,7	3 — 3,6
recent beach rock	11 — 20,4	7 — 8,4
vermetid limestone	21 — 38,8	40 — 47,5
algal limestone	5 — 9,3	6 — 7,2
coral fragments	— — —	1 — 1,2
coquinite	——	——
total	54	84

sample R-A 1: — Algal limestone — mass constituted of *Goniolithon* and *Porolithon*, nodular, compat. Algal biomicrite — only algal structures transforming in micrite, many unfilled pores.

sample R-A 2: — Algal limestone — nodular mass of thik branches of *Lithophyllum*. Algal biomicrite — algal structures with a certain micritic cement in which occur some small, angular quartz grains

sample R-A 3: — *Halimeda* limestone — with mass of *Halimeda* stems, very soft *Halimeda* biomicrite with quartz — micritic mass of calcite, almost without structure, about 10% of subangular quartz

sample R-V 1: — Vermetid limestone — mass vermetid shells (*Petaloconchus* cf. *varians*) with a thin algal crust at some places. Vermetid biomicrite — vermetid fragments in random sections, some foraminifera, micritic cement, 2% of small, angular quartz grains culiar that these species are rather pure; no mixed types were found with the exception of some vermetid limestones which may show a thin crust of calcareous algae.

The petrographical description of some characteristic samples has been mentioned also in table XIII, (detailed paper, see Mabesoone, 1971b).

Vermetid limestones. — These are composed of small tubes, shells of *Dendropoma* (*Novastoa*) cf. *irregulare* and *Petaloconchus* (*Macrophragma*) cf. *varians* (Laborel & Kempf 1967). In its pores quartz sand grains and small-size organisms such as foraminifera may accumulate. Some samples show a thin crust of calcareous algae.

Their petrographical aspect is a brownish (5 YR 6/4 colour) mass of vermetid tubes; a present algal crust is always thin and has a whitish colour. In thin section one may observe these tube fragments in random sections. In the micritic cement, small quartz grains and foraminifera may be distinguished. The rock may thus be called a vermetid biomicrite (in the sense of Folk, 1959).

Algal limestones. — Four different types of limestone fragments built by algae may be found on the coast.

The first type is a composite structure of the algae *Porolithon* and *Goniolithon*. Generally, the latter is present as nodular masses around a nucleus which may often be a coral fragment. The first occurs as nodular crusts on other algae, with a somewhat rough surface. Figure 52 shows a section through such a type in which the white (N 9 colour) laminae are constituted by *Goniolithon* and the gray (N 5 colour) by *Porolithon*. In thin section they presented only algal structures which are transforming themselves into a micritic mass; still many pores are present.

A second type is constituted of branches of *Lithophyllum* with a 10 YR 6/6 (yellowish-orange) colour. They are not frequent on the Piedade beach. The branches are thick, irregular and ramificated; sometimes they form small nodules.

Also occur nodular masses of the same colour, but without branches. A thin section through such a mass showed algal structures with a micritic cement in which small, angular quartz grains could be determined. This type is fairly frequent.

The fourth type, rarely occurring because of it being so friable, constitutes aggregates of with *Halimeda* stems. These

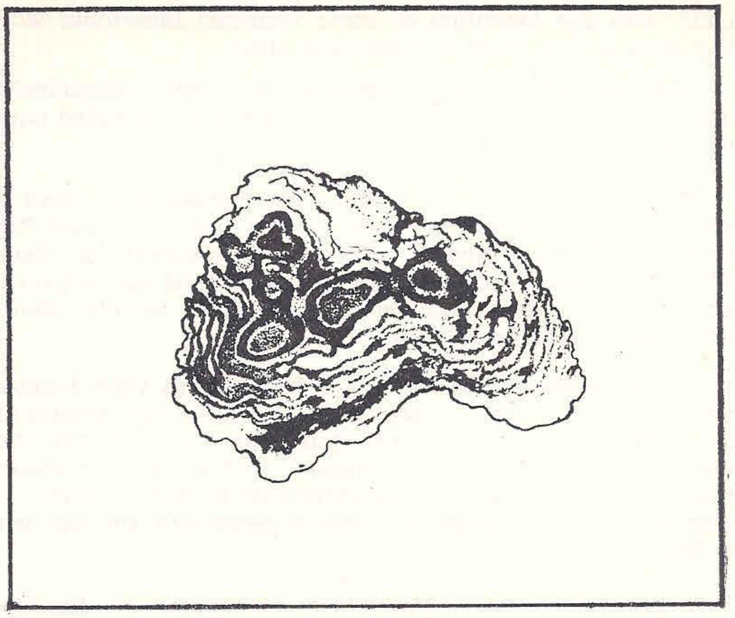

Fig. 52 — Section through algal limestone of *Porolithon* and *Goniolithon* (Mabesoone 1968).
Corte de um calcário de algas *Porolithon* e *Goniolithon*.

are often not completely calcified, which causes the softness of the rock. In the pores occurs a fine muddy mass of desintegrated *Halimeda* fragments. This causes that in thin-section the aspect is of a micritic mass with only a few algal structures. Surprisingly, up to 10% of angular quartz grains were found in one sample.

Corals. — Broken fragments of corals are also found in the beach area. They must have been derived from the coral cover of the sandstone reefs which occurs at various places in the investigated area.

Coquinite. — Rare fragments of masses of shells are met with in Piedade. They are more oftenly found in the beaches of Rio Grande do Norte State. Their open spaces are filled up by beach sands so that they may be considered as beach rocks. The species are all of recent mollusks which are still living in the area.

Provenance of fragments. — The limestone fragments accumulated on the beach came from the seaward side of the "reef" zone. An interesting study published by Laborel & Kempf (1967) gives a good explanation.

The vermetids grow with calcareous algae in shallow water, agitated, clean and well aerated, generally at the seaward side of reefs and rocks, whereas the type of substratum is of minor importance. This latter was proved to be beach rock (sandstone reef), ironsandstone reef, hard rock exposed at the coast, coralligenous flats and even a drowned hull of a ship. The algae have not been determined, but the vermetids show the two species already mentioned above: *Dendropoma* (*Novastoa*) cf. *irregulare* and *Petaloconchus* (*Macrophragma*) cf. *varians*. The first is very abundant and covered with calcareous algae; the second is found only as empty tubes covered by *Dendropoma* as if it was substituted recently the latter.

A nice example is the Maracajaú reef in Rio Grande do Norte (fig. 53, after Laborel & Kempf 1967), belonging to the

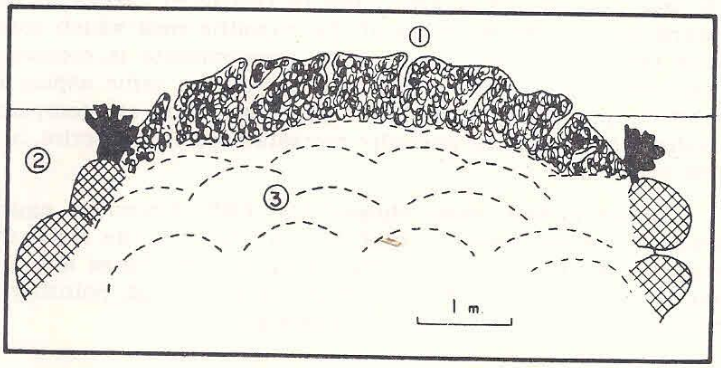

Fig. 53 — Maracajú reef (Rio Grande do Norte State; modified after Laborel & Kempf 1967); 1: vermetids, 2; coral (alive), 3: coral (dead).
Recife de Maracajú (RN), 1: vermetes, 2: corais vivos, 3: corais mortos.

reef complex of Cape São Roque. It is an elliptical shaped formation in shallow water, 5 miles long and 2 miles wide. The base is made of corals and is only a few meters thick, not falling dry at low tide. Alongside the borders, living corals occur in small knobs of some meters in diameter; the chief species are *Siderastrea stellata* and *Millepora alcicornis* on which grew a 10-30 cm thick crust of calcareous algae and *Dendropoma*, this latter very active and abundant. The concretions possess a cover of small infra-littoral algae, whereas the sessile foraminifer *Homotrema* is abundant in the numerous open spaces.

On the Gaibu beach (32, on fig. 23), samples have been found at heights of 2-3 m above the actual sea level (see Chapter 2). Their absolute age determined by the C-14 method revealed ages of 1200-3500 years (van Andel & Laborel 1964). In these samples the vermetids are more abundant than the algae. The vermetids were still living in abundance at about 1650 A.D., as shows the crust on the stones of the fort of Suape. Actually the algae seem to substitute the vermetids in this area, especially *Petaloconchus*. Their disappearance may be due to the more mud-loaded water brought to the ocean by rivers because of the deforestation of the interior.

Recently, from another area some more samples were collected. It is the "in situ" occurrence on the Santo Aleixo island, off the Pernambuco coast in the municipality of Serinhaém (see 46, 47 on fig. 23), described by Pedrosa Jr. (1969). On this island there occur pure limestones and a conglomerate with lime cement. They are found in restricted areas, at the seaward side, in the fractures of the rhyolitic rock which constitutes the base of the island. The conglomerate is composed of rhyolite pebbles with a lime cement of the same aspect as that of the pure limestones. These pure limestones are composed of *Halimeda* fragments, partially recrystallized into micrite, and a few intraclasts.

A mineralogical study showed the *Lithothamnium* agglomerates to be composed of high-Mg calcite, and the *Halimeda* accumulations of aragonite. The vermetid limestones are also chiefly aragonitic. Low-Mg calcite is almost absent, pointing to a fairly recent formation of the limestones.

SHELF ENVIRONMENT

Limestones

In figure 54 are presented also the localities on the shelf where limestones have been dredged up. They occur in almost the whole of the investigated area. Certainly, a more detailed survey will show much more places with such limestone formation. The facies in which these rocks are found, are the biodetrital, algal, and slope facies (for their description, see Chapter 3). Table XIV shows a number of petrographical analyses. A detailed consideration has been given by Mabesoone (1971a).

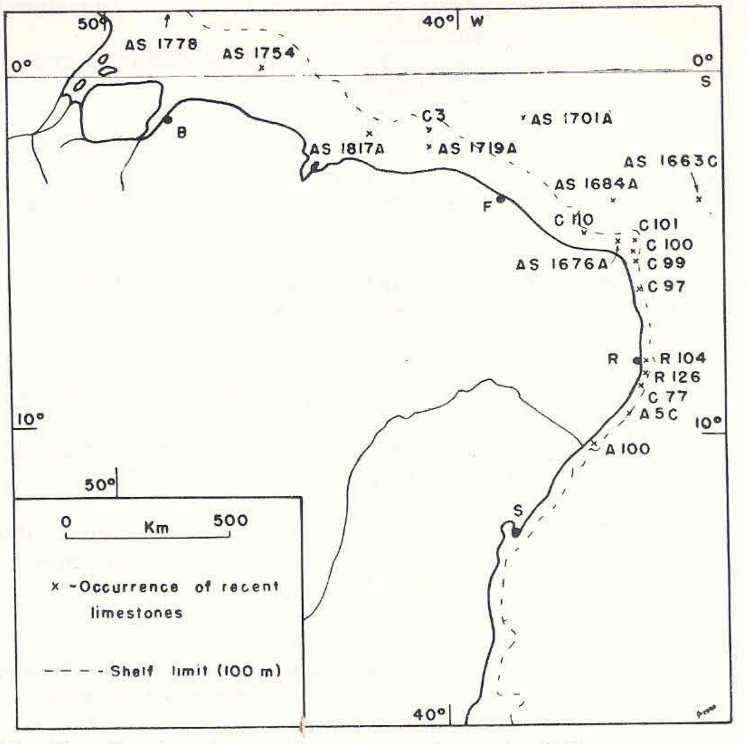

Fig. 54 — Location of recent limestone samples on the shelf.
Localização das amostras dos calcários recentes na plataforma.

The limestones of the algal facies are the most abundant. They have a crust-like character with their pores filled up with sand-size material: quartz and organisms. Often they are still very friable, but at some places they constitute already real limestones. In thin section they present abundant algal structures with some quartz grains in the pores, as well as foraminifera and fragments of other organisms. The whole has a micritic cement which makes them algal biomicrites.

In the biodetrital facies the limestones are biomicrites. Here the algal structures do not dominate; in thin section were also determined foraminifera, fragments of bryozoans and mollusks, and intraclasts. The whole is bedded in a micritic cement. In hand specimens one observes a gray-coloured friable and porous limestone in which the individual organisms are often recognizable.

Table XIV — Petrographical description of some limestones found on the shelf
Descrição petrográfica de alguns calcários encontrados na plataforma

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sample A = 100 — Algal biomicrite: micritic mass with many algal structures, some foraminifera and other fossils, a few quartz grains.

sample A = 5C — Foram biosparite: limestone composed of almost 100% organogenous fragments, chiefly foraminifera, a sparse sparitic cement, many unfilled pores.

sample C = 77 — Algal biomicrite: typical algal structures transforming in a micritic mass.
Similar samples: C = 97, C = 100, C = 101, C = 110, AS = 1663C, AS = 1701A.

samples R = 126 — Algal biomicrite: chiefly algal structures, also some other organisms present (foraminifera) few micritic cement.
Similar samples: R = 104, AS = 1676A, AS = 1754.

sample C = 3 — Biomicrite: biogenic limestone with many different organisms, such as algae, bryozoans, foraminifera, mollusks and some intraclasts, with a micritic cement and a few subrounded quartz grains.
Similar samples: AS = 1684A, AS = 1719A.

sample AS = 1817A — Micrite with quartz: a micritic mass almost without structures (possibly algae recrystallizing), some angular quartz grains scattered in the mass.

sample AS = 1778 — Calcarenite with quartz: almost equal proportions of fine, angular quartz and organogenous fragments, presence of glauconite, micritic cement.

An interesting limestone has been dredged up from the continental slope off Alagoas (sample 5C, from depths of about 300 m). It is a yellowish-coloured and friable mass, totally composed of organisms which give it a very detrital aspect: a real calcarenite. In thin section the sample shows itself composed of micro-organisms, chiefly foraminifera determined as being planktonic by Tinoco (Mabesoone & Tinoco 1967), and of intraclasts. The cement is only scarce, but where it exists it is sparitic. This makes the rock a foraminiferal intrabiosparite, in the sense of Folk (1959).

As far as the limestone samples could be desaggregated, the microfauna of foraminifera has been determined. The same five groups, as distinguished by Tinoco (1970; see Chapter 5), have also been distinguished here. It appears that the samples reflect the foraminiferal assemblage of the bottom deposit at that place. The foraminifera of group I (planktonic forms) dominate in sample 5C from the continental slope. The algal limestones possess more forms of group V (large foraminifera), whereas the biodetritic facies samples show more forms with a perforated calcareous test (group III).

Among the other micro-organisms and small-size components, the following may be mentioned: calcareous algae (often *Halimeda* stems), micro-mollusks, and not more recognizable fragments of other organisms.

The bigger-sized fauna represented in the shelf limestones also reflets the fauna of the surrounding bottom. Most of the species have still to be determined. Calcareous algae are often dominant; abundant are also bryozoans. Mollusks are abundant in biodetrital bottom limestones, where the quartz content is low. Corals constitute a considerable amount only there where coral reefs are frequent.

With respect to the mineralogical composition, the minerals present are aragonite and high-Mg calcite. The low-Mg calcite content is very low to almost zero, with the exception of sample 5C from the continental slope. Two groups of limestones can thus be distinguished. The first shows a considerable (90-100%) high-Mg calcite content, containing the samples of the algal facies, with a dominance of lithothamnioids. The second group is that of the aragonitic limestones, constituted of *Halimeda* accumulations and the limestones of the biodetrital facies bottoms.

Sandstones

In the area covered with the littoral sand and with the mixed quartz-biodetrital sand, also hard rocks in formation have been dredged up. These are the samples AS = 1720 from the littoral sandy facies, AS = 1731 from the Parnaiba river delta, and AS = 1773A and 1778 from the Amazon influence area. A petrographical description has been given in table XV.

The sample from the littoral facies (AS = 1720) is composed of subangular to subrounded quartz grains showing a chemical

Table XV — Occurrence of recent sandstones on the shelf and petrographical descritpion of some representative samples
Ocorrência dos arenitos recentes na plataforma e descrição petrográfica de algumas amostras representativas

AS=1720	2°31,0' S	40°22,0' W	depth 23 m	sandy littoral shelf facies
AS=1731	2°30,0' S	41°51,0' W	24	delta Parnaiba river
AS=1732	2°15,0' S	41°51,0' W	52	delta Parnaiba river
AS=1742	1°36,0' S	44°01,0' W	31	sandy littoral shelf facies
AS=1762	0°13,0' N	46°55,0' W	36	sandy littoral shelf facies
AS=1773 A	2°28,0' N	48°13,5' W	85	mixed facies of quartz and biodetrital sand

sample AS = 1720 — Calcareous sandstone: subangular-subrounded quartz grains showing chemical attack, 25-35% of organogenous fragments, micritic cement

sample AS = 1773A — Calcareous sandstone: subangular-subrounded quartz grains almost not attacked, few organogenous fragments, micritic cement

sample AS = 1731 — Sandstone with some calcite: rounded to subrounded quartz grains, 5% of organogenous fragments, few micritic cement

attack. This means that the rock might be not very recent, because it is already suffering from a fairly strong diagenesis. Furthermore, it occurs in an area where the sediment is thought to be relic.

Sample AS = 1731 is constituted of rounded quartz grains, evidently coming from the Parnaiba river. It is almost a pure sandstone with only a low carbonate content and therefore very friable .

The samples from the Amazon area also sandy with more or less biodetrital fragments. They might also be relic, because the present Amazon facies on the shelf is purely muddy.

Anyhow, the environment appears to be suited for the cementation of quartz sands too. That means that the water is really supersaturated with calcium carbonate which can precitat as to form real sandstones.

ORIGIN

With respect to the beach rock, its microcrystalline lime cement has a purely chemical character pointing to a precipitation from supersaturated water. This is in favour of Russell's ideas (1962) on the origin of beach rock. The organogenous limestone fragments found in this environment seem to disappear in the beach rock. During the continued diagenesis they loose partially their structures by recrystallization, so that they constitute zones of higher lime content in a calcareous sandstone. Only the shells of the coquinites loose their character more difficultly. This all will result in the formation of calcareous sandstones with concentrations of fossils at certain places.

The limestones which occur on the shelf and even on the upper part of the slope, however, are much purer. They are composed, in the investigated area of northern and northeastern Brazil, chiefly of algal structures. These structures tend to disappear rather rapidly, whereas a micritic mass is to be formed (Wolf 1965); incipient phenomena of this process could already be distinguished in a number of thin sections. The other organisms, chiefly foraminifera and various fragments, remain intact and easily distinguishable in the micritic mass in which they will often not dominate and appear scattered in it. The result will be a somewhat fossiliferous limestone, fairly hard and compact, a foraminiferal fossiliferous micrite. Maybe later such limestones with only a few fossils will become "lithographic" limestones.

It is curious that all limestones found in the investigated area are micrites. This means, in the sense of Folk (1962) and Bissel & Chillingar (1967), that the environment of formation is or was quiet to moderately agitated with only weak to moderate currents. This cannot be confirmed because no current measurements were made at the bottom. But it is known that at the surface the South Equatorial Current is fairly strong. Another possibility is that the biodetrital fragments were cemented by algae which later transformed in micrite, loosing their typical structures. But it is true that the cement has been later introduced in the biodetrital material already present on the bottom surface. Generally, the bottom sediment on which the limestone fragments are found, is composed of the same material in unconsolidated form, almost without a fine fraction. This may favour the idea that algae were the most important factor in cementing the loose material. Indeed, at one station, living calcareous algae were found with numerous biodetrital fragments between its fibers. An incipient cementation by algae may favour a precipitation of fine crystalline calcite from the supersaturated water.

The only sample with a beginning sparitic cement is A = 5C, provenant from the continental slope off Alagoas (depth 370 m). The cement must be of direct precipitation, because so many pores are still void. The environment is possibly not quiet enough for microcrystalline ooze to remain within the pores, so that only a coarser crystalline cement can be formed.

The cementation of the quartz sands into sandstones may have the same beginings as that of the limestones. The always present biodetrital fragments, even in small amounts, entangled in algal fibers may cause the precipitation of calcium carbonate in the pores of the loose sediment.

The conclusions are that the limestones and calcareous sandstones from the investigated area are recent formations, composed of the same material as the surrounding bottom. This recent age is confirmed by the dominance of unstable calcium carbonates. The rocks do not show evidence of having been exposed to subaerial conditions so that lithification must have occurred under the sea water level. The environment of formation is an open ocean shelf, with not so strong currents ,high temperature and salinity, basic pH, and a bottom of biodetrital calcareous sediment.

SINÓPSE

1. Introdução

Esta monografia resume os conhecimentos atuais sôbre a geologia litorânea e da plataforma continental do Norte e Nordeste brasileiro. Ésses conhecimentos aumentaram muito desde 1958 com o funcionamento do Instituto Oceanográfico da Universidade Federal de Pernambuco, cuja equipe de pesquisadores, com ajuda de outras da Marinha do Brasil e da SUDENE, executou vários estudos nessas áreas.

Todos os dados, às vêzes de difícil acesso, foram reunidos, abrangendo a área entre Cabo Orange e o arquipélago dos Abrolhos, incluindo as ilhas oceânicas e os bancos em frente da plataforma continental. Os resultados do estudo da geologia dêsse ambiente foram apresentados num mapa.

Sendo a área muito extensa, é de se compreender que ainda faltam muitos problemas a resolver. Porém, com a publicação do que já se conhece atualmente, existe uma base para futuras pesquisas.

2. Ambientes litorâneos

Introdução. — Foi adotada a divisão do litoral brasileiro, proposta por Silveira (1964), do qual na área estudada se encontram os seguintes tipos: (1) costa amazônica ou equatorial, (2) costa nordestina ou das barreiras, (3) costa oriental. A costa amazônica estende-se do Cabo Orange até a parte oriental do Estado do Maranhão. Ela pode ser subdividida em três partes bem individualizadas. A costa guianense, ao norte da foz do Amazonas, é uma região baixa com sedimentos recentes com depósitos argilosos fornecidos pelo rio e transportados para o norte pela corrente oceânica. O golfão amazônico possui uma costa instável, devido à interação das correntes fluviais e aquelas das marés. A terceira parte, a costa amazônica oriental, é caracterizada por numerosos estuários pequenos, onde as grandes diferenças de maré agem muito destrutivamente. O litoral arenoso possui extensas acumulações de dunas. A costa nordestina ou das barreiras estende-se desde o delta do Parnaíba até a baía de Todos-os-Santos. No litoral norte entre o Parnaiba e o Cabo de São Roque, a área é sêca com dunas, poucas fozes de rios e salinas. O trecho nordestino ao sul do Cabo de São Roque é típico por suas falésias que chegam até o mar, as chamadas "barreiras". Acompanham esta costa linhas de recifes de arenito, às vêzes com uma capa de corais e algas calcárias. Onde as marés penetram nos vales fluviais, existem mangues. Ao sul da foz do rio São Francisco aparecem dunas bastante altas. A costa oriental ao sul da baía de Todos-os-Santos, é baixa com poucas barreiras de menor importância. A sedimentação recente causa aqui a existência de numerosos cordões litorais. Continuam nesta área os recifes de arenito com corais.

O clima da faixa costeira é tropical com estação sêca pronunciada. Na costa norte entre Amapá e Ceará e na costa leste ao sul de Salvador, o clima é do tipo *Aw'* segundo a classificação de Köppen, e entre Natal e Salvador do tipo *As'*. A costa norte do Rio Grande do Norte é semi-árida quente, do tipo *BShw*.

O regime das marés mostra amplitude máximas entre 2 e 4 m, chegando em alguns lugares até 8 m.

Estuários. — Existem muitos estuários na costa da área em apreço.

O estuário do Amazonas foi alvo de várias pesquisas. A foz mostra, além de uma grande erosão, também certa sedimentação como testemunham as ilhas aluviais. A sedimentação mais forte ocorre, porém, na região dos Estreitos de Breves onde se forma uma espécie de delta. O resto do material chega no oceano, onde a Corrente Sul-Equatoriana transporta-o para norte. O caráter do sedimento na área é ainda desconhecido. O Amazonas é, na realidade, um rio que constrói deltas; sua fase estuariana é apenas temporária.

A costa amazônica oriental possui grande número de estuários. Há também um fornecimento de muito material que se espalha sôbre a plataforma.

A baia de São Marcos, na cidade de São Luís do Maranhão, é o estuário de alguns rios. A profundidade à maré baixa é pequena. Em alguns lugares há uma forte sedimentação, enquanto em outras existem falésias vivas em fase de plena erosão.

O estuário do rio Potengi, em Natal, foi estudado mais detalhadamente, devido à existência do pôrto dessa cidade. Mostrou-se que na área portuária há pouca sedimentação. O mar traz pouco material, embora que as correntes de maré penetrem muito para o interior. A zona salobra, onde o material em suspensão trazido pelo rio se deposita, está localizada fora do pôrto, rio acima. Os sedimentos no estuário são arenosos, de diferentes tamanhos médios.

Um estudo do mesmo tipo foi efetuado no estuário do rio Paraíba em cuja foz se encontra o pôrto de Cabedelo. As fortes correntes de maré causam uma maior influência marinha nos depósitos de origem fluvial.

O rio Capibaribe possui o estuário melhor estudado, devido à situação da cidade do Recife. O rio sofre, às vêzes, de enchentes desastrosas, que inundam partes baixas da cidade, e causam uma deposição de muita lama na bacia do pôrto. Normalmente a sedimentação da pouca matéria fina ocorre onde a salinidade é mais baixa uns poucos quilômetros rio acima. Os sedimentos na área do pôrto são argilosos no centro e arenosos na entrada e na chamada "bacia de Pina". A lama é de origem fluvial, enquanto as areias são de origem marinha.

Deltas. — Os deltas não foram ainda estudados. O do rio Parnaiba possui muito material arenoso, acumulado ao lado oeste da foz, devido à corrente oceânica. O delta do rio São Francisco é do tipo cúspide, com cordões litorâneos numa planície costeira.

Baías. — Das baías pequenas foi estudada a de Tamandaré, no Estado de Pernambuco. Esta representa o padrão de sedimentação geral da costa, protegida por um recife. Há depósitos arenosos terrígenos e biodetríticos, com suas respectivas misturas. A parte com maior quantidade de material terrígeno encontra-se mais perto da praia. No centro da baía existem sedimento compostos de fragmentos de algas calcárias. O recife possui uma capa de corais.

A baía de Todos-os-Santos ainda não foi estudada. Sabe-se apenas que existem sedimentos de algas calcárias no interior, exploradas para a indústria de cimento.

As baías de Cabrália e Pôrto Seguro são importantes por terem sido os primeiros lugares de atração dos descobridores do Brasil.

Mangues — Os mangues são freqüentes nos lugares tranquilos da costa nordestina. Foram feitos vários estudos, especialmente na Barra das Jangadas, sôbre sedimentos e ecologia. À base da ocorrência de crustáceos decápodos pôde ser estabelecida uma zonação. Os mangues crescem melhor sôbre sedimentos arenosos finos com uma certa quantidade de argila.

Lagoas. — Das lagoas existem trabalhos sôbre uma pequena, chamada Olho d'Água, principalmente no sentido ecológico, e sôbre aquela do tipo "liman", a Lagoa de Mundaú, no Estado de Alagoas. Nesta lagoa foi feito um estudo completo, em relação à cultura do sururú. Os sedimentos são finos, argilosos no centro, arenosos finos na foz do rio, e arenosos grosseiros para o lado do mar e nos canais. Na lama há maior concentração de matéria orgânica.

Praias. — Estudos sistemáticos das praias foram feitos em Pernambuco, especialmente dos minerais pesados. Foram encontradas algumas concentrações de minerais magnéticos, com dominância de ilmenita; a monazita é um mineral raro nessa área.

Uma consideração sedimentológica existe sôbre a praia de Piedade, onde foram executadas análises granulométricas e de matéria calcária. A percentagem dessa última é alta na praia úmida, diminuindo gradativamente em direção da praia sêca.

Sôbre algumas outras praias existem estudos especializados, como por exemplo, sôbre os foraminíferos ou a malacofauna.

Recifes. — Existem três tipos de "recifes" no Nordeste brasileiro: recifes de arenito ou rocha de praia, recifes de arenitos ferruginosos e recifes de rochas calcárias. Dêstes os dois últimos tipos são de sedimentos meso e cenozóicos, que por acaso afloram no litoral.

O tipo mais interessante é aquele dos arenitos de praia. Branner em 1904 escreveu um estudo completo sôbre essas rochas, obra ainda atualizada. Os estudos posteriores apenas complementaram as primeiras observações ou consideraram-nas sob outro ponto de vista. Os arenitos de praia ocorrem desde Fortaleza até a região dos Abrolhos. São areias de praia consolidadas por matéria calcária, geralmente fragmentos de organismos calcários recristalizados. As rochas se formam perto do nível onde o lençol freático chega na praia. Em alguns lugares pode ser encontrado arenito de praia em formação.

Em vários lugares crescem também corais, em forma de recifes. Geralmente possuem como base um "recife" de arenito, especialmente na zona ao norte da foz do rio São Francisco. Recifes de coral do tipo "pacífico" não foram ainda encontrados. Junto com os corais há abundante crescimento de algas calcárias.

Dunas. — Dunas são também freqüentes, principalmente na costa norte entre São Luís do Maranhão e Natal e na costa nordeste de Sergipe a Salvador. Existem já alguns estudos sôbre as mesmas, concluindo-se que há várias gerações. As dunas mais antigas possuem uma cobertura de vegetação, enquanto as dunas mais recentes são, na sua maioria, ainda migrantes. A ocorrência é paralela à direção dominante do vento.

Geomorfologia. — As feições morfológicas das costas da zona tropical úmida, apresentam-se mais em formas de acumulação do que em formas de erosão. Os estudos de Tricart baseiam-se nesta conclusão e são plenamente aplicáveis na área estudada.

A erosão é representada pelas falésias de rochas duras e incoerentes, consequência da ação das ondas, do ataque do sal e da ação biológica. Porém, a maioria das falésias é morta.

A acumulação mostra-se nas praias, nos diversos níveis de terraços marinhos e nos mangues, todos muito abundantes na região.

Podiam ser estabelecidos alguns períodos morfogenéticos, saindo do período atual. Os fenômenos são explicáveis principalmente pelo contrôle glácio-eustático, mas há também indícios de atividade tectônica recente. Foram encontrados vestígios de uma acumulação pré-flandriana, seguido por um período de mais erosão. Depois houve a enorme deposição das areias das praias, processo que não continua nos tempos de hoje. Também a formação dos arenitos de praia, alguns dêles datados pelo método C-14, está relacionada com êstes processos. A relação com o nível do mar subindo desde o último período de glaciação ainda não foi bem definida.

Vestígios de épocas anteriores são os terraços marinhos em diversos níveis, bem estudados na ilha de Itamaracá, no Estado de Pernambuco, sendo considerados como representantes de fases dentro da última glaciação (Würm = Wisconsin).

3. Ambiente da plataforma continental

Introdução. — Apenas nos últimos anos aumentou o conhecimento sôbre a topografia e a natureza do fundo, pelas diversas expedições realizadas na área, especialmente pelo N.Oc. "Almirante Saldanha" da Marinha do Brasil.

Topografia. — A idéia que temos da plataforma é mais ou menos em relação à extensão e à profundidade. Em geral, a plataforma é bem larga em frente da foz do Amazonas, diminuindo sua extensão para leste de 150 a 25 milhas. A rutura no norte se encontra aproximadamente a 100 metros, também diminuindo até mais ou menos 80 m. Ao longo da costa oriental a plataforma é estreita numa média de 20 milhas, sendo a parte mais estreita 5 milhas ao sul de Salvador .Sòmente no sul da área estudada a largura da plataforma aumenta novamente, na região de Belmonte e nos Abrolhos.

A plataforma em frente de Recife mostra influência de falhamento, sendo muito irregular. Na foz do São Frncisco existe um canyon. Em frente da plataforma de Ceará e Rio Grande do Norte aparecem ainda alguns bancos de pouca profundidade.

Fácies sedimentares. — Podiam ser distinguidos vários tipos de fácies sedimentares nos depósitos do fundo. A composição granulométrica é menos decisiva tendo em vista a mistura de material de tamanhos diferentes. Existem as seguintes fácies na área estudada:

(1) fácies litorânea,
(2) fácies de lama,
(3) fácies biodetrítica,
(4) fácies de algas,
(5) fácies mixtas.

A fácies litorânea encontra-se na faixa mais próxima da costa, larga na plataforma do Norte e estreita na do Nordeste. A maior parte é constituída de areias quartzosas com poucos fragmentos orgânicos. Em lugares restritos, sòmente mapeáveis com estudos detalhados, encontram-se algumas subfácies, que podem ser de lama, recifal, etc. Os depósitos são sempre misturas de material terrígeno com biodetrítico. A subfácies recifal mostra abundantes fragmentos de algas calcárias e corais.

A fácies de lama cobre na plataforma essas áreas onde se depositam os sedimentos finos trazidos pelos rios Amazonas e São Francisco. O sedimento é síltico-argiloso quase sem fragmentos orgânicos.

A fácies biodetrítica compõe-se de mais de 50-60% de fragmentos de organismos, como são: foraminíferos, briozoários, ostracodes, moluscos, algas calcárias e corais. Geralmente nenhum tipo domina; onde há certa dominância pode-se distinguir uma subfácies.

A fácies de algas foi, por sua enorme extensão, separada da fácies biodetrítica. Nela dominam os fragmentos das algas calcárias *Lithothamnion, Lithophyllum* e *Halimeda,* que podem ser até do tamanho de cascalho. Em alguns lugares dominam as placas de *Halimeda*, como subfácies típica.

Onde dois tipos de fácies mostram misturas em proporções mais ou menos iguais sôbre áreas mapeáveis, essas são consideradas como fácies mixtas. A primeira fácies mixta é aquela de areia quartzosa e material biodetrítico ou de algas; a outra compõe-se de um depósito arenoso de material biodetrítico com blocos de algas.

A idade dos sedimentos é ainda duvidosa. O estudo da fauna não foi concluído, e outros critérios são difìcilmente executáveis. Porém, existem indícios que grande parte do sedimento do fundo pode ser chamado de "relíquia", ou seja de uma certa idade e não recente.

Distribuição das fácies na plataforma. — O mapa em anexo mostra a distribuição geral das fácies na área estudada entre Cabo Orange e Abrolhos; esta área divide-se claramente em quatro trechos distintos:

(1) Cabo Orange até a foz do Amazonas,
(2) foz do Amazonas até o delta do Parnaiba,
(3) delta do Parnaiba até a foz do São Francisco,
(4) foz do São Francisco até Abrolhos.

Os dados oceanográficos mais importantes são mencionados para cada área.

A parte mais setentrional da plataforma brasileira, entre a foz do Amazonas e Cabo Orange, é caracterizada pela abundância de sedimentos argilosos, trazidos pelo rio e transportados para o norte pela corrente oceânica. A argila compõe-se quase que ùnicamente de nontronita. Notável é a ausência de fragmentos orgânicos. Na beira da plataforma aparece ainda uma faixa estreita de sedimentos biodetríticos, nos quais as algas calcárias são ausentes.

A plataforma entre os rios Amazonas e Parnaiba mostra uma extensa zona com areias quartzosas da fácies litorânea. O delta do Parnaíba possui um tipo de areia diferente do comum, sendo assim material de origem fluvial; esta areia ocupa também uma área relativamente vasta na plataforma. Mais para a beira da plataforma a fácies torna-se biodetrítica, com uma larga faixa de fácies mixta. Na zona biodetrítica as algas ainda não dominam, porém ocorrem, às vêzes, com blocos na areia mais fina.

A área entre o delta do Parnaiba e a foz do São Francisco possui como elemento típico a grande extensão da fácies de aigas, muitas vêzes como a subfácies de *Halimeda*. A faixa com areias litorâneas é estreita. Perto do Parnaiba existe ainda alguma mistura, mas para leste a zona é tão estreita que não é mais mapeável. Perto da beira da plataforma que ocorre já a uma profundidade de 70 m, o sedimento torna-se mais biodetrítico. A área em frente do Recife foi estudada pormenorizadamente; podem-se distinguir a fácies litorânea com as subfácies de lama e recifal, a fácies de algas com a subfácies de *Halimeda*, e uma estreita zona de fácies mixta litorânea e de algas. Outra área estudada em maior detalhe encontra-se em frente de Alagoas. São mais características as fácies litorânea e de algas com *Halimeda;* ocorrem alguns pequenos lugares com lama, e ao norte da foz do São Francisco a fácies biodetrítica.

O quarto trecho distinguido, da foz do São Francisco para o sul, mostra fácies quase idênticas àquelas da área mais para o norte. A diferença, porém, é que a área em frente da Bahia é pouco conhecida. Os limites entre as diversas fácies são inferidos. Aqui também, a zona litorânea é estreita e a maior parte é coberta pela fácies de algas. Nos Abrolhos encontra-se a subfácies de corais. A região melhor conhecida é a foz do São Francisco e a plataforma de Sergipe. A lama do rio influi a zona para sul, assim que as algas são pouco abundantes aí. A maior parte da lama, porém, é transportada numa corrente de turbidez constante no canyon do rio para profundidade maiores.

Sôbre a subsuperfície da plataforma, os dados são ainda escassos. Atualmente são efetuados estudos geofísicos com principal objetivo a ocorrência de petróleo, em frente das faixas sedimentares no continente.

Talude continental. — Foram coletadas poucas amostras do talude. Os seus lugares e tipos de sedimento são marcados numa figura. Os depósitos são muito variados, possuindo certa relação com a fácies da plataforma adjacente.

4. Ilhas oceânicas e bancos fora da plataforma

Introdução. — As diversas operações dos navios oceanográficos também visitaram os bancos de pouca profundidade que se encontram em frente da plataforma do Ceará e do Rio Grande do Norte, as ilhas oceânicas de Rocas e Fernando de Noronha e os penedos de São Pedro e São Paulo. Onde existiram possibilidades, foram coletadas amostras das diversas plataformas.

Fernando de Noronha. — Almeida (1958) fêz um estudo geológico completo dêsse arquipélago, incluindo também os sedimentos mais recentes. A base da ilha é de origem vulcânica; os sedimentos são poucos, de origem litorânea, eólica e marinha.

Os sedimentos antigos são marinhos e litorâneos. O chamado arenito Caracas parece ser um eolianito. Os calcários marinhos ocorrem numa área restrita. Além disso, existem ainda conglomerados de terraços marinhos.

Os depósitos recentes são, em primeiro lugar, as areias de praia quase totalmente compostas de minerais vulcânicos. Há também dunas ativas acumuladas dessas areias. No pé de alguns taludes existem detritos. Os recifes são compostos de algas calcárias e vermetes; êles existem no lado sudeste, onde as ondas são mais fortes. Guano encontra-se acumulado em certos lugares da ilha Rata.

A plataforma possui um fundo de sedimentos compostos de fragmentos de algas, igual à fácies de algas da plataforma continental. Perto da beira da plataforma da ilha também a fácies muda para a biodetrítica.

Rocas. — O chamado "atol" das Rocas é uma ilha de forma redonda, composta na sua maior parte de algas calcárias e não de corais. Os depósitos são arenosos, quase ùnicamente de fragmentos dessas algas. Podem ser distinguidos vestígios de oscilações do nível do mar, pelo menos um nível de 2 m acima do atual e outro de 5 m abaixo dêle. Existe também um estudo da microfauna dos foraminíferos, mostrando a associação comum da região.

São Pedro e São Paulo — Os penedos são de difícil acesso, por isso existem ainda poucos estudos. Recentemente foram visitados pela equipe de "Woods Hole Oceanographic Institution". Os penedos são tôpos do Dorsal Atlântico Central, compostos de rochas ultrabásicas. A plataforma não mostra sedimentos, existindo lá um "fundo duro". Há, porém, sedimentos consolidados nas ilhas, especialmente fosfáticos, devido à abundância da fauna ornitológica.

Bancos fora da plataforma. — Trata-se de elevações pouco profundas, cuja base é desconhecida. O sedimento pertence geralmente à fácies de algas, mudando na beira em biodetrítica.

5. Fauna no sedimento

Neste capítulo foram apresentadas listas de alguns grupos faunísticos, encontrados no sedimento, segundo as publicações sôbre o assunto. Assim existem as espécies determinadas e seus lugares de ocorrência dos seguintes grupos: foraminíferos, briozoários, equinodermas, moluscos e corais. Interpretações sôbre as respectivas faunas podiam ser dadas dos foraminíferos e dos corais.

As associações de foraminíferos, tanto nas praias, quanto na plataforma, provam que a totalidade da área se encontra na província zoogeográfica das Índias Ocidentais ou Caribeana. As espécies são as típicas das latitudes baixas. Há indícios da existência de uma subprovíncia possível no norte e nordeste do Brasil, caracterizada pela presença do foraminífero *Amphistegina radiata* forma *tumida*.

Os corais ocorrem freqüentemente em duas zonas. A zona setentrional entre o Cabo São Roque e a foz do rio São Francisco fossui formações coralígenas especialmente sôbre recifes de arenito. A espécie *Mussismilia hartii* é um importante construtor nesta área. A zona meridional estende-se entre Bahia e Abrolhos, constituindo a foz do São Francisco uma barreira por causa dos seus sedimentos em suspensão. Uma espécie-índice é *Mussismilia hispida,* cuja subespécie *hispida* aparece apenas na área sul e a subespécie *tenuisepta* apenas na área norte.

Foi determinada também a bionomia bentônica dos diversos fundos encontrados na plataforma. Cada substrato possui sua própria associação faunística. Alguns fundos mostram-se bastante pobres, enquanto o fundo de algas calcárias é rico em espécies. Esta última fácies pode ser subdividida em duas subfácies, infra-litoral e circa-litoral, das quais a última parece ter um sedimento relíquia.

6. Calcários e arenitos recentes

Introdução. — Foram encontrados em muitos lugares da costa acumulações de rochas calcárias, como também em alguns lugares da plataforma, calcários e arenitos recentes. O estudo dessas rochas está sendo feito, apresentando-se apenas alguns resultados preliminares.

Ambiente litorâneo. — Acumulam-se nas praias, principalmente no inverno, muitos fragmentos de rochas calcárias orgânicas, compostas de algas e vermetes. Às vêzes, são encontrados fragmentos de coral e de lumachela, além de arenitos de praia.

O estudo petrográfico dêsses calcários mostrou as estruturas típicas dos seus componentes (algas: *Porolithon, Goniolithon, Halimeda,* e vermetes). Já são notáveis alguns fenômenos de diagênese. Os fragmentos são provenientes dos recifes, dos quais formam erodidos e transportados para a praia.

Ambiente da plataforma. — Neste ambiente os calcários são acumulações cimentadas da fácies biodetrítica ou de algas. Os calcários de algas mostram as estruturas comuns, com certas transformações em massas micríticas. Os calcários biodetríticos são verdadeiros biomicritos, acumulações dos mais diversos organismos com um cimento incipiente de micrito. Onde domina a fácies arenosa litorânea e existe também uma certa quantidade de material calcário, formam-se em alguns lugares arenitos calcários. O cimento parece ser calcita recristalizada.

Origem. — A origem ainda não é bem esclarecida. Também é possível que as formações não são muito recentes. O ambiente é favorável para a cimentação de sedimentos incoerenets na área estudada. As temperaturas altas e a supersaturação de matéria carbonática causam fàcilmente precipitações de aragonita e calcita nos interstícios dos depósitos biodetríticos e quartzosos, consolidando-os.

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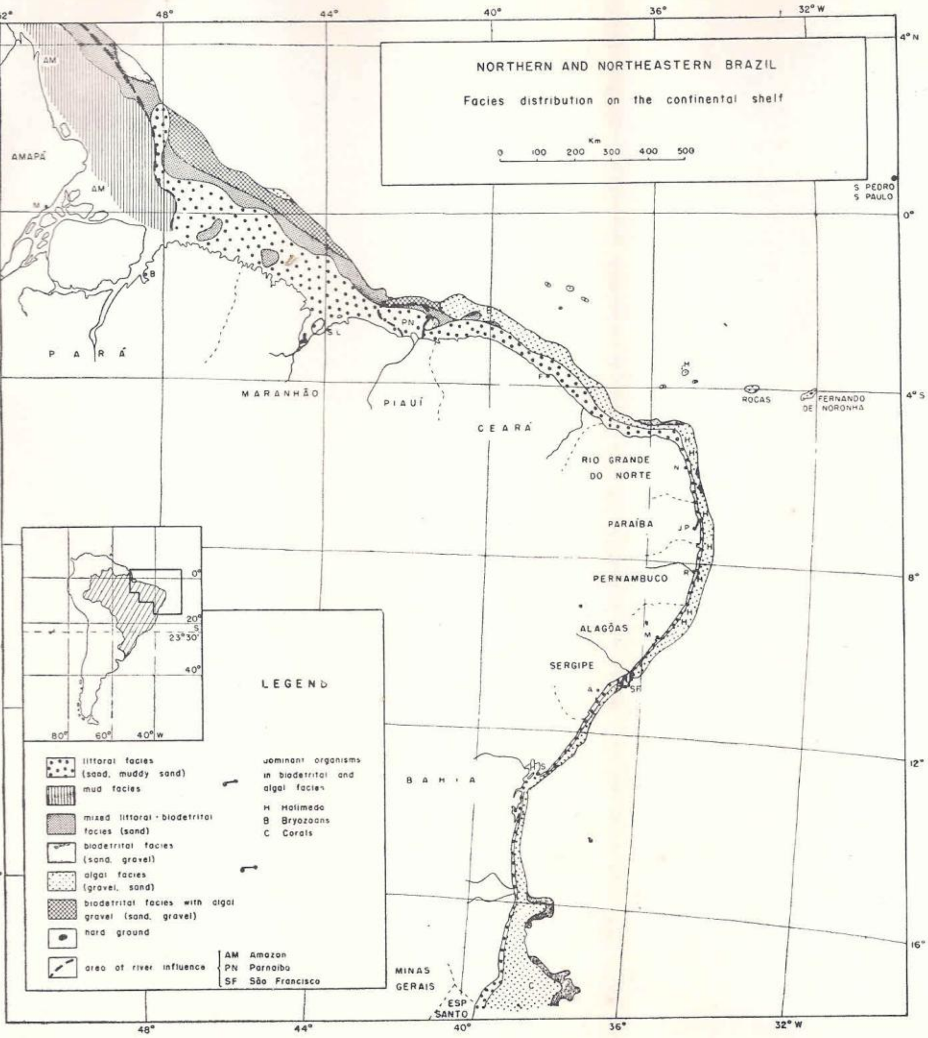
NORTHERN AND NORTHEASTERN BRAZIL
Facies distribution on the continental shelf
Km
0 100 200 300 400 500
52°
48°
44°
40°
36°
32° W
4° N
0°
4° S
8°
12°
16°
AMAPÁ
AM
P A R Á
MARANHÃO
PIAUÍ
CEARÁ
RIO GRANDE DO NORTE
PARAÍBA
PERNAMBUCO
ALAGÔAS
SERGIPE
B A H I A
MINAS GERAIS
ESP SANTO
S. PEDRO S. PAULO
ROCAS
FERNANDO DE NORONHA
PN
SL
SF
LEGEND
littoral facies (sand, muddy sand)
mud facies
mixed littoral - biodetrital facies (sand)
biodetrital facies (sand, gravel)
algal facies (gravel, sand)
biodetrital facies with algal gravel (sand, gravel)
hard ground
area of river influence
AM Amazon
PN Parnaíba
SF São Francisco
dominant organisms in biodetrital and algal facies
H Halimeda
B Bryozoans
C Corals
80°
60°
40° W
20°
23°30'
40°