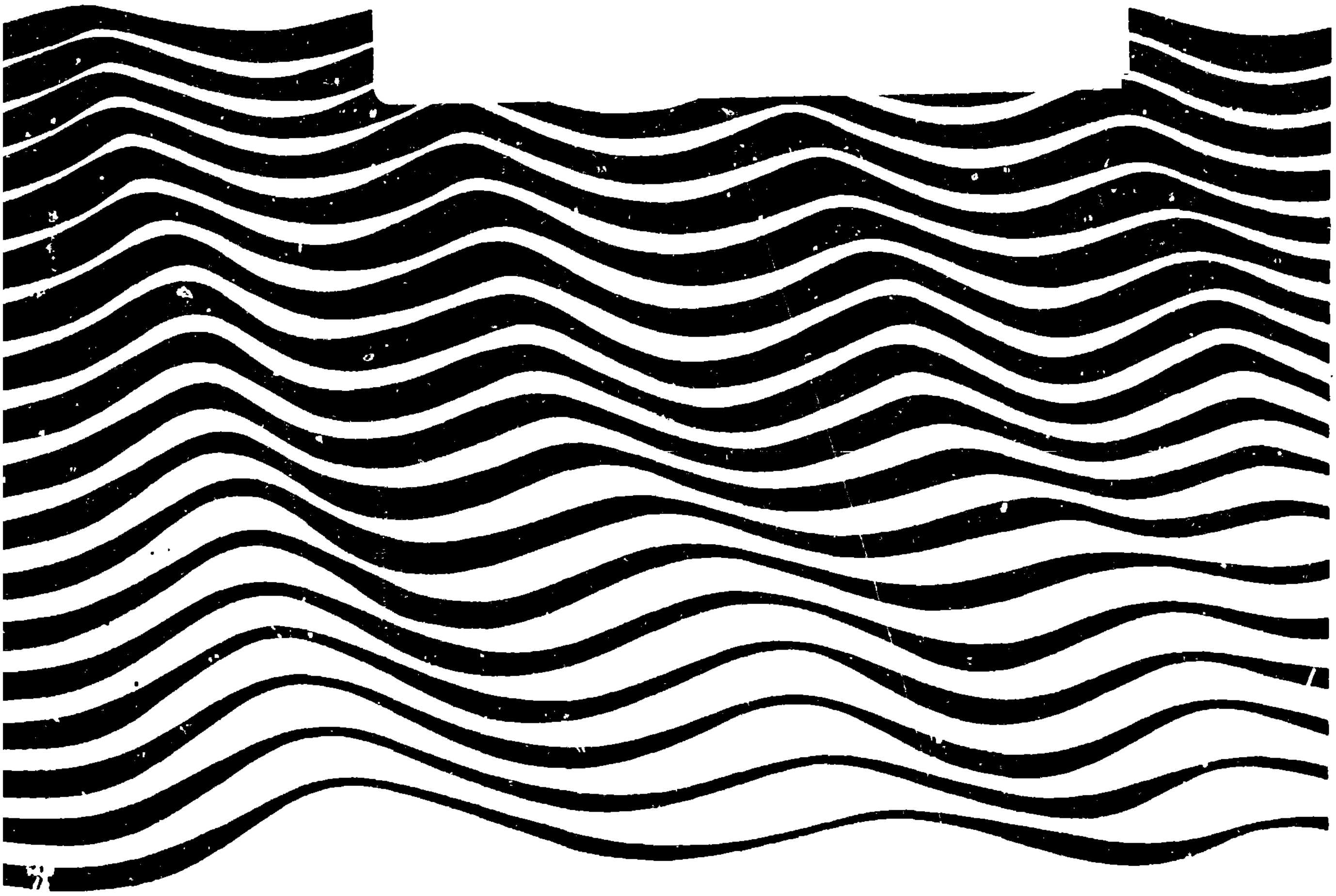
Unesco reports in marine science 43

Quaternary coastal geology of West Africa and South America

Papers prepared for the INQUA-ASEQUA Symposium in Dakar, April 1986



Unesco, 1987

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PREFACE

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ABSTRACT

The present report, consisting of three chapters, is devoted to the evolution of the Atlantic coastal zones of Africa and South America in the Quaternary.

In Africa, long-term (epirogenic), medium-term (combination of previous and climatic) and short-term (climatic and oceanographic) changes have been studied and their influence on coastal development is described herein.

In South America, it is shown that the principal factors in coastal zone evolution have been sea-level fluctuations, availability of sandy sediments, wave and long-shore current dynamics and coastal features propitiating entrapment of sediments. In the central part of the Brazilian coastline, three high sea-levels have been identified in the Quaternary.

RESUME

Le présent rapport, qui se compose de trois chapitres, est consacré à l'évolution des zones du littoral Atlantique de l'Afrique et de l'Amérique du Sud au quaternaire.

Pour l'Afrique, il porte sur l'étude des transformations à long terme (épirogéniques), à moyen terme (à la fois épirogéniques et climatiques) et à court terme (climatiques et océanographiques) et donne une description de leur incidence sur l'évolution du littoral.

Pour l'Amérique du Sud, il montre que les principaux facteurs de l'évolution des zones côtières sont les fluctuations du niveau de la mer, la présence de sédiments sableux, la dynamique des vagues et des courants côtiers, et les caractéristiques du littoral qui favorisent le piégeage des sédiments. Concernant la partie centrale du littoral brésilien, il met en évidence trois pics atteints au quaternaire par le niveau de la mer.

RESUMEN

Este informe, que consta de tres capítulos, se refiere a la evolución de las zonas de la costa Atlántica de Africa y de Sudamérica en el Cuaternario.

En lo que atañe al Africa, se han estudiado los cambios a largo plazo (epirogénicos), a medio plazo (combinación del anterior y climáticos) y a corto plazo (climáticos y oceanográficos), discutiéndose su influencia sobre la evolución de las costas.

En cuanto a Sudamérica, se demuestra que los principales factores en la evolución de la zona costera han sido las fluctuaciones del nivel del mar, la presencia de sedimentos arenosos, la dinámica de las olas y de la corriente litoral y los accidentes costeros que favorecen el depósito de sedimentos. En la parte central de la costa del Brasil se han determinado tres niveles de alta mar en el Cuaternario.

РЕЗЮМЕ

Данный доклад, состоящий из трех глав, посвящен вопросам эволюции прибрежных атлантических зон Африки и Южной Америки в четвертичный период.

В нем исследуются долгосрочные (эпирогенические), среднесрочные (сочетание предыдущих и климатических) и краткосрочные (климатические и океанографические) изменения в Африке и излагается их воздействие на динамику побережья.

Показывается, что в Южной Америке основными факторами эволюции береговой зоны являются колебания уровня моря, наличие песчаных наносов, динамика волн и воздействие крупных течений и специфика побережья, способствующая отложению наносов. В центральной части береговой линии Бразилии выявлены три уровня повышения уровня моря, имевших место в четвертичном периоде.

ملخص

يتألف هذا التقرير من ثلاثة فصول ، وهو يبحث على وجه التحديد تطور المنطقتين الساحليتين من افريقيا وأمريكا الجنوبية المطلتين على المحيط الأطلسي في العصر الجيولوجي الرابع .

فبالنسبة لأفريقيا ، درست التغيرات طويلة الأجل (التمعجية) ومتوسط الأجل (التمعجية والمناخية في وقت واحد) وقصيرة الأجل (المناخية والمحيطية) ، ويرد في هذا التقرير وصف لتأثير هذه التغيرات على تطور المنطقة الساحلية .

وبالنسبة لأمريكا الجنوبية ، يبين التقرير أن العوامل الرئيسية في تطور المنطقة الساحلية تتمثل في التقلبات الطارئة على قاع البحر ، ووجود رواسب رملية ، وفي دينامية الأمواج والتيارات الساحلية ، وفي التضاريس الساحلية التي تيسر احتجاز الرواسب . وتم تحديد ثلاثة مستويات عالية لقاع البحر في الساحل البرازيلي في العصر الجيولوجي الرابع .

摘　　要

本报告包括有三章，专门研究第四纪非洲和南美洲大西洋海岸带的演变。

在非洲，研究了长期（造陆）变化，中期（综合上述和气候）变化及短期（气候和海洋）变化。其中也说明了这些变化对海岸发展所造成的影响。

在南美洲，情况表明海岸地带演变的主要因素是海平面的升降起伏，砂质沉积物的存在，波流和沿岸流的动态以及促成沉积物截留的海岸地形。在巴西海岸线的中段，已经确定认清了有三道第四纪高位海平面。

TABLE OF CONTENTS

EVOLUTION OF THE ATLANTIC COASTAL ZONE OF AFRICA IN THE QUATERNARY

J. Paul Barusseau and Pierre Giresse
University of Perpignan, Perpignan, France

Introduction

The subject of this article is limited to the coastal zone of West and Central Africa in the Quaternary.

Regarding geographical coverage, we decided, following in this respect the limits assigned to the WACAF programme (an acronym for West and Central Africa, WACAF is the name of the environmental action plan adopted by the UN for this region), to take into consideration the coastline of Atlantic Africa between the North and South boundaries of Mauritania and Angola, while claiming the freedom to go beyond these limits, whenever necessary for better understanding or better grounding of the discussion.

Similarly, we did not want to restrict the definition of coastal zone to its narrowest meaning. It is necessary to pay attention not only to the coast itself, but in fact to the entire set of Quaternary shorelines. Their eustatic succession provides a sequence of indicators from the edge of the continental shelf, or from the top of the slope, all the way to upraised marine terraces found in certain coastal basins.

Regarding time, it is often difficult to establish the real position of the official lower limit of Quaternary areas, for lack of radiometric dating. We therefore limited ourselves to geological formations characterised by their sedimentological, palaeobotanical or biological content, and associated with relief shaped by marine action.

The outline of the article is as follows:

1. Geology of continental margins

2. Coastal deposits and shorelines

   - Ocean level variations

   - Environments and deposits.

The evolution of margins is under the control of highly interactive geological and climatic factors. In this respect, the shape of the margin, its geodynamics, and the type and quantity of deposits reflect the contribution of geological factors to margin structuring; it is this initial aspect that we present in the first part.

We shall try to bring out all the historical geological factors that have influenced the rheological and tectonic behaviour of African margins during the Quaternary, as well as those that modified margin physionomy, in particular through the deposition of new material.

Part I: GEOLOGY OF THE CONTINENTAL MARGINS OF WEST AND CENTRAL AFRICA

The margins of the West coast of Africa are structurally dependent on events belonging to three episodes, with the following chronological development:

1) Formation of Precambrian basements;

2) Thermotectonic genesis of the Pan-African, Caledonian and Hercynian zone, and constitution of Palaeozoic basins;

3) Formation of the Atlantic Ocean.

Among these events of unequal importance, the last, albeit the least extensive in time, has left the greatest mark. It could be said that the morphology and the history of West and Central African margins are determined by the mode of continental disjunction (shearing or spreading) that then occurred, and by the processes following this separation and more or less related to it: changes in the geometry and migration of plates, sea level variations, definition of weak and resistant zones, and of lines of slumping and uplifting.

Consequently, in the sequel we dwell essentially on specifying the nature and the chronology of the last episode, taking everything related to older events as given and indisputable data; even if it is obvious that some of the main thrusts (this will be pointed out as appropriate) have a permanence that reaches beyond the temporal limitations of the Atlantic cycle.

The approach involves considering first the structuring of the margins, that is, everything contributing to their general organisation, and then moving on to an inventory of their geodynamic tendencies in the Quaternary, as a heritage of their evolution.

1. STRUCTURING OF WEST AFRICAN MARGINS

1.1. THE OPENING OF THE ATLANTIC OCEAN

Chronology

The first signs of the fragmentation of Pangea appeared very early, at the beginning of the Mesozoic, but the separation between Africa and America took place over several periods, which justifies viewing the African continent as a collection of several "micro-plates", whose pre-drift contours differ substantially from the present borders.

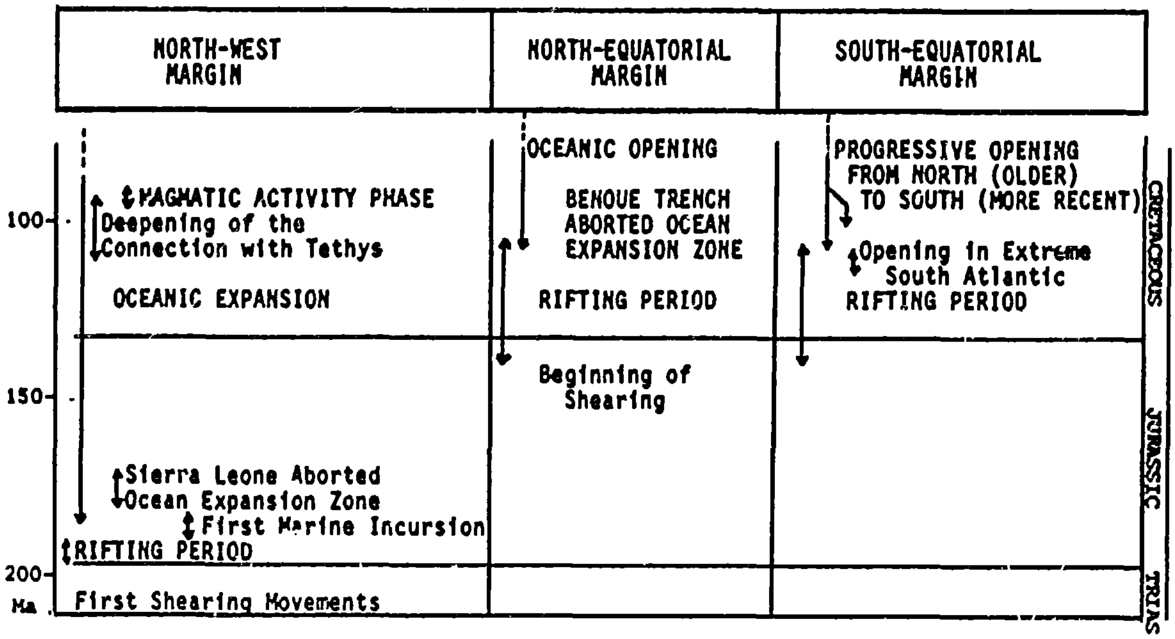


Table I: MAIN PHASES OF THE AFRICA-AMERICA SEPARATION

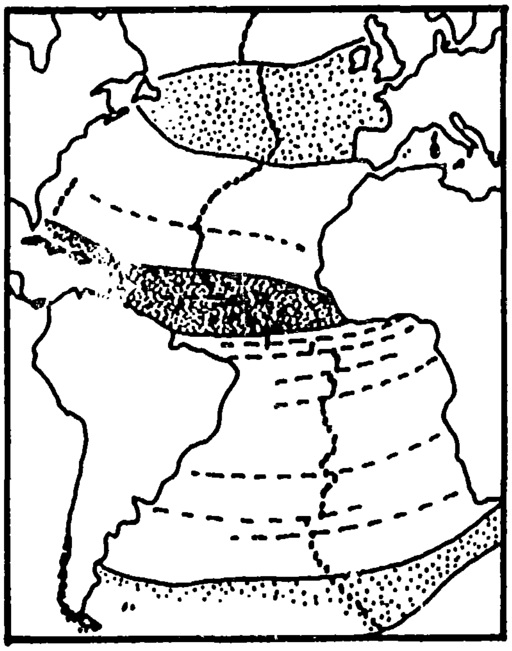


Fig. 2 - THE TWO TYPES OF AFRICAN ATLANTIC MARGINS

Spreading margins are shown by thick dashes, and translation margins or parts of margins by continuous solid lines.

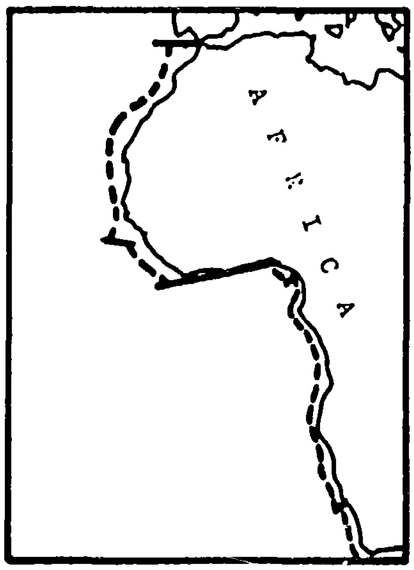


Fig. 1 - POSITION OF THE TRANSITION AREA CORRESPONDING TO THE SIERRA LEONE-LIBERIA MARGIN

The unshaded zones correspond to oceanic areas with parallel fracture zones. In the central "intermediate corner" (heavy shading), the 15°-20° (to the N) and St. Paul (to the S) fracture zones converge towards the Sierra Leone-Liberia margin. Only some of the fracture zones are shown.

The separation movements are oldest in the North-West (see Table I). Evaporites are formed right to the Senegal Basin in a series of narrow channels, without it being known for certain whether these arms of the sea come from the North or from the Tethys. The oldest section of the Atlantic Ocean floor between Africa and North America was formed in the Aalenian about 180 Ma, with the opening continuing with rate irregularities, such as the one associated, in the Cenomanian, with deepening of the connection with the Tethys.

The southern part of this region, at the level of Sierra Leone and Liberia, underwent a slightly different evolution (aborted ocean expansion zone, Cenomanian magmatic activity), reflecting the specificity of an area which, lying between the major fractures of Barracuda-15°/20° to the North and St. Paul to the South, constitutes a transition zone between oceanic openings of different ages (Figure 1).

In the northern equatorial region, continental separation is dominated by a transformal movement along fracture zones, which generates basins parallel to the faults. Opening is not in evidence until the Aptian, about 110 Ma B.P. In the basins of Côte d'Ivoire and Benin, the first marine strata, which are Albian and Cenomanian, overlie truncated strata of the Lower Cretaceous. At the extreme end of the north-equatorial section, one finds yet another specific area, also with an ocean expansion zone which seems aborted (although this point is debated), and a volcanic axis (that of Cameroon) appearing as soon as separation between Africa and South America sets in.

In the South Atlantic the phenomena are not synchronous. An oceanic area appears to the extreme South of Africa as of 119 Ma B.P., but its northward progression seems to be interrupted, while at the same time the resulting stresses are resolved by events connected with the Central Atlantic opening. Thus the southern Atlantic Ocean ultimately opens from North to South, with a rifting phase extending over 40 Ma to the North (Gabon, Congo-Cabinda-Zaire) and only 10 to 20 Ma to the South (Cuanza, Moçâmedes), while crevasse formation, starting at about 105 Ma to the North, ends roughly 95 Ma B.P.

The different types of resulting margins

As a result of oceanic opening, two basic types of margins are to be found along the Atlantic coast of Africa:

- divergent margins in North-West and South-Central Africa,
- a translation margin in equatorial Africa (Fig. 2).

There are still some doubts regarding a few restricted sectors:

- to the South of Cape Verde,
- off the coast of Guinée-Sierra Leone,
- off the coast of Angola at about 12° S, where the temporary functioning of aborted ocean expansion zones complicates the issue a bit.

The two divergent margins have evolved according to slightly different models. To the South, the Gabon-Angola margin was formed by a process of disjunction by listric faults, which delineate massifs tipped by some 20 to 30°, with throws over several kilometres.

These curved tilting faults extend right to the base of the brittle crust by thinning of the ductile crust. To the North, in addition to this type of genesis, the margin of North-West Africa exhibits the formation, where the continental and oceanic crusts meet, of an intrusion of basic and ultrabasic rocks.

In both cases, the shearing resulting from the separation of continental massifs was affected by pre-existing structural lines, which transversally interrupted the continuity of major geostructural units. Basins were formed in recessions, while the deposit centres were narrower off the coast of protrusions.

The Gulf of Guinée translation margin is very different. In this region we find virtually pure translations, although some questions remain to be answered in this respect. This type of genesis results in steep continental slopes and greater separation of basins, while friction, in triggering substantial heat flows, modifies the types of sedimentation and engenders plutonic rises in the hinterland (Younger Granites of Nigeria and Niger up to the beginning of the Tertiary).

1.2. GEOSTRUCTURAL ASPECTS

The structure of West and Central African margins is under the control of tectonic and sedimentary factors, which result in a succession, along the present coastal zone, of geostructural units characterised by alternation of basins, with varying dimensions and where most deposits are located, and of basement elements, faintly outlined by limited sedimentary accumulations.

The factors determining structure

Tectonic and crust movement factors

Basins are often separated by basement ridges, or elevations inherited from the geological evolution preceding the splitting of Gondwanaland, and consisting of Precambrian, Pan-African or Palaeozoic material. This is true, for instance, of the Palaeozoic Anti-Atlas to the North of the Tarfaya-EL Aaiun Basin (Figure 3), of the Reguibat High between this basin and the Senegal-Mauritania Basin, of the North end of Gabon Basin, marked at about 1° N by a high N-S axis, and of Lunda Ridge between the basins of Cuanza and Moçâmedes. Sometimes basins are subdivided longitudinally by basement ridges, for example the Gabon Basin by the Gamba-Ikassa-Lambarene horst alignment.

In the intermediate equatorial region, basins are separated by ridges marking out fracture zones. They correspond closely to ridges of the South American margin. Respectively, these are the ridges of Liberia (Anapa), Côte d'Ivoire (Ceara) and Fernando Poo-Cameroon (Nore--Pernambuco). These ridges acted as sedimentation dams by obstructing sedimentary transport. They run either along the continental slope, as off the coast of Côte d'Ivoire, or cut across it more obliquely, echoed by structures further inland. The Bénoué Trench is very explicit in this respect, since its edges run along Chain Fracture Zone, extended on land by Okitiputa Ridge (Figure 4), and along Charcot Fracture Zone, outlined by Abakaliki Anticline below the Niger Delta and beyond.

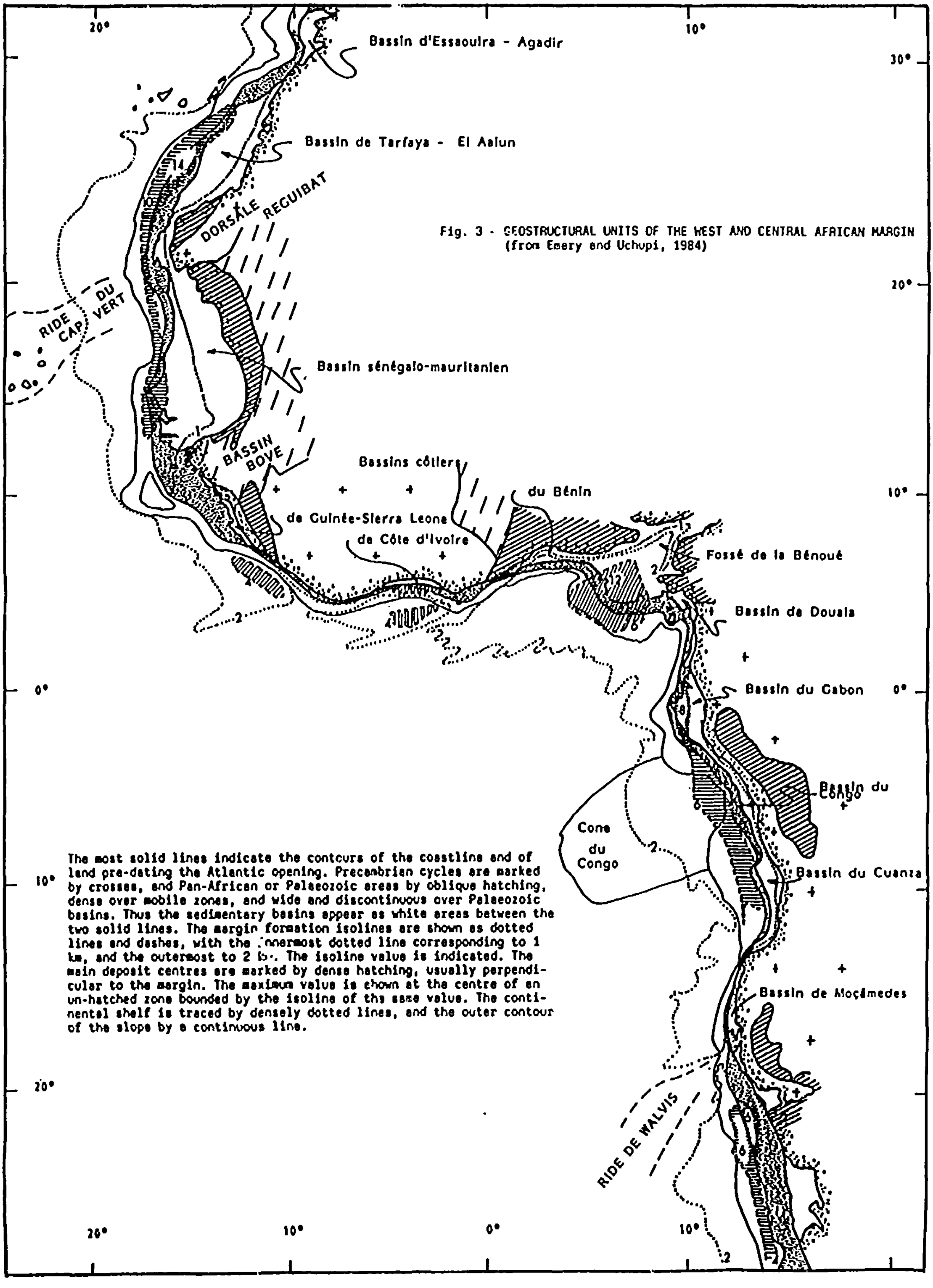


Fig. 3 - GEOSTRUCTURAL UNITS OF THE WEST AND CENTRAL AFRICAN MARGIN (from Emery and Uchupi, 1984)

The most solid lines indicate the contours of the coastline and of land pre-dating the Atlantic opening. Precambrian cycles are marked by crosses, and Pan-African or Palaeozoic areas by oblique hatching, dense over mobile zones, and wide and discontinuous over Palaeozoic basins. Thus the sedimentary basins appear as white areas between the two solid lines. The margin formation isolines are shown as dotted lines and dashes, with the innermost dotted line corresponding to 1 km, and the outermost to 2 km. The isoline value is indicated. The main deposit centres are marked by dense hatching, usually perpendicular to the margin. The maximum value is shown at the centre of an un-hatched zone bounded by the isoline of the same value. The continental shelf is traced by densely dotted lines, and the outer contour of the slope by a continuous line.

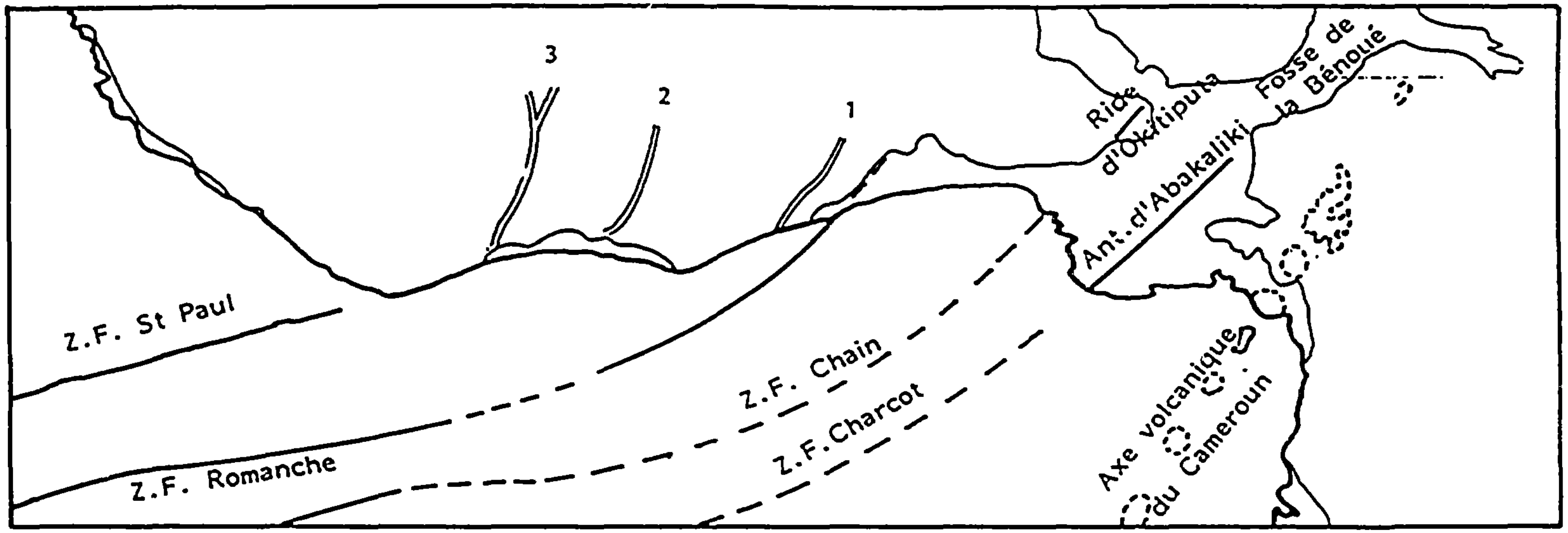
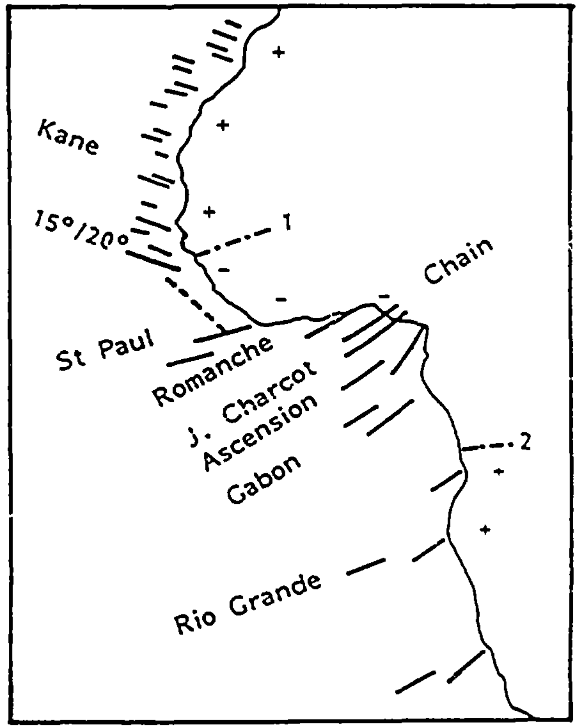


Fig. 4 - TRANSLATION MARGIN IN THE GULF OF NIGER

1 - Akwapim Fault
2 - Alépé-Bondoukou Fault
3 - Dimbokro Fault
F.Z. - Fracture Zone
F.P. - Fernando Poo

Fig. 5 - VERTICAL MOVEMENTS OF THE ATLANTIC MARGIN OF AFRICA

The lines off the coast represent the main fracture zones. The - signs indicate subsidence or slumping, while the + signs indicate a tendency for land to rise. The dashed lines 1 and 2 mark off the three sectors of the Atlantic margin of Africa.



A special role is played by the volcanic axis of Cameroon, which is also an extension of another fracture zone, that of Ascension. The volcanic islands marking it out are recent (Fernando Poo: 1.1 Ma; Principe: Oligocene; São Tome: 0.1 to 15.7 Ma; Annobon: Miocene).

A third structuring factor is that of reactivation of old lines of weakness in different ages. To the North, there is the encounter of the mobile Atlas zone and the margin; in the centre, below Niger, the junction of the oceanic and continental crusts is unstable because of an excessive sedimentary load. Along the same line of thought, several tectonic stages play a noteworthy part in the geological evolution of the North-West margin. A major stage of the Upper Cretaceous is highlighted, in the Senegal Basin, by the formation of faulted anticlines and the appearance of voluminous magmatic intrusions, which generate circular gravimetric anomalies. It is also in the Santonian that a powerful compression stage determines the Abakaliki Anticline, while further South monoclinal undulations are observed in the coastal basins of Congo and Gabon. Tectonic activity is even more pronounced in the Tertiary, when the effects of Alpine orogenesis are felt right down to the latitude of Dakar with two main periods: the Pyrenean stage (Upper Eocene) with consequences, for instance, in Essaouira-Agadir Basin, and the Alpine stage, in the Upper Oligocene, the Miocene and the Plio-Quaternary in Tarfaya-El Aaiun Basin, with positive movements of the Anti-Atlas and Reguibat High. Further South, Tertiary to Recent throws are observed for the major faults (such as the Akwapim Fault Zone) of the Gulf of Niger periphery.

Finally, many areas are the site of active subsidence, which is particularly intensive in basins. The example of the Congo-Cabinda--Zaire Basin shows that such subsidence accompanies the long stage of rift formation, initially in a continental environment in the Jurassic, becoming lacustrine in the Upper Jurassic, and then briny (Aptian evaporites). Subsidence continues in a marine environment during the drifting stage, from the Albian right to the Campanian; it is particularly evident at this time, stopping at the end of the Cretaceous. In the equatorial sector, it starts and continues in the Cenozoic; thus the South-West of Bénoué Trench is the site of massive progradation of the Niger Delta.

Sedimentary factors and their consequences

Usually they are just the result of new conditions laid down by tectonic evolution, but they in turn have consequences that cannot fail to influence the appearance of margins.

Evaporitic series (with the associated saline tectonics) lead to the development of often extensive diapir fields, in which halokinesis causes deformation of structures. To the North of the region under study, there is the vast field of Morocco, perhaps resulting from two evaporitic stages: a debatable one in the Upper Triassic and another in the Aalenian. It extends over more than one thousand kilometres. To the North-West of Tarfaya Basin, it is located under the continental slope over a width of some fifty kilometres. The Senegal-Guinée field, which seems to be Middle Jurassic, is more modest; measuring 300 km by 50 to 100 km, it affects the shelf and the top of the slope. A vast field is to be found between Gabon and Cuanza Basins, between 1° N and 13° S, over a width of 100 to 250 km; the salt there is Lower Cretaceous to Aptian and can be found under the entire shelf and slope top.

The re-organisation of drainage is also a significant morphological and structural factor, especially with respect to the deposits of a river like the Congo. The age at which this land-locked basin started to deliver water to the Atlantic is an open question, not yet sufficiently well studied to be resolved. In any event, this transition is certainly very recent, perhaps just Upper Quaternary, and the fact that the Congo's alluvium ends up in the Atlantic must be viewed as a major phenomenon in that ocean's recent evolution.

A third and final sedimentary factor contributing to structure consists of major deltaic accumulations. The Niger Delta is the prime example with an accumulation started by a first sedimentation cycle in the Turonian-Coniacian. Subsequently the deposit centres were shifted as a result of tectonic events. Two deltaic complexes functioned in the Oligocene and the Lower Miocene, separated by Abakaliki Anticline, which was reactivated several times after the Santonian stage. Their joining at the end of the Lower Miocene widened the deltaic front, but greater subsidence to the West slowed down its progression with respect to the Eastern lobe. The resulting thick sedimentary accumulation is subjected to argillitic diapirism, and to load-induced overthrust of the foot of the deltaic shelf. In the case of the Congo River, the presence of a deep canyon, cutting across the diapir field, results in most sedimentary material being delivered directly to the bottom of the continental shelf.

The North-South succession of geostructural units

Processes related to the opening and subsequent geodynamic factors have determined the succession of different geostructural units composing the margin. Figure 3 shows their locations.

As shown, the margins are of unequal range, and the sum of the two constituting supersequences, namely rifting and drifting, is seen to have variable thickness. The widest and thickest is to the North-West, where the continental separation is the oldest. The narrowest corresponds to the translation margin of the Gulf of Guinée. The deposit centres usually appear off the edges of basins, sometimes encroaching onto presently emerged land, but extending in particular under the external plateau and the top of the continental slope.

The following table summarises which of the above factors has affected each section of the margin:

	BASEMENT RIDGES	FRACTURE ZONES	TECTONIC ACTIVITY	SUBSI-DENCE	SALINE TECTONICS	DRAINAGE CHANGES	MAJOR DELTAIC ACCUMULATION
INACTIVE MARGIN OF NW AFRICA	X		X	X	X		
TRANSLATION MARGIN		X	X	X			X
CENTRAL ATLANTIC INACTIVE MARGIN	X			X	X	X	X

2. GEODYNAMICS OF AFRICAN ATLANTIC MARGINS IN THE QUATERNARY

At this stage of the presentation, it is necessary to bring together the major facts, in order to try to estimate, independently of purely glacio-eustatic factors, the quantitative and directional impact of geological processes that shaped the margin during the Quaternary, by comparing them with indicators of tectonic activity and vertical land movements.

The subsidence of some sectors (in particular in the coastal area of Guinée) is attested to in the Quaternary by the settling and submersion of lateritic shells; throughout this region and to the South of Bové Basin, the Quaternary is pelliculer and limited in range. There is also subsidence in the hollow of the Gulf of Niger, but with a different effect, because sedimentary inflow allows for delta progradation. However, quantitative indicators are not sufficient for an evaluation of the relative settling of different coastal sectors. It is certain that the rate of subsidence varies not only transversally, but also along the margin, as shown by deformed shorelines, a point we shall come back to.

Tectonic activity is an inherent part of Cenozoic phenomena. In the North, the end of the Alpine cycle determines the uplifts that lead to the formation of raised beaches in Essaouira-Agadir Basin. Tectonic activity is also expressed by seismicity, with the Koumbia event in Guinée in December of 1983 as an example. These phenomena are interpreted as the re-activation of older structures, some of which are land-based extensions of oceanic fracture zones, while others correspond to old accidents or to fundamental structural lines (lineaments) of Africa. Examples are the Akwapim Fault near Accra, the Kandi Fault of Bénin, several elements in Côte d'Ivoire (Alépé-Bondoukou Fault, Dimbokro Fault, etc.), and NNW-SSE and NE-SW strike slip faults to the West of Bové Basin. Moreover, faults parallel to the coast determine slumping of the margin. For instance, the Ghana Fault has been active since the end of the Jurassic at an average rate of 35.7 m per Ma. Identical manifestations are observed off the coast of Abidjan, and the earthquakes of Turner Peninsula in Sierra Leone are also caused by tectonic settling of the offshore coastal zone.

Finally, the Atlantic African margin turns out to be highly compartmentalised by the heritage of its own geological history. In the Quaternary, interactions of these phenomena lead to distinguishing among three areas, each characterised by positive or negative vertical land movement (Fig. 5). In the North-West, down to Senegal Basin, whose southern part (Casamance) constitutes a natural limit, the coastal zone is tending to rise. The intermediate sector of the Gulf of Guinée is stable or subsiding slightly, whereas to the South of Cabinda one again finds positive vertical movement, which increases as one moves southward, with a rate to 10-15 cm per century in the Lobito-Benguela--Moçâmedes region.

Part II: QUATERNARY COASTAL DEPOSITS AND SHORELINES ALONG THE ATLANTIC MARGIN OF AFRICA

The map of Quaternary shorelines, published in 1981, shows that there are, on the West African coast, emerged indicators attributed to the Final Holocene (2,500-6,000 years B.P.) and Eemian (about 120,000 years B.P.).

In fact, the information now provided by this map is of questionable interest in some cases. Nevertheless, a number of sectors, in Mauritania, Senegal, Côte d'Ivoire, Bénin, Nigeria, Gabon and Angola, have been sufficiently thoroughly analysed to permit the plotting of regional curves of relative ocean level variations in the course of the Holocene. In this case, observations of neighbouring hinterland environments, or continuous recordings of off-shore under-water sedimentation often provide the additional information needed to define regional factors.

On the other hand, the significance of many Pleistocene terraces, attributed to the influence of sea action, is now being questioned. Sometimes individual surfaces, presumed to have marine origins, are the result of one or several continental morphogenetic factors, controlled by reactivation of old Precambrian lineaments; at other times the marine materials are the result of human activity, or of colluvial re-working of older material, which may be Pliocene.

Under these conditions, studying the Quaternary phenomena of the coastal zone of Atlantic Africa involves making a long-term effort aimed, for example through the PICG 200, at identifying indicators of sea level variation, and at quantifying the processes of this evolution. At a time when the concept of a global sea level has been rejected, it has become necessary to draw up a body of knowledge that could help to define a systematic study project to meet these objectives.

In the sequel, we shall present a table of ocean level variation, and then a review of coastal environments and deposits, successively taking into consideration the Pleistocene, the Holocene and the Recent, an interval defined arbitrarily as a time scale covering those phenomena that have occurred since the post-glacial sea level reached an altitude close to the present zero (between 7000 and 5500 years B.P.), from which it has varied but little since.

1. OCEAN LEVEL VARIATION

Quaternary sea level fluctuations are a reaction to purely eustatic factors, but are also due to geophysical (intensity of the gravitational field, variable over space and time), geological (variations in local stresses bearing on the crust) or climatic (for instance, temperature) causes.

The consequences can be quite varied and are manifested by morphological, sedimentological, geochemical, climatic, biological or archeological markers, bearing witness to such fluctuations.

However, there are still many sources of error, regarding both the age and the altimetric significance of markers, which generate uncertainties in the reconstitution of the local sea-level variation curve, and consequently of the shoreline of a given isochronal contour as well.

Moreover, one observes consistent shifts between curves determined at different locations, which brings into question the variety of rheological crust reactions and of geoid behaviours.

These uncertainties are all the greater as one moves away from the last glacial eustatic event. Our ignorance is often considerable, both for lack of information and because of the fragility of chronology indicators. It is therefore necessary to distinguish in the sequel between that which pertains to sedimentary cycles, that is, in the sense of sea-level movements, which are often relatively well known, and that which has to do with the actual position of the shoreline with respect to the Present, which is often hypothetical or undetermined.

1.1. THE MARINE CYCLES OF THE PLEISTOCENE

The margin and coastal sector with the richest Pleistocene record is in Morocco, and more specifically southern Morocco.

Even though this sector is outside the margins that constitute the subject of the present report, it is not possible to gloss over this important benchmark, which provides chronological references and has made it possible to hypothesise correlations with neighbouring Mediterranean coasts: Fouartian with Plaisancian, Messaoudian with Calabrian, Ouljian with Tyrrhenian, etc. However, progress made thanks to radioactive dating has brought to light, for several regional coastal sectors, various interferences of eustatic movements with regional climatic variations, and also with discontinuous manifestations of tectonics. This progress leads one to renounce an excessively rigid classification of transgressive cycles and their uplifted references; thus the correlations with Mediterranean coasts remain hypothetical, and towards the South direct comparisons are even more difficult because of the prevalence of Guinean fauna.

There is a marked contrast between the Safi-Cap Sim sector in the North, where the transgressions cover and obliterate one another, and the Cap Sim-Agadir sector in the South, where the continuous upthrust of the Atlas Mountains (especially at Agadir) makes it possible to pick out major high ocean levels.

Several marine cycles fit into the Lower Pleistocene: the Maghrebian, Fouartian, Messaoudian and Maarifian are successively staggered until the boundary of the Brunhes and Matuyama ages (0.7 Ma). More recently, the Anfatian, with two occasionally indistinguishable levels between 0.52 and 0.34 Ma, and the Harounian-Rabatian, dated at 260,000 years, provide two additional references before those cycles whose presence is recorded outside Moroccan regions as well, namely the Ouljian I, II and III.

We note that observations and measurements pertaining to the Ouljian II and III suggest emersions of 20 to 50 m in 40 to 70 thousand years, and these accelerated emersion rates of about the last 100,000 years are incompatible with the notion of regular emersion of these coasts, suggested previously by Stearns.

It is not until the Ouljian I that one finds chronologically equivalent formations in the Senegal-Mauritania Basin (see Table II).

Age (x 1000 years)	Moroccan Atlas	Tarfaya Basin	Mauritania	Senegal
2-3 3-4 5-6 7-11	Mellahian		Tafolian Nouakchottian	Dakarian Tafolian Nouakchottian Tchadian
25-43	Ouljian III		Inchirian	Inchirian
60-97	Ouljian II		Aïoujian	
110-148	Ouljian I	Ouljian I'	Tafaritian	

Table II: EUSTATIC CYCLES OF THE UPPER PLEISTOCENE AND THE HOLOCENE TO THE NORTH OF THE EQUATOR

The Tafaritian forms vast outcrops in Mauritania, but it is not strongly represented at the level of the present coast, except at Cap Tafarit, whose section constitutes a reference location. The Aïoujian forms the coasts of Cap Blanc Peninsula, in particular. The Inchirian corresponds to the transgression that preceded the last Würmian glacial pulsation. Its deposits form a halo around Ndrhamcha Sebkha, and are found in the vicinity of the present coast, near Tenioubrar Sebkha in the southern end of Akchar. Further to the South, it seems to be represented by beach-rock formations in the Senegal Delta substratum; levels of -16 and -21 m, dated at 26,205 years B.P., have also been noted in Mauritania.

In this North-Western region of Africa there is a climatic transition between the most northerly part (Moroccan borders), where the high levels correspond to interpluvial periods and the low levels to pluvial periods, and the more southerly part (starting from Western Sahara), where the low levels accompany arid phases and the transgressions are associated with more humid periods. The same reversal is observed in the southern hemisphere, starting at the latitude of Swakopmund in Namibia.

To the South of the Senegal-Mauritania Basin, records of Pleistocene marine levels are rare. Datings of wood, done some time ago, indicate the presence of the Inchirian in the Lanté Depression in Sierra Leone (-9 to -14 m). The circumference of the Gulf of Guinée seems to be totally devoid of an outcrop record, but on the other hand there is an indicator, albeit not verified, of Riss-Würm (Eemian) in Cameroon, in the form of the large sand belts of Tiko.

Thus it is necessary to go to Angola to find more reliable information based on very precise field studies conducted by Portugese authors at the beginning of the sixties, on fauna inventories and on more recent isotopic datings. A particular level at 125,000 years is widely observed and corresponds to a cycle that managed to pass beyond the present zero. Prior to that, dates have been provided in the Moçâmedes Basin by formations that no doubt belong to the Riss-Mindel interglacial. It is difficult to associate these measurements (between 133 and 174.10^3 years in one case; between 170 and 300.10^3 years in the other) with a precise eustatic cycle, because the former corresponds to transgressions of different ages, while the latter fits into too wide an interval to be significant.

Moreover, one notes that the terminology (Eem I, II, III) is radically different from that used to the North of the Equator, even if an attempt has at least been made, but without convincing anyone. This disparity serves to illustrate the difficulties that must be overcome to achieve the objective of identifying levels.

In the last part of the Upper Pleistocene, two 230Th/234U and 213Pa/235U datings at 36,000 years serve to corroborate several 14C radiometric measurements, and define a high level of the Interpleniglacial 3 in Cuanza Basin. Marine deposits of the same age are known in Namibia, where radiocarbon dating also indicates ages between 27,100 and 25,250 years B.P., thereby underscoring the presence, from the central desert of Namibia to the southern half of Angola, of a transgressive cycle in equivalence with the Ouljian III-Inchirian.

Over the margin as a whole, the extreme regression that followed on this second-last eustatic rise is suggested not by visible marine formations, but by the continental record. Generally speaking, and in particular among Francophone authors, this regressive phase is associated with the Ogolian; it brings the sea-level beyond the present line of about 100 m.

1.2. THE POST-GLACIAL CYCLE AND THE HOLOCENE

The record of the Holocene transgression has been observed along most African margins, and is particularly well recognised on the Atlantic side. This transgression represents a general oscillation occurring within a time frame of 1,000 to 10,000 years, and including climatic or hydrological change phases on the order of 10^2 to 10^3 years. Thanks to interdisciplinary studies, sometimes conducted over the entire emerged, buried and submarine record, the succession of coastal environments is known in many basins, in particular Senegal, Côte d'Ivoire, Benin, Nigeria, Gabon and Congo.

Ocean level variations, and in particular the rising rate of the last transgression, have had an evident effect on marine sedimentation rates. Even though the number of submarine shoreline indicators that have been dated is quite substantially less than that related to the emerged coast, the overall results make it possible to trace the chronological evolution of sea-level displacement. However, rather than plotting a general curve on the basis of necessarily composite information, it is preferable to show separately sections of curves that have been proposed for the areas off Mauritania, Senegal, Côte d'Ivoire and Gabon--Congo, while accepting the rather provisional nature of these curves. Indeed, the fact that such curves for the last six or seven millennia have been shown to be meaningful on a very regional basis leads one to think that curves for older movements should be at least as specific.

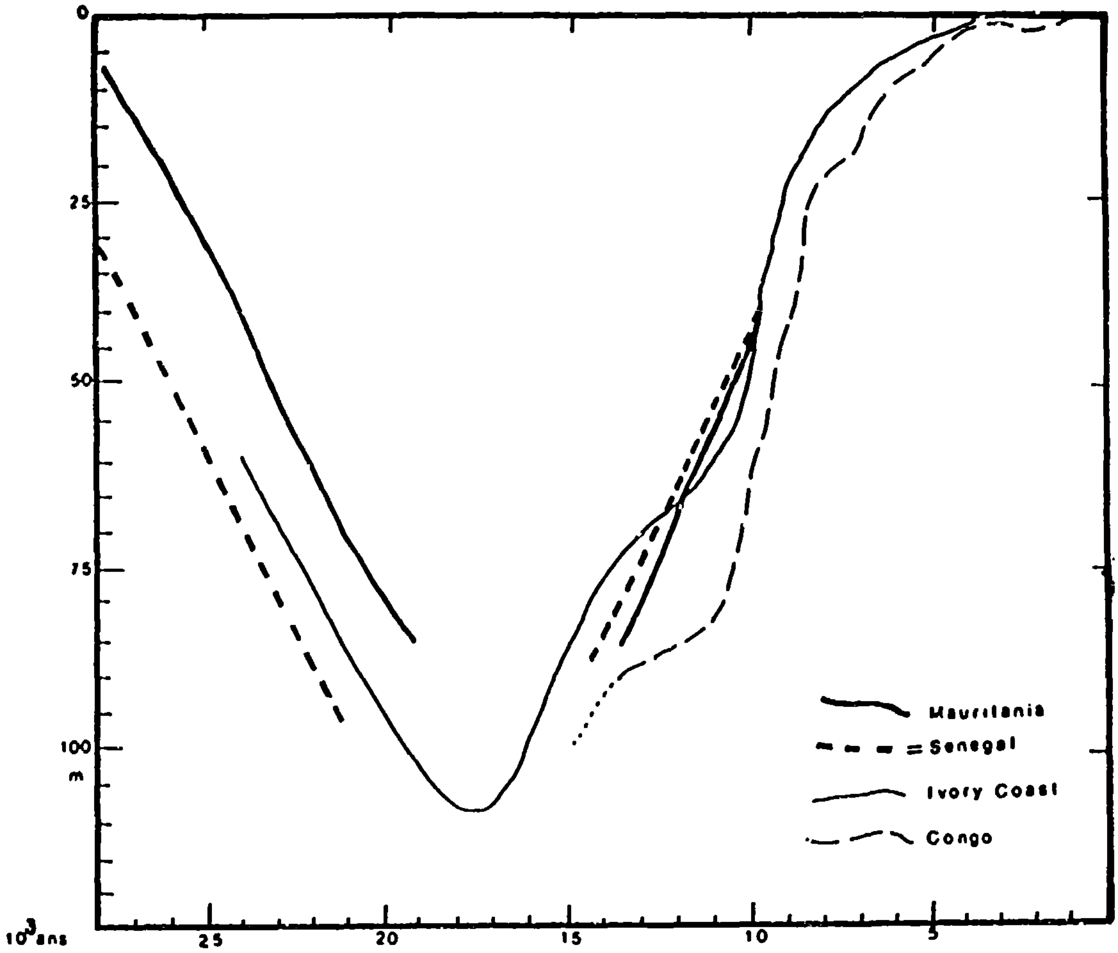


Fig. 6 Sea-level variation curves from 28 000 years B.P. to the present

The four curves of Figure 6 show that there have been rather substantial lags. And while some radiometric measurements for periods preceding 18,000 years B.P. are too close to methodological limits to be taken entirely into consideration, the number and the reliability of datings after this age are more acceptable. One notes an apparent and partial delay of the transgression in Côte d'Ivoire over that of Mauritania and Senegal, and an apparent, much more significant, lag towards the Recent of that of Gabon-Congo over that of Côte d'Ivoire. The cause of this asynchronicity could be related to regional oscillations of the paleogeoid (with an amplitude that can be as great as 20 m), or to vertical lithosphere movements, whose effects have been observed with respect to high Pleistocene sea-levels, and which we shall discuss later on.

Three eustatic phases are common to these curves:

- a low-level period (about 110 m), centred around 18,000 years B.P. and probably lasting some 3,000 years;

- an active eustatic period from 15,000 to 7,000 years B.P.;

- a post-eustatic period from 7,000 years B.P. to the present, during which the ocean level is relatively stable around the current zero.

Moreover, both the Côte d'Ivoire and Congo curves show up a period, centred around 12,000 years B.P., of rapid deceleration of the transgression. This event, which seems to coincide with the Gothenburg geomagnetic movement and with a planet-wide hypothermal pulse, is also recorded off Senegal, by the development of a *Cyprideis torosa* lagoon in between dunes.

Generally speaking, the West African platform presents a record of post-glacial shorelines at about -80, -50, -35 and -20 m, but it is not yet sufficiently dated. One can postulate, subject to further confirmation, that the most substantial accumulations are contemporaneous with phases of stabilisation, or at least deceleration of the transgressive movement, and consequently correspond to the low level at 18,000 years B.P., to the 12,000 years B.P. hiatus in the active eustatic phase, and to the high level near the Present, starting in 7,000 years B.P.

During the intervening periods, the level rises rapidly, sometimes maintaining a substantial rate for several centuries, as in the vicinity of 8,000 years B.P. (5 cm/yr).

1.3. RECENT OSCILLATIONS

The arrival of the sea in the neighbourhood of the current zero is accompanied by small-scale oscillations, whose number, age and amplitude are often uncertain and controversial. Several well-dated "models" have provided frequently imitated prototypes, which is no doubt regrettable, for then, in the name of comfortable conformity, relevant signs and the very sense of discovery tend to fade away.

Without going to such extremes, it nevertheless seems that one can outline some general trends. The ocean level was higher than in the Present at about 5,000 ± 500 years B.P. ("Nouakchottian"), and then experienced a decline over 1,000 or 1,500 years. The most uncertain period is from about 3,500 to 1,000 or 1,500 years ago. Local behaviours must then have predominated over purely eustatic variations. Several oscillations can be observed, and this period generally ends with a minor transgression, followed, starting in 1,500-1,000 years B.P., by a regressive movement bringing the level to its present position.

These trends are most distinct in the North (Mauritania-Senegal) and in the South (Congo); on the other hand, the picture in the central region, from Sierra Leone to the trough of the Gulf of Guinée, is much more fuzzy. In this region a relative variation ending in submersion is noted on several occasions, and is perhaps responsible for the submerged beach of Aberdeen Creek near Freetown.

Finally, we recall that the often quoted measurement of the present rate of sea-level rise (1.2 mm/yr) is not a matter of consensus, particularly among geologists and engineers. This raises the problem of cyclicity, which cannot be tackled without reference to theories (astronomical, climatic, geophysical), and especially not without more precise measurements (in particular surveying and dating).

2. COASTAL ENVIRONMENTS AND DEPOSITS

The temporal breakdown used in the description of sea-level variations can be applied to environments and to the sedimentary formations that developed in their vicinity. For the types of observations are different and their number unequally represented for each of the three periods.

During the Pleistocene, most of the record consists of emerged terraces, but the reliability of these altimetric and morphological criteria diminishes and disappears when crust movement induced level separation becomes insufficient, because the rate is too small or is inverted by subsidence. Moreover, Pleistocene formations of the platform are still basically unknown.

Information about the Post-Glacial is less accessible than emerged terraces. However, there are surveys (sometimes very complete, as in Gabon-Congo) covering the three sectors of the margin, and providing a basis for a comparative representation of Holocene transgression deposit environments.

The last interval of time taken into consideration, the Present, brings together the most favourable conditions for a detailed study: access is generally easy in the present coastal zone, and datings are relatively numerous. However, incompleteness of methodological approach obscures a clear view of phenomena during this period so close to us.

2.1. PLEISTOCENE ENVIRONMENTS AND DEPOSITS

<u>To the North of the Equator</u>, stratigraphic and chronological studies of coasts have been based on exchanges and migrations of Lusitanian

and Senegalese fauna, which allowed for palaeo-oceanic and palaeo-climatic reconstitutions with respect to altimetrically well referenced horizons.

Morocco once again provides a reference framework. Vertical movements of the southern coast coincide with the relief of the Atlas Mountains, whose erosion resulted in an isostatic uplift; in addition, the site of Agadir is at the South Atlas flexure. This sector is the most favourable for complete observation of high emerged levels over the last three million years or so. The main points of the Biberson classification are applicable, and correlations with isotopic cycles of ocean bottom oxygen are acceptable, as long as one remains within sectors whose crust movement rates are not too low.

The recognised high levels are shown in Table III.

CYCLE	AGE (years x 10^3)	ALTITUDE (in m)
Ouljian III	25-43	0/+ 1
Ouljian II	60-97	+ 2/+ 4
Ouljian I	110-148	+ 5/+ 6
Harounian	260	+ 20
Anfatian	340-520	+ 20/+ 30
Maarifian	600-1000	+ 20/+ 50
Messaoudian	1100-1800	+ 83/+ 117
Fouartian	2400-2800	± 180
Moghrebian	3000-4200	± 360

Table III: HIGH LEVELS ALONG SOUTHERN MOROCCAN COASTS

The irregularity of their distribution over time is also very pronounced over space. Thus the vertical shelf of the Moghrebian exhibits relief variation of 150 m over approximately 30 to 40 km of coast, the Messaoudian high level shifts by 50 m at the latitude of the Atlas Mountains, the Maarifian altitude varies from +20 to +50 m, the Harounian culminates at +20 m only to the South of Agadir, and the Ouljian, finally, which can be traced continuously over more than 100 km to the North of Agadir, passes below the present zero to the North of Cap Sim. These platforms are covered with an irregular but often thin layering of bioclastic sands and shingle with many Mollusc fauna intrusions.

At Tarfaya, at the border of Morocco and Western Sahara, one observes a decrease in the altitude of marine terraces. The Moghrebian is only at +50 m, and the Messaoudian is reduced to the single bed

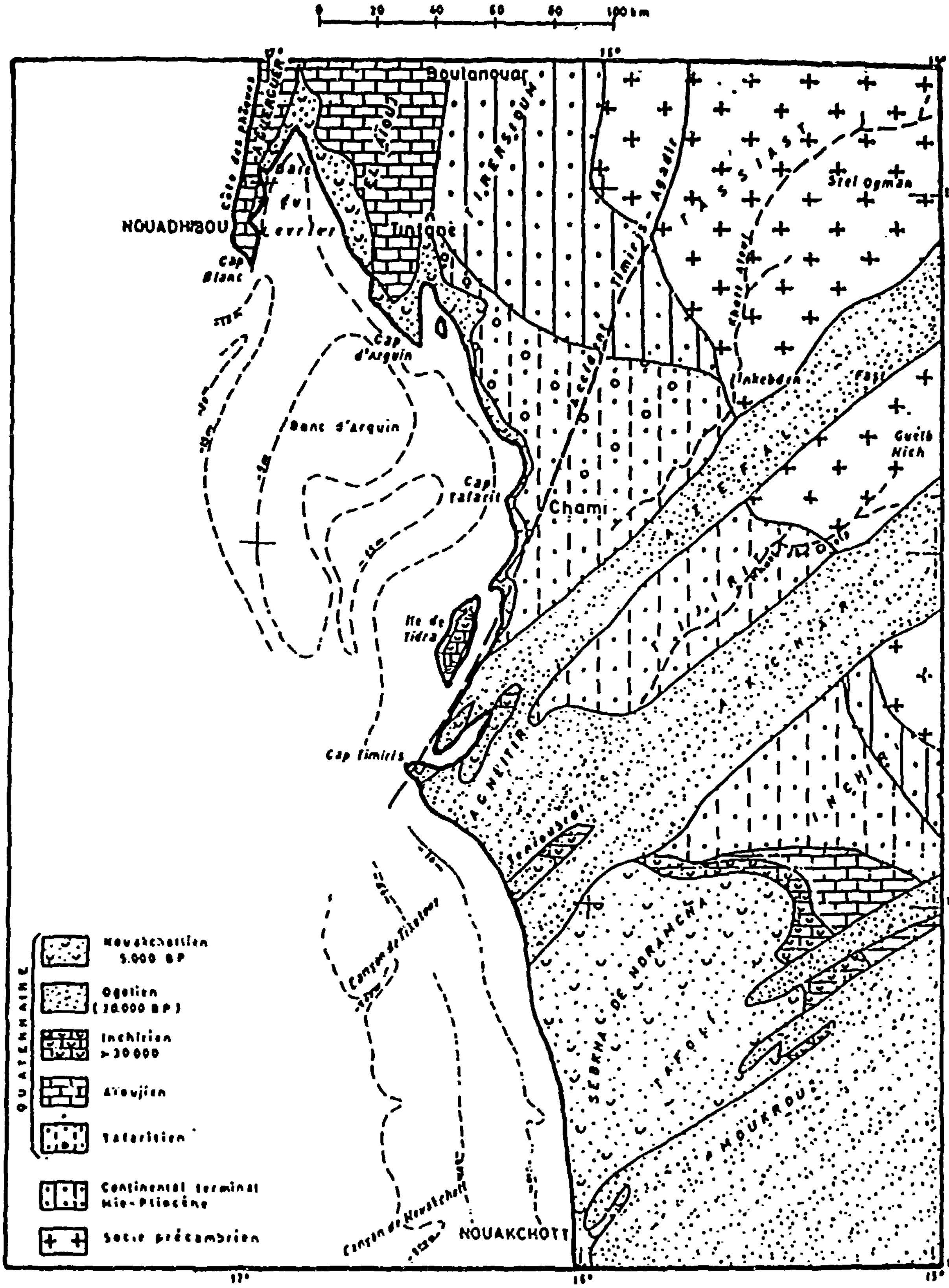


Fig. 7 - GEOLOGICAL SKETCH OF WESTERN MAURITANIA (in Hébrard, 1978)

of Sidibou-Maleh (+30 to +40 m), previously attributed to the Maarifian. Above the level of +5 m, the Ouljian (perhaps even the Harounian-Rabatian) is still hypothetical, and further to the South, direct comparison is difficult due to the predominance of Guinean fauna.

To the South of Western Sahara, a lumachella slab, observed at +30 m, can be followed right to the vicinity of 23° N. The Aïoujian, and its regression facies (or its dune belts?), the Aguerguerian, can also be followed all along the coast for more than 100 km. To the North of Mauritania, Pleistocene formations, albeit faintly stratified, stake out the shorelines of gulfs (Fig. 7).

In Senegal, these younger than 150,000 year deposits are generally buried at depths compatible with limited post-sedimentary crust movements; this is true of Inchirian beach-rock commonly encountered at -20 m in the Senegal delta substratum.

<u>In the intermediate area, from Sierra Leone to Cameroon</u>, the presence of high levels is noted, with pleistocene associated deposits. However, in the complete absence of datings, this question must be considered uncertain and open, and the indicators must be viewed with caution and a critical eye. In Sierra Leone, 5 levels (118, 66-64, 44-36, 29, 15-13 m) have been noted on Freetown Peninsula. Two are identified as "upthrusted" beaches, sculptured in the Tertiary and Quaternary series of Bullom. In Liberia, a marine terrace at 7-10 m is claimed. In Côte d'Ivoire and in Ghana, several high platforms are grouped in four or five families, of which at least 2 seem to be pre--Ogolian: more than 16 m and 13-8 m; but it is also recognised that distinct individualisation of shapes is rare. However, poorly dated Pleistocene sedimentary formations have been bored or are visible as outcrops, the oldest being the "Terre de barre", without doubt continental, and down from which one finds low plateaus, consisting of Ogolian clayed sands overlying lagoon levels of unknown age. Further East, in Cameroon, while tiered levels are to be found, there is no proof of their marine origins, even though they are sometimes described, without convincing argumentation, as being formed by the ocean. In this region, neo-tectonic activity correlated with the Cameroon volcanic axis is probable.

<u>To the South of the Equator</u>, there are no emerged indicators at all until the vicinity of the Congo Estuary. On the other hand, terraces exist in the Cuanza and Moçâmedes Basins. But the picture is far from being a clear one, because crust movement is differentiated, with the central sector of Lobito (Cuanza) turning out to be more sensitive than the southern region. The intensity diminishes towards the Equator, disappearing completely to the North of the mouth of the Congo, where a terrace at +25 m, at Moanda lighthouse, may well mark the boundary of this positive altimetry sector. It is also attenuated to the South in Moçâmedes Basin and in the North of Namibia.

The Pleistocene record is grouped in two terraces, at 8-20 and 90 m. The measured ages and the terracing are variable. Nevertheless, the 8-10 m part of Cuanza is associated, on the basis of 2 datings at 36,000 years, with the Interpleniglacial corresponding to isotopic stage 3. The higher platforms (12, 15, 20 and sometimes 25 m; 90 m) belong to various Eemian periods or to older stages. Dating them precisely is tricky and may be illusory, for it is evident that they have been covered by transgressive seas of different ages. The cliffs bordering them must also result from the repeated action of several eustatic high levels.

Thus along these coasts there is no precise correlation between the morphology (terraces and cliffs) and the overlying littoral deposits; the latter often appear as isolated accumulations, at times next to, at times on top of each other, or even widely separated. Consequently, the lithic activity remnants they contain (Oldowayan at +100 m in Lobito Sul and at +35 m in Moçâmedes) cannot provide valid indications for overall morphological and sedimentological genesis.

On the continental shelf, the discovery of Pleistocene levels is limited to regions that have been investigated by vibration core drilling: the platforms of South Gabon and Congo, and a few other localised sectors (Senegal, etc.). However, discontinuous markers of the "Ogolian" regression, of ages between 18,000 and 26,000 years B.P., have been discovered accidentally. These are regressive coastal shelly sands and littoral sandstone, preserved at various depths, and encountered, for instance, on the platforms of Namibia and Mauritania.

In the North-West, the regressive palaeo-shoreline of 18,000 years B.P. has not determined an abrasion surface at about -110 m, as is the case, on the contrary, in Côte d'Ivoire and Nigeria. Between Congo and Zaire, the deposit record is more distinct: calcareous ooze at Globigerines at -105/-115 m, carbonated deposit off Cabinda at about -50 m, Kouilou peat, foraminiferal sand at -30/-40 m off Djeno in the Congo, depression deposits of the medium platform detected under 10 to 15 m of Holocene. A regression palaeo-shoreline also determines a marine abrasion terrace at about -105/-120 m.

2.2. POST-GLACIAL ENVIRONMENTS AND DEPOSITS

This period corresponds to the level change that raised the ocean from its -110 m in the regressive "Ogolian" period to a level close to that of the Present, between 18,000 and about 7,000 years B.P., after which only slight modifications occurred.

Three better studied sectors, the platforms of Congo-Gabon, Côte d'Ivoire and Senegal-Mauritania, provide markers that can be used to compare this period's environments and sedimentation types.

During the low level of 18,000 years B.P., pelitic deposit centres developed on the outer platform of Congo-Gabon. Their lateral extension decreases towards the North; less present in Côte d'Ivoire, they are replaced by terrigenous alluvial silt, coming in from a continent subjected to arid conditions. The emerged platform becomes covered by alluvial deposits, mostly located on the inner plateau, where they settle as a function of palaeo-flows, but also, perhaps, of stages when the regression stops, as seen to the South of Dakar, for example. However, most of the silt on the platform is due rather to dune formations, which are particularly extensive on the North-West margin (Ogolian erg).

Glauconitic sediments are formed during this phase at about -120 m in the Congo. Glauconite formation, from fecal matter of detritus--feeders, starts at -22 to -24,000 years and results in relatively mature glauconites (up to 6 % potassium oxide). The abundance of this type of substratum corresponds to super-activation of upwelling currents, which raises primary production on the ledge. There are glauconitic sediments off Côte d'Ivoire as well, but to a lesser degree, because of more efficient iron retention in pedological profiles, and less production of fecal matter. Off the coast of Senegal only berthierites are observed, with different epigenetic media (Ostracode tests).

Low sea-level carbonate production is poorly known, even though bioclastic elements of the outer platform and of oolites are formed this way.

During the active eustatic period corresponding to the post--glacial transgression, the main sedimentary event is the constitution, at a depth range of 80 to 120 m, of a belt of outer carbonated sands. They are the debris of red algae, of Molluscs, Echinoderms and Bryozoa associated with benthic Foraminifera, including Amphistegina gibbosa Orb. This "Amphistegina fauna", dated on Congolese and Côte d'Ivoire material at 13,000 to 11,000 years B.P., is known to be present throughout the margin, where it has developed in deep (3à-50 m) and warm waters.

During the transgression the pre-existing material is reshaped, but, contrary to an accepted notion, it does not spread in regular fashion over the platform as the shoreline progresses. Quite the opposite, for a littoral prism is built up only during periods of stabilisation (deceleration or halt) of the coast-line. The "palaeo-shorelines", identified at about 40-50 m and 20-30 m, therefore owe their definition to the recognition of a durable action, sometimes manifested by more or less continuous relief contours, and often by deposits that can be distinguished by texture analysis of sediments. Behind the dune belts accompanying these littoral structures, lagoon systems sometimes find shelter, such as those dated at 8,100 years B.P. on the Senegal Platform.

These fossile shorelines can be of economic interest, because mineral concentrations, such as the phosphatised placer of Djeno in the Congo at -40 m, tend to develop there. Between periods of stagnation, sedimentation occurs only in morpho-structural depressions that trap the material. For instance, in Congo-Gabon, 10 to 15 m of sediments were deposited between 11,000 and 9,000 years B.P. in the depressed parts of the medium platform.

2.3. ENVIRONMENTS AND DEPOSITS FROM THE RECENT TO THE PRESENT

Except for a short dry period between 7,000 and 6,500 years B.P., the evolution of the coastal zone of Senegal and Mauritania took place primarily in a humid environment during this most recent stage. The transgression accelerates and reaches its maximum between 6,800 and 4,200 years B.P.; the Nouakchottian culminates between +1 and +2 in Senegal and attains +3 in Mauritania. In this last country, the record of this maximum includes Mollusc fauna positioned at the border of the Lusitanian and Senegalese provinces.

Subsequently, and independently of low-amplitude eustatic oscillations, the influence of pronounced aridity phases, at various times, leads to specific types of environments. This is the case of some marine incursions into the inner basin of the Senegal River. During the Holocene, each of these incursions had important ecological and hydro-geological consequences. The droughts presumed responsible are on the order of those recorded three times since the beginning of the century (1913, 1941 and 1975); these three dryness maxima are also observed in the Sahel, where each time they correspond to a solar spot activity minimum. An understanding of the periods of these variations now has an important application to water management and agriculture in the Senegal Delta.

In addition, negative oscillations, such as that of the Tafolian, have controlled the closure of gulfs. And then the present landscape is determined as a function of the balance of eustatic factors and oscillations of the hydrous regime: for example, the extension into the Ferlo of brackish facies, at about 3,300 and between 1,800 and 1,500 years B.P., corresponds to two periods when the Senegal River runoff and the phreatic level were higher than at present.

Finally, we note that the Senegal River Basin, with an alluvial plain close to the oceanic zero extending over almost 150 km of coast, constitutes an a priori favourable site for verification of the Clark models. Measurements taken there indicate a deformation of (about) 2 m over 7,000 and of one metre over 6,000 years. Thus the rigidity of the mantle or lithosphere under this part of the West African margin is greater than that admitted in models previously studied in Australia and in Brasil.

In the coastal region of the Gulf of Guinée, the edgeless relief of Pleistocene colluvial deposits (continental terminal) did not favour as extensive a development as in Senegal of bays and estuaries, when the Holocene sea arrived. Only the deep valleys cutting through low plateaus were invaded by the transgression, creating a substantial system of rias. In Côte d'Ivoire, the marshy forest along the coast is relatively constant as of 5,000 years B.P., but with, nevertheless, four negative pulsations, whose record contains less than 10% mangrove pollen. Morphological and sedimentological studies of these regions yield the following suggested chronology, although opinions in this respect are not completely convergent:

- as of 6,000 years B.P., the ocean level, attaining or exceeding the present zero, determines the establishment of a first generation of white littoral belts, while lagoon peat develops upstream from present valleys.

- in about 4,000 years B.P., a negative oscillation is observed (about -1 m), allowing lagoon implantation behind the belts.

- between 4,000 and 1,000 years B.P., a second positive oscillation leads to the accumulation of a second generation of belts, this time reddish-brown; they reach +2.5 m (?); brackish water penetrates the river valleys.

- isolation of most of the lagoons occurs at about 1,000 years B.P. in favour of a slight regression (-1 m ?), or perhaps as a consequence of progradation of the littoral belts; the deltaic formations of the Bandama and the Comoe were emerged at this time.

- a slight sea-level rise results in partial erosion of the reddish-brown belts (record at +0.5 to +1 m dated at 760 years B.P.).

- return to the present zero constitutes the last stage of this evolution of the Côte d'Ivoire coast-line.

With some variations and uncertainties, often for want of a sufficient number of datings, the same evolution is to be found from Sierra Leone to North Gabon. A new variable comes into play in Cameroon, in view of that area's neo-tectonic activity.

Further South, the evolution of the coastal zone of Congo-Gabon gives a good idea of the processes prevailing during the Recent. As in the case of Côte d'Ivoire, fluviomarine bays have limited extensions; the estuaries were implanted in deep rias cut through colluvial regression material, or below old Eolian belts, whose relief (from +10 to +30 m) made a deeper marine incursion impossible. Lack of evidence for a high level, equivalent to the Nouakchottian, must be noted; this is by no means the case in Angola, where the corresponding beach is lifted up to +5 m! Very soon the landscape becomes unstable, the channels start to wander, and at about 5,000 years B.P. a shelly marine sand formation attains the present zero.

It seems that relative sea-level stability did not favour, as in the North of the Gulf of Guinée, progradation of littoral transgression belts, despite the intensity of littoral drift transfer. During this age mangroves are still luxuriant and experience their greatest development on the edge of rias whose consolidation is not yet complete: this applies in particular to the palaeo-valley of Kouilou. The most common mangrove species are R. mangle, R. harrisonii and Acrostichum aureum, and no Graminaceous pollen are to be found.

From about 3,000 to 4,000 years B.P., the sea-level no longer rose, and may even have fallen a bit, as would be indicated by a littoral extension of the Eolian deflation. Then a last positive oscillation is manifested; it slightly exceeded (0.5 m) the present zero in an environment which, albeit dominated by tropical forest and mangroves, shows a re-appearance of Graminaceae and Cyperaceae. The last millenium displays, in a generally humid climate, several manifestations of a slight aridification tendency.

It is clear that one of the questions to be resolved is the discrimination between that which depends on eustatic phenomena, and that which is attributable to climatic processes and their sedimentary effects. In both cases, erosions and deposits can appear, depending on the direction of the trend. Identity of effects makes it difficult to identify causes.

The picture would not be complete without particular stress being laid on the current processes at work in the coastal system, which are the object of international study and surveillance programmes, under the aegis of the UNESCO/UN-DAESO/UNEP project entitled "Preventing coastal erosion in West and Central Africa" (WACAF 3). Moreover, variations in fauna illustrate the impact of climatic cycles in relatively recent times, as observed in the Senegal Delta, where Pachymelania aurita and P. *fusca* have deserted the bottom since less than 2,000 years ago, and in addition to these disappearances, substantial changes in territory occupied by other species are noted. Similarly, the flora, and in particular the mangroves, also displays significant modifications, observed not only in the northern part of the margin, but also along its central and southern sections.

The most recent studies (see WACAF 3), regarding the present stability of the coastal zone, show that the behaviour is not uniform, even within each of the three major margin areas.

The coasts of Mauritania are the site of contrast between the North (Banc d'Arguin), where sedimentation dominates, and the South, where some erosion can be detected. The same contrast is to be found in Senegal, where a dynamic equilibrium exists down to Cayar, whereas further South localised erosion expresses a state of disequilibrium of the deposit-transport balance. Building up processes prevail from the Casamance all the way to Sherbro Island in Sierra Leone; however, this finding must be qualified: the positive balance of deposits, which are substantial in this area, over subsidence is to some extent precarious, and some worrisome local evolutions (Conakry, etc.) should be stressed. The southern part, from Sierra Leone to Liberia, is a sensitive area where local erosion can also occur; it is not inconceivable that this results from human intervention, a major hydroelectric programme having been undertaken in Sierra Leone during the sixties.

From Cap des Palmes on, the coast of Côte d'Ivoire exhibits a varied balance, with 205 km of stable coast between the mouth of the Cavally and Fresco, in the West, while a 165 km central sector would seem to be retreating; the eastern part, some 70 km in length, seems to be building up, a trend that continues into Ghana, and local evolutions are observed over some forty irregularly distributed kilometres. To the East of Cap des Trois Pointes in Ghana and continuing on to the Niger Delta, one finds one of the most studied sectors in West Africa, because of the erosion processes prevailing there (2.2 m/yr at Ada, 6 m/yr from 1959 to 1975 at Keta, 20 m/yr to the immediate East of Lomé, etc.), with temporal and spatial irregularities that make it extremely difficult to understand the phenomena involved, especially for lack of a century- or millenium-old perspective. It is also clear that human development of the coast has not been without influence on certain spectacular and local changes, even if there exists a natural unfavourable imbalance.

Along the Niger Delta, it is surprising to find a rather general erosion trend, except at the river outlet; the main cause seems to be pronounced littoral drift (500,000 m^3/yr), both to the West and to the East. Now this material does not contribute to the western and eastern coasts, because it is drained away by canyons (Avon, Mahin, Calabar) and therefore cannot maintain the littoral prism; this phenomenon is also valid to some extent for the Congo River, 1,000 km further South. To the South-East of the delta and as far as Cap Lopez in Gabon, limited observations provide evidence for a general dynamic equilibrium, despite several indicators of substantial erosion or accumulation (Cap Lopez). From this last point, voluminous littoral drift (300,000 to 650,000 m^3/yr) does not seem to be sufficient to prevent a number of shoreline retreats, which appear to be seasonal in Gabon, and can locally attain impressive magnitudes in the Congo (Loango). Despite all this, generally speaking a dynamic equilibrium prevails in this region and in Cabinda. To the South of the Congo estuary, penetrated by the canyon over some forty kilometres, there are 1,400 km of Angolan coast, which but little information is available. The littoral drift, from the South to the North, maintains numerous and well-developed littoral deflections. Crustal movement variations in Cuanza Basin are used to explain erosion and sedimentation phenomena, but this issue has not yet been sufficiently argued.

It would be premature to draw up an inventory of presumed causes of sedimentary changes in the coastal zone of Atlantic Africa. The most that is possible is to summarise the most frequently quoted factors.

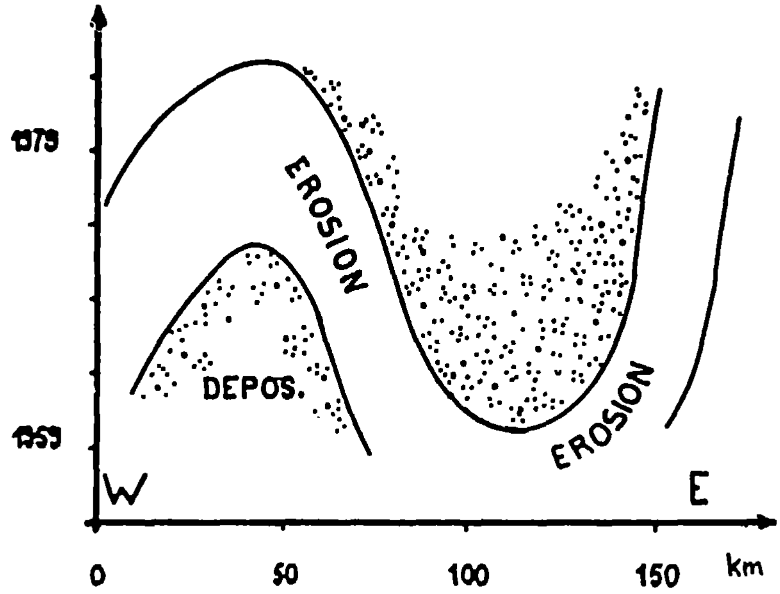
Table IV concerns erosion phenomena.

	ANTHROPOGENIC PHENOMENA				NATURAL PHENOMENA								
	DISAPPEARANCE OF MANGROVES	INTERRUPTION OF LITTORAL TRANSIT BY WORKS	SAND UTILISATION	HYDROELECTRIC DAMS	TRAPPING IN OFF-SHORE DEPRESSIONS	COASTAL HYDRODYNAMICS	CLIMATIC VARIATIONS	VEGETATION COVER CHANGES	PROXIMITY OF CANYON	LOCAL PLATFORM NARROWNESS	SEISMICITY	SUBSIDENCE	UPWARD CRUST MOVEMENT
Mauritania - Senegal			X			X	X	X	X	X			X
Guinee and G. Bissau	X					X						X	
Sierra Leone - Liberia		X	X	X	X	X					X	X	
Gulf of Guinee coasts		X		X		X			X	X	X	X	
Gabon - Congo	X					X		X		X		X	
Angola						X	X	X	X	X			X

Table IV: MAIN FACTORS INVOLVED IN PRESENT COASTAL EROSION PROCESSES

Finally, it is worth recalling that it is more and more common to highlight the cyclical nature of coastal evolution, in relation to the passage of "sedimentation waves", which are no doubt constituted from a complex balance of factors. A study along the Benin coast (Fig. 8) could well suggest that more research be undertaken along these lines.

The passage of sedimentation "waggons" would seem to correspond to shoreline stabilisation stages, with erosion predominating in the intervals between. In the case of Benin, the sedimentation wave moves at the rate of 2.8 km/yr, and its alternation periodicity amounts to 25 years.



The dotted areas indicate accumulation of deposits, while the band in between corresponds to erosion that is shifting in time and in space.

Fig. 8 - SEDIMENTATION WAVE ALONG THE COAST OF BENIN

CONCLUSIONS

Comparing the geological types and the Quaternary evolution of the Atlantic margins of Africa, between Mauritania and Angola, leads to the following three points of view, each of which brings out distinctions between the different sectors.

For the long term (Pleistocene), there is a natural contrast between the margins that are the site of positive crustal movements (Mauritania, Angola), whose rates and causes have been more or less completely analysed, and those, from the South of Senegal to the North of Angola, where one finds greater stability or even indications of subsidence.

For the medium term (Post-glacial), regional climatic factors and their evolution have an influence that differentiates inter-tropical regions from sub-tropical regions. The former have a detritus production that is generally more abundant, more regular and finer than the latter, where the solid discharge of rivers is barely present, but then increases tenfold during climatic transition periods. Moreover, new glauconite generation also differentiates between these regions, displaying a South-North gradient that benefits from a conjunction of factors pertaining to successive climatic periods, supports being particularly abundant wherever iron is delivered during eustatically active periods. However, this climatic effect interferes with an eustatic effect, which favours the formation of major sedimentary accumulations at levels of temporary stabilisation of the transgressive sea.

For the short term (Recent and Present), one can measure the impact of minor variations (eustatic, oceanographic, hydrological, sedimentological, climatic), that are filtered over the medium and long terms by the amplitude of changes, or by the total or partial erasing of the record. This then obscures our perception. It is necessary greatly to increase identifications of phenomena that are well determined and well localised in space and time. In this respect, it is regrettable that radio-carbon dating has not become more common in practice.

EASTERN SOUTH AMERICA QUATERNARY COASTAL AND MARINE GEOLOGY:

A SYNTHESIS

By

Luis R. Martins
Jorge A. Willwock
Instituto de Geociencias UFRGS. Porto Alegre, Brasil

CONTINENTAL MARGIN FRAMEWORK AND DEVELOPMENT

1.1 Introduction

The youngest structural province of the Western South Atlantic, was developed during the separation of South America and Africa, and includes the coastal plain and the continental margin.

Rift valleys and coastal basins filled with Mesozoic-Cenozoic continental, transitional and marine deposits are the main elements of the unit.

According to ALMEIDA et al. (1981), the coastal plain is the physiographic feature of the emerged part of this province, with a surface just few meters above sea level and composed by deposits of various kinds.

Sediments of fluvial, lacustrine, lagunar, deltaic, estuarine and eolian origin can be found along the area.

The coastal plain is characteristically narrow and very elongate, even discontinuous at some places.

Major expressions can be seen at the Amazon river mouth, Paraná delta and other river-delta systems such as those of Parnaiba, São Francisco, Doce, Paraíba do Sul, Colorado and others which supply Holocene sediments to the coast.

Other expressive areas are located at the Rio Grande do Sul coastal plain and its lagunar complex (Brazil) and the eastern Buenos Aires coastal plain.

The continental margin, the submerged part of the province, shows a variable physiographic and sedimentary aspects, the last ones developed during the Quaternary.

The sedimentary sequences have accumulated mainly in coastal grabens and half-grabens, as clastics and carbonates of Cretaceous and Cenozoic age, and they form the evidence for the successive stages during the process of continental break-up (rift) and the beginning of the continental drift.

The main aspects of that history will be discussed in this summary.

1.2 South Atlantic opening and sedimentary basins of South America

Since from more than 100 million years, a progressive separation between Africa and South America was manifested.

After an intracratonic incision and a rift valley formation, sedimentary basins predominantly of marginal type were formed along both continental margins.

During the process of sea floor spreading, continental rotation points were generated and the progressive separation left a series of faulting lines. Other fracture lines of less displacement affected the continental border modifying its structure by producing positive and negative features.

The negative areas or sedimentary basins have maintained since the beginning an almost continuous process of subsidence.

On the history of each basin and along continental margin, successive tectonic episodes with various intensites were responsible for several changes in the sedimentation of the different depositional centers.

In a large scale we can mention three main tectonic types:

a) From the north Amazon region to the Fernando de Noronha archipelago the translation style is dominant coinciding with the Equatorial fracture zone;

b) From Sao Roque cape to Malvinas archipelago the predominant tectonic style is divergent with the development of a graben and semi-graben system controlled by fractures with NS direction almost constant;

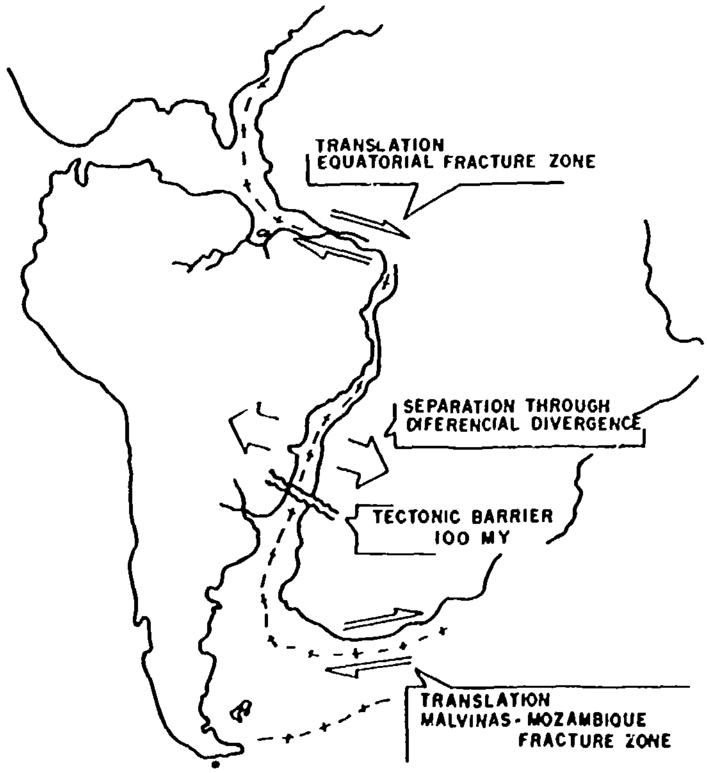
c) At the north of the Malvinas Plateau the tectonic style is again translation type coinciding with the north Malvinas scarpment (Fig. 1).

According to OJEDA (1982) four fundamental phases characterize the tectonic-sedimentary evolution of the Brazilian marginal basins:

a) Intumescence phase (Late Jurassic-Early Cretaceous) with crustal uplift, formation of intracratonic peripheric basins and deposition of continental sediments.

b) Rift phase (Neocomian Barremian) with intense taphrogenic activity and development of a symetric central along the intumescence axis, adjacent assymetric rift valley systems, where a thick sequence of fluvio-deltaic-lacustrine sediments were accumulated.

PROTO - CONTINENT RECONSTRUCTION
180 MY



Eschematic reconstruction of the Africa - America do Sul link, with the mayor fracture zones and its mechanics. The tectonic barrier corresponds to the Rio Grande - Walvis rise.

Modified from Urien and Martins, (1979)

Fig. I

c) Transition phase during the Aptian, with relative tectonic stability when evaporitic and clastic fluvio-deltaic sediments were deposited.

The sediment supplies are from the clastic of continental provenance and from the salt water of the gulf, located in the central graben, between Florianópolis and Maceio along the east margin, and probably between Cassiporẽ and Touros in the equatorial margin.

d) Drift phase, from the Albian to Recent, when occurred a crustal dumping to east with formation of hinge, shallow and extense homoclinal, and when clastic-carbonate marine and non marine were accumulated.

In several basins, diapiric structures of salt and shale, deformed sedimentary sequences from the Upper Cretaceous in the proximal areas to younges sediments on distal zones.

Two periods of major igneous activity occurred: in the Early Cretaceous associated with the rift phase, and in the Oligocene-Miocene, during the drift phase.

URIEN, et al., (1981) described the main episodes of the complex geological history and therefore complex regional pattern of the southernmost portion of Eastern South America. Here the continental drift and subsequent sea floor spreading stages affected dramatically the continental margin with the formation of positive and negative units accordingly with successive diastrophic episodes.

The diastrophic phases gave rise to basement fracturing with both gravitational and translational faulting. Hence depositional centers were generated with diverse structural styles.

On the continental margin border half graben or marginal basins are the dominant architecture.

Other structural styles are also observed as result of the continent's migration and rotational poles. These basins are taphrogenic (such as Salado and Colorado). Others are intracratonic pull apart basins (San Jorge and Valdés Basins).

The Malvinas and Magellan Basins as well as the Malvinas Plateau Basinal Complex are partially sculptured within the continental margin, however they also lie on continental basement. Anyhow, genetically talking they are not attributed to the Atlantic province but to the Pacific. These complex basins are found South and Southwest of a subpositive mass which is recognized as the Massif-Malvinas Arch.

The sub-hercynian movements caused little modifications to this pattern, except for an enlargement and, in Colorado basin coalescence of depositional centers. The second major tectonical phase took place in Cenomanian time. These movements brought forth the coalescence of most Atlantic basins, and the inception of new ones in the foot of the continent beneath the continental rise as a continental embankment.

Discussing the evolution of the Brazilian Continental margin, ASMUS (1984) distinguished the stages of pre-rift (Neojurassic), rift (Eocretaceous), proto-oceanic (Aptian), and Oceanic (Albian).

During the pre-rift stage, positive areas were sedimentary sources to the filling of interior basins development on its peripheric portions, like Paraná basin, Congo basin and the Afro-Brazilian depression between Brazil and Africa. On these paleogeographic picture (topographic highs surrounded by peripheric basins) fluvio-lacustrine and eolian sediments were accumulated (continental sequence).

The rift stage was characterized by crustal fracturing and abatement with locally vulcanism.

The resulting tectonic basins are rift arch - volcanic type (Santos basin) and rift crevice type (like Cassipore, Potiguar, Sergipe/Alagoas).

Clastic sediments of lacustrine character are dominant.

The proto-oceanic stage is distinguished through the first marine ingression during the Aptian like a gulf feature of restricted circulation, that was responsible for an evaporitic sequence deposition.

During the oceanic stage, continental portions originally connected during the first evolutionary phases, started to spread for increasing distances due to the oceanic floor generation.

The spreading is obtained through succesive intrusion and extrusion episodes of basaltic magma over the Mid Atlantic ridge.

The main aspects of the ASMUS (1984) stages are shown in Fig. 2.

More recently URIEN and MARTINS, resumed the main episodes of the South Atlantic opening, that is shown in Figs. 3 to 7.

Sedimentary basins of South Western Atlantic are shown in Fig. 8.

The principal types of the internal structure of the marginal basins were discussed by several authors (URIEN and MARTINS, 1979, ASMUS, 1984) and is resumed in Fig. 9.

1.3 Summary of the marine sedimentation

The marine sedimentation on the South Atlantic started with the formation of the Atlantic proto-ocean (OJEDA, 1982; ASMUS, 1984; URIEN and MARTINS, 1985).

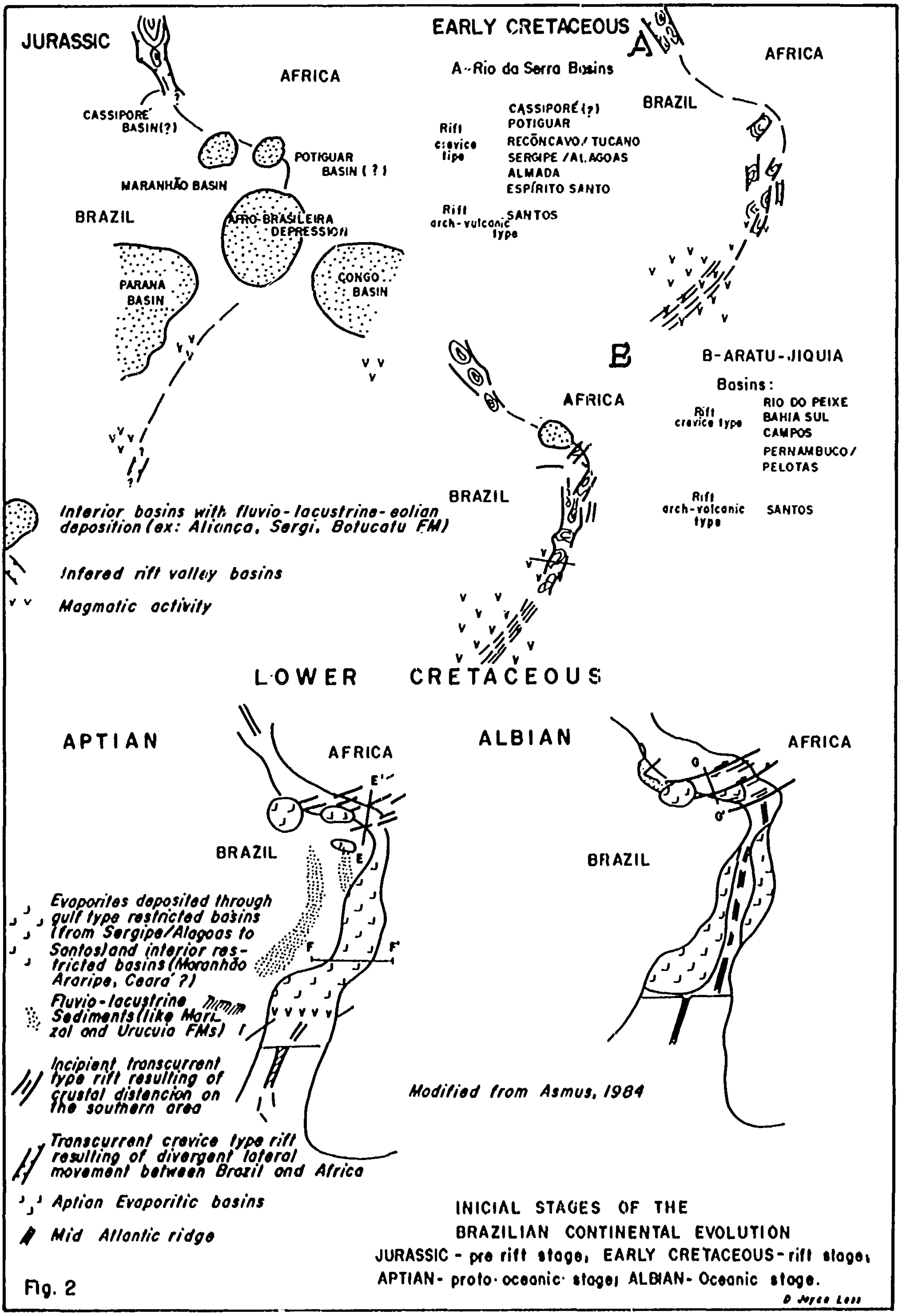
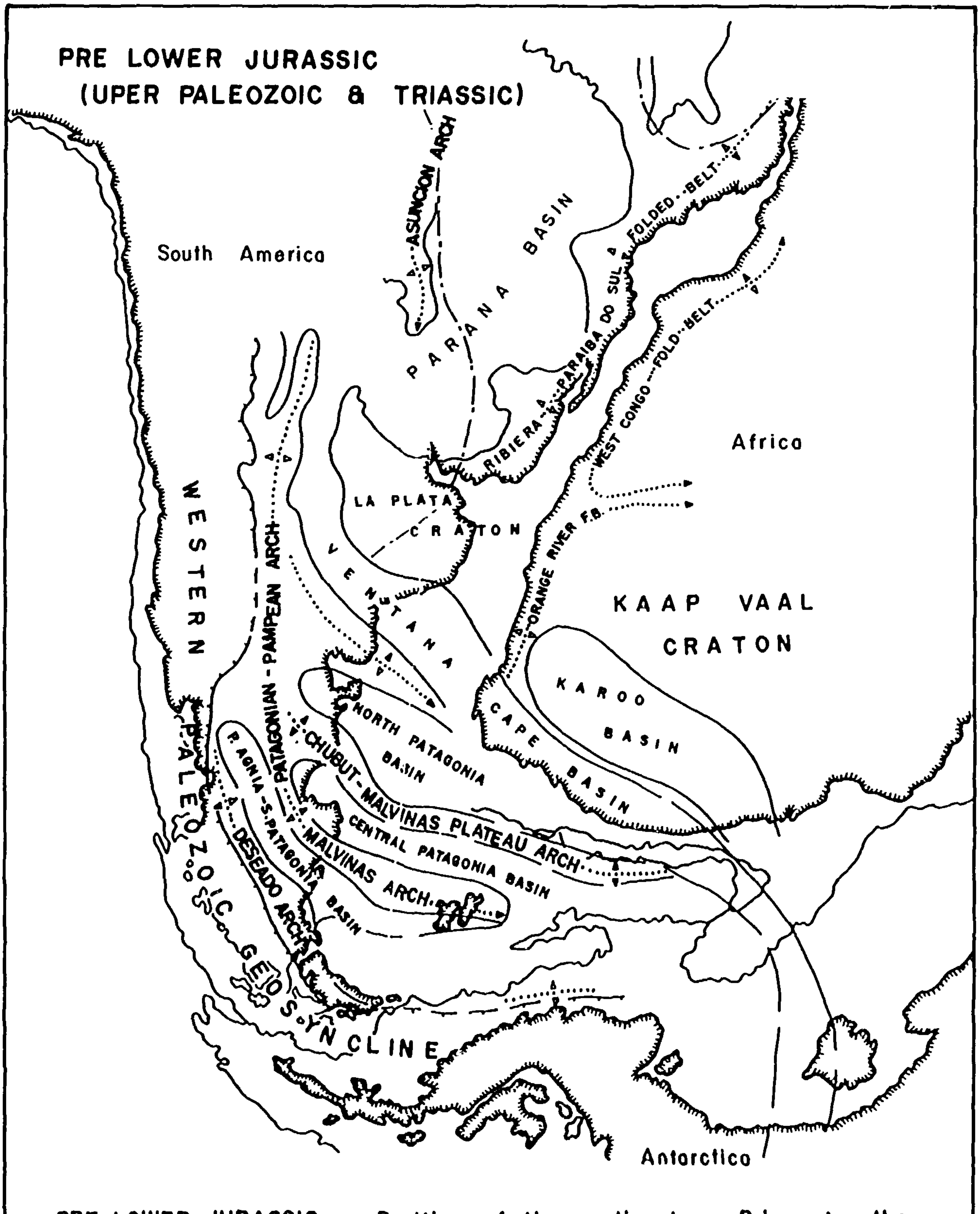


Fig. 2

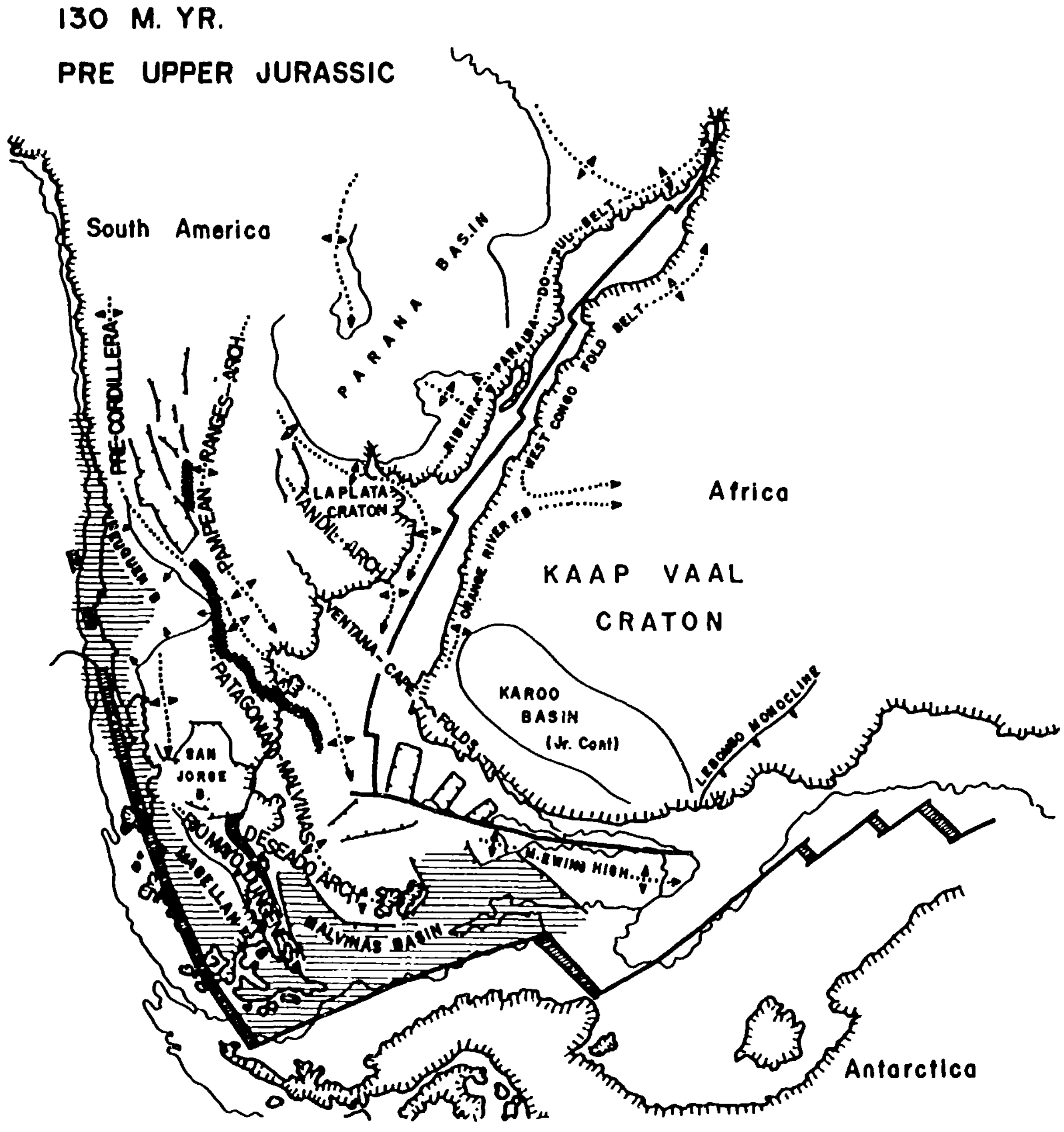
INICIAL STAGES OF THE BRAZILIAN CONTINENTAL EVOLUTION
JURASSIC - pre rift stage, EARLY CRETACEOUS - rift stage, APTIAN - proto-oceanic stage, ALBIAN - Oceanic stage.



PRE LOWER JURASSIC - Position of the continents. Prior to the spreading many morphostructural. units can be linked between S. American and South Africa, e.g. Ventana System and Cape Basin (Upp. Paleozoic) North Patagonian basin and Agulhas Bank basins. Patagonian-Pampean Arch (Upper-Precambriam to Lower Cambrian) with the Malvinas Plateau nuclei. The Western South America Paleozoic geosynclinal extends within Antartica.

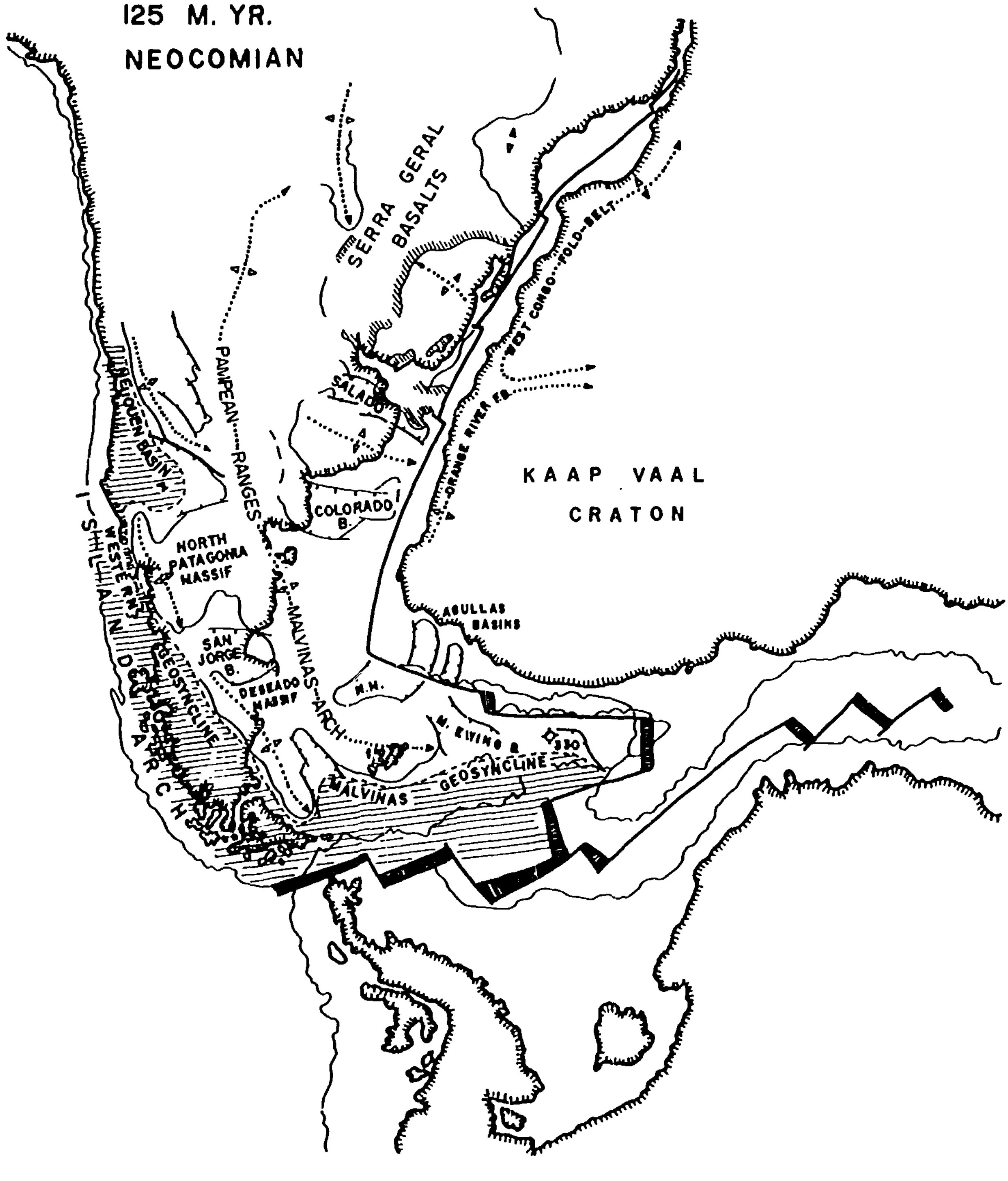
Modified from Urien and Martins (1985)

Fig.3



130 M. YR. Position of the continents prior to the spreading. Spreading centers are also associated with transcurrent zones. Dark heavy line between America and Africa is the possible location of the early rift valley. Dark cross shadows are the intermediate and acidic extrusives North boundary. Horizontal lines, marine sedimentation within the Neuquen. Magellan and Malvinas basins. In the white (within the basins boundary) are continental deposits. Dotted lines with arrows, positive units (uplifts), mainly igneous.

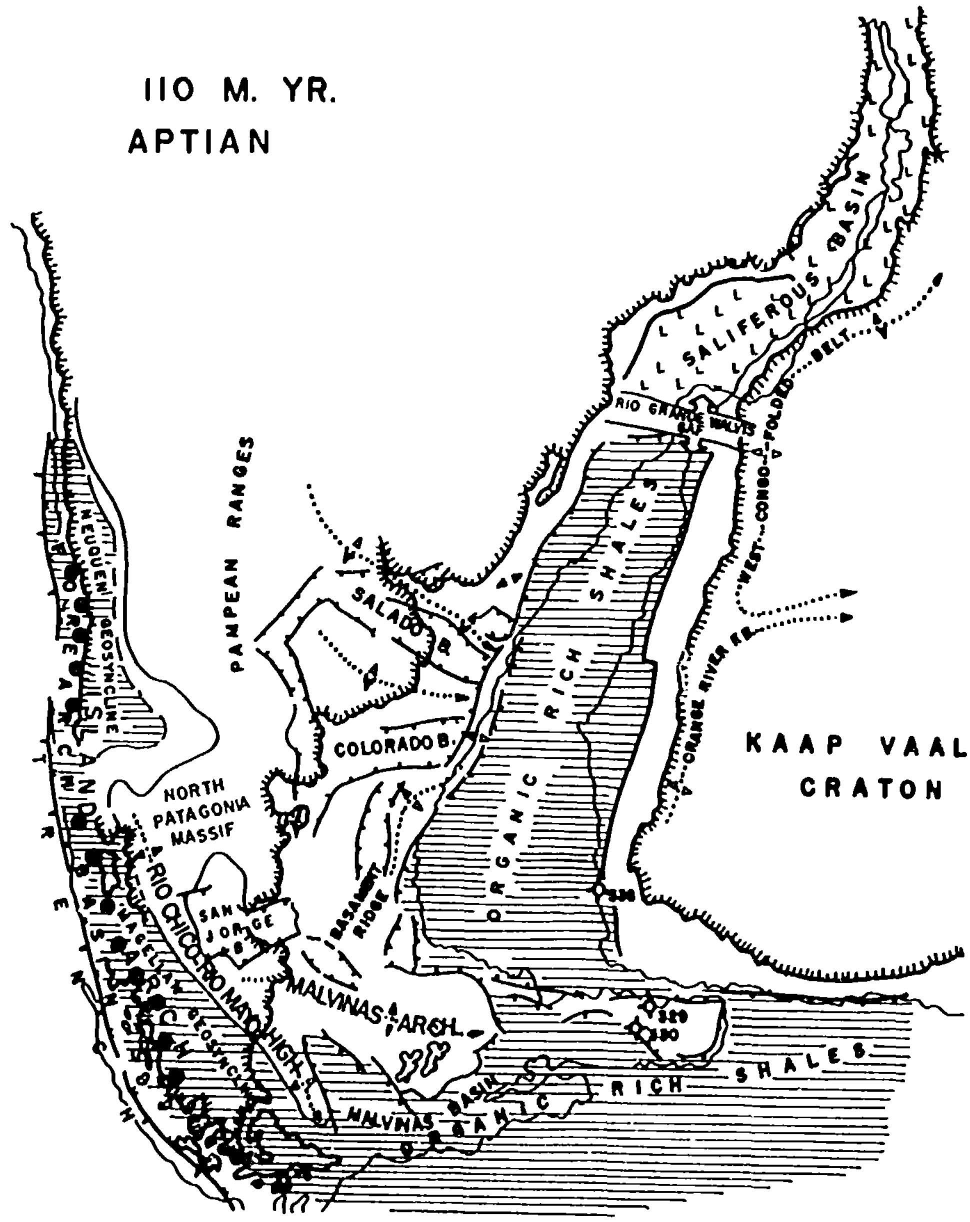
Fig. 4



125 M. YR. Lowermost Cretaceous reconstruction. Position of the continents prior to main spreading. Marine deposits were recorded only in the South on Western part of South America (Pacific province). In South Brasil the Serral Geral Basalts cover extends up to the Salado basin area. Colorado & Salado basin are rifts insepted perpendicular to the main spreading. In the Southern Cape province the transform zone generates the Malvinas - Agulhas fault lineament, it is extending also into the Mozambique channel.

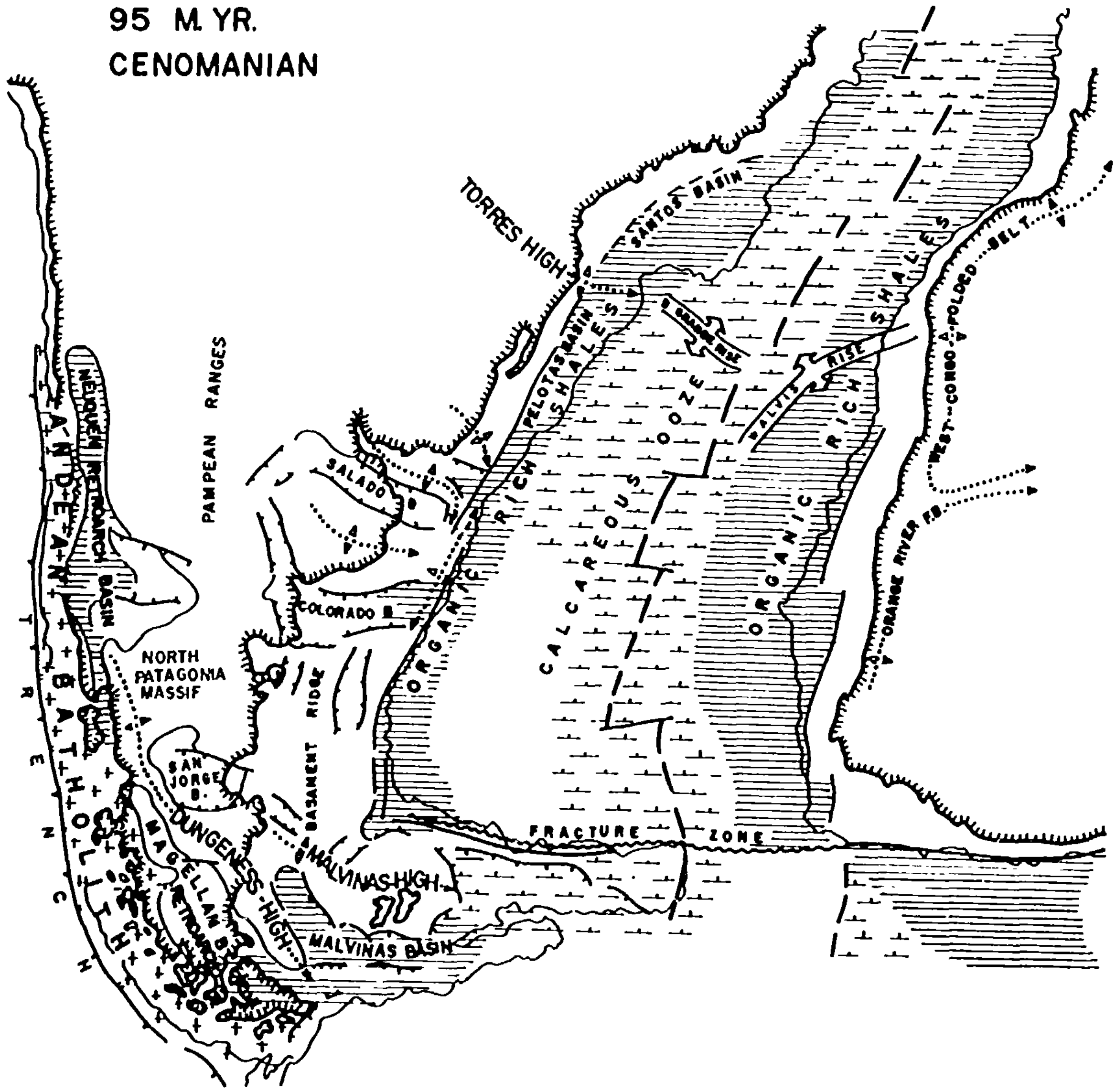
Fig. 5

110 M. YR.
APTIAN



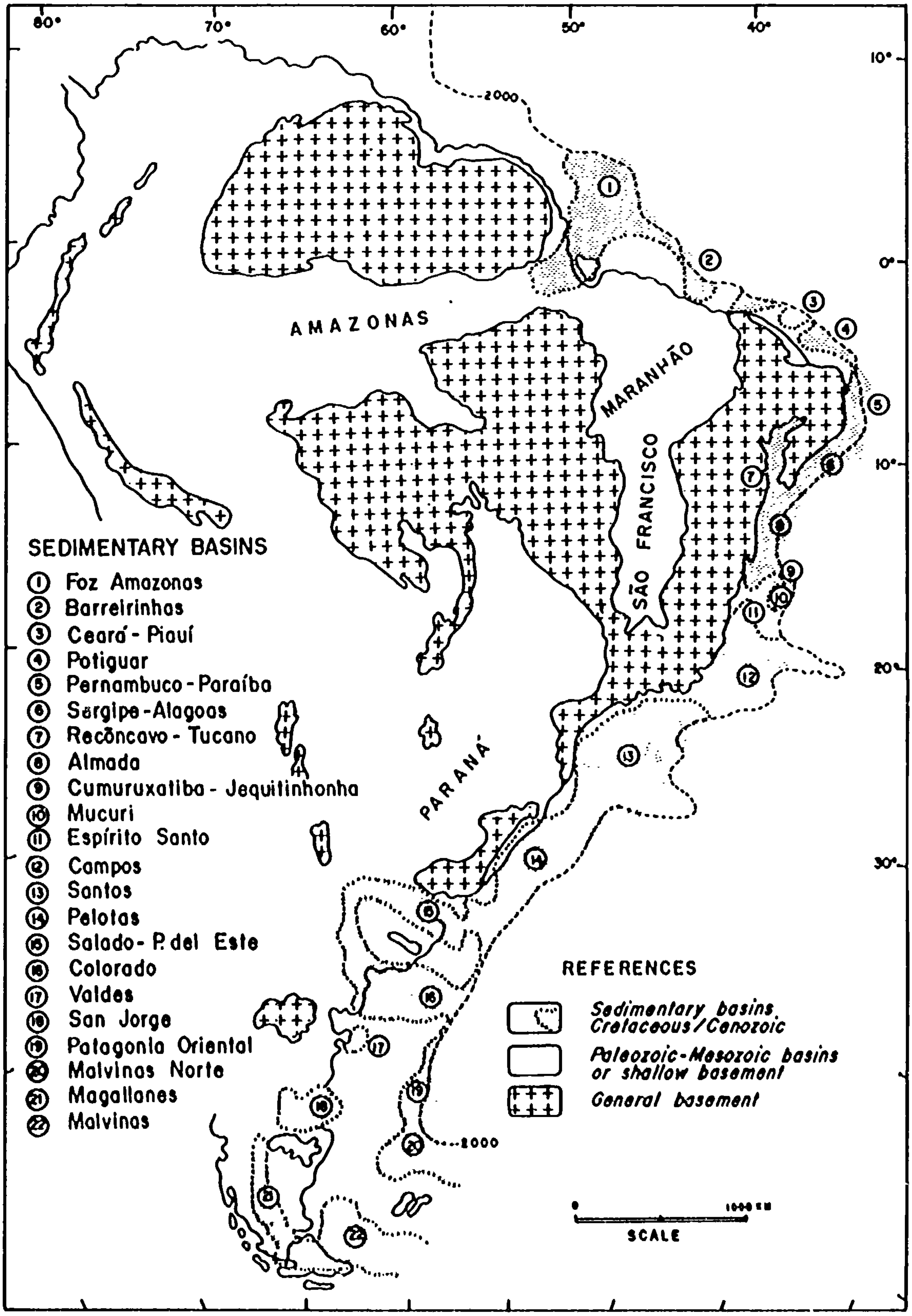
110 M. YR. Reconstruction during Aptain time. North to the Rio Grande - Walvis gap there are indications of a restricted low circulation basin with evaporites deposits under particular climatic conditions. In the South also low circulation conditions prevail with black marine shales sedimentation. Heavy line on the continents shoulder represent the Rabinowitz's Continental Oceanic Crust boundary. Most of shelf basins were filled with predominantly continental beds.
On the West, in Neuquen - Magellan geosyncline, an island arch and foreach basin are active on the subduction zone.

Fig. 6



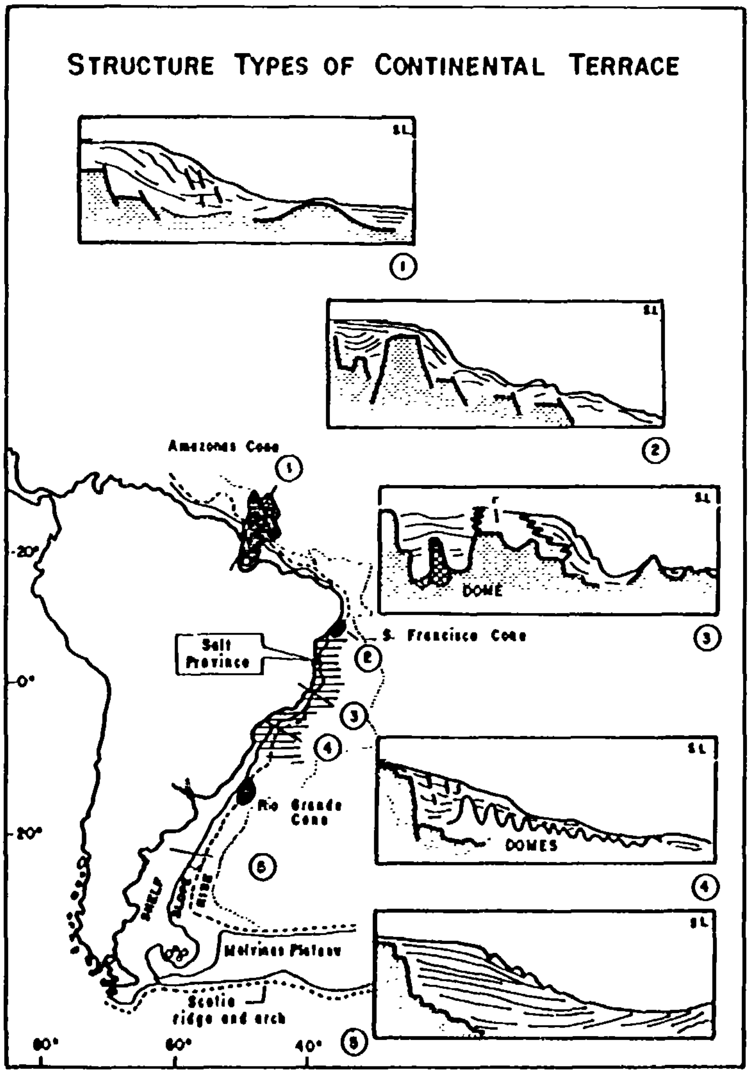
95 M. YR. Cenomanian Reconstruction showing the final opening stage of the South Atlantic Ocean. The Midd Atlantic Ridge and transformed zones were generated. The Rio Grande and Walvis Ridge subside from shallow to deep water, North of Malvinas Plateau and South to Cape a fracture zone is extending up to Mozambique chanel. In the Salado and Colorado basins the begining on the first marine deposition took place. In the Southern Magellan and Malvinas basins marine enviroments prevail. Farther North of Sa'ado carbonatic platform are predominant as well as on the West Africa continent shoulder. The terrigenous clastic and non clastics (organic rich shales) are predominant on the slopes and rise from Eastern South America and Western Africa. The western border of S. America is instruded by igneous due to the begining of the Andean orogeny.

Fig. 7



Main sedimentary basins of South Western Atlantic.

Fig. 8 *Modified from Urien and Martins, 1979*



CARACTERISTIC TYPES OF THE INTERNAL STRUTURE OF THE MARGINAL BASINS :

1 - Deltaic, prograding through the slope and rise.
2 - Faulting blocks
3 - Similar to ② but with development of reefs that encloses sedimentation centers.
4 - Sinked blocks through normal basin faults.
5 - Prograding type over the gradual sinked basement. The growth is predominantly deltaic.
The map shows the main zones of deep sea sedimentation (Cones) and the saliferous area north of Rio Grande Rise.

Modified from Urien and Martins, 1979

Fig. 9

Immediately after the development and opening of the rift valley, a gulf mediterranean type sea was formed between Africa and South America, north of Rio Grande and Walvis rise.

Shortly after the first marine water spilled over the Rio Grande - Walvis Ridge, evaporites were deposited over rift facies in all South Atlantic basins. This episodes took only a few million years and by Albian times shelf limestone deposition dominated these basins.

South of the Walvis Ridge there is little evidence from Atlantic shelf basin regarding to the nature of Aptian or immediate pre-Aptian deposition overlying non-marine clastics.

Thick sections in both shelf and deep sea at this time, compared with those north of the Walvis Ridge, are attributed to greater river activity.

North of the Walvis the excess of evaporation over precipitation not only permitted deposition of evaporites but also helped to limit the amount of fluvial activity in pre-Aptian time.

In the Cenomanian, South America continues to separate from Africa, and about this time most of the Rio Grande-Walvis complex drops below sea level.

The Cenomanian transgression (98 MY) was developed mainly at the north of Rio Grande do Sul, along the northeast and Brazilian basins. In the intracratonic basins of Salado, Colorado, Valdes and San Jorge the continental sedimentation is dominant.

The progressive sea level culminated in Maestrictian with the Upper Cretaceous transgression.

An extensive marine transgression covers the east part of the continent farther than the actual coast line mainly in the souther parts (Argentina). This is a shallow water epicontinental sea that covers the continental lowlands.

The sedimentation was more pronounced on the Cretaceous sedimentary basins, where the subsidence was marked.

During the Tertiary the continental shelf was submitted to successive transgression/regression processes, due to epirogenic effects, that was favourable to the development of several sedimentary depositional environments with different facies mainly controlled by latitude.

Thus, at the northeast of the continent the carbonate facies prevails combined with clastics of deltaic origin. To the south, mainly due to climatic control, the facies are conglomeratic, sandy and pelitic related to more proeminent hydraulic conditions and development of extense coastal plains and deltas, cyclic covered by the sea.

During the sea level fluctuations, the deltaic changes reached repeatedly the shelf border, furnishing clastic sediments to deep sea, through the activity of turbidity currents.

During the Oligocene, a great regression was observed and a large part of the continental shelf was exposed to subaerial conditions.

Paralic marine facies, predominantly carbonate in a large extension were developed beyond the south latitud of 42°.

In the Miocene, several changes occurred in the sea level, but smaller than in Maestricktian time.

This was responsible for the generation of prograding facies of the continental terrace and an increase of sediment accumulation in the continental slope and rise. Many depocenters started their development during this stage, like the Rio Grande cone described by MARTINS and URIEN, (1972) and MARTINS, (1984).

During the Pliocene and Pleistocene the transgressions and regressions were successive and cyclic along the continental shelf with the development of coastal plains barrier coast, estuaries, lagoons and deltas.

In these areas where the sedimentation rate was higher than the subsidence an accretion of the continental terrace was observed; on the contrary, where the subsidence was higher than the sedimentation rate, piling up of the sediments occurred.

In both cases, each megacycle (transgression-regression) was generally manifested with a sedimentary growth of the external continental terrace.

QUATERNARY GEOLOGY OF THE MARGIN AND COASTAL PLAIN

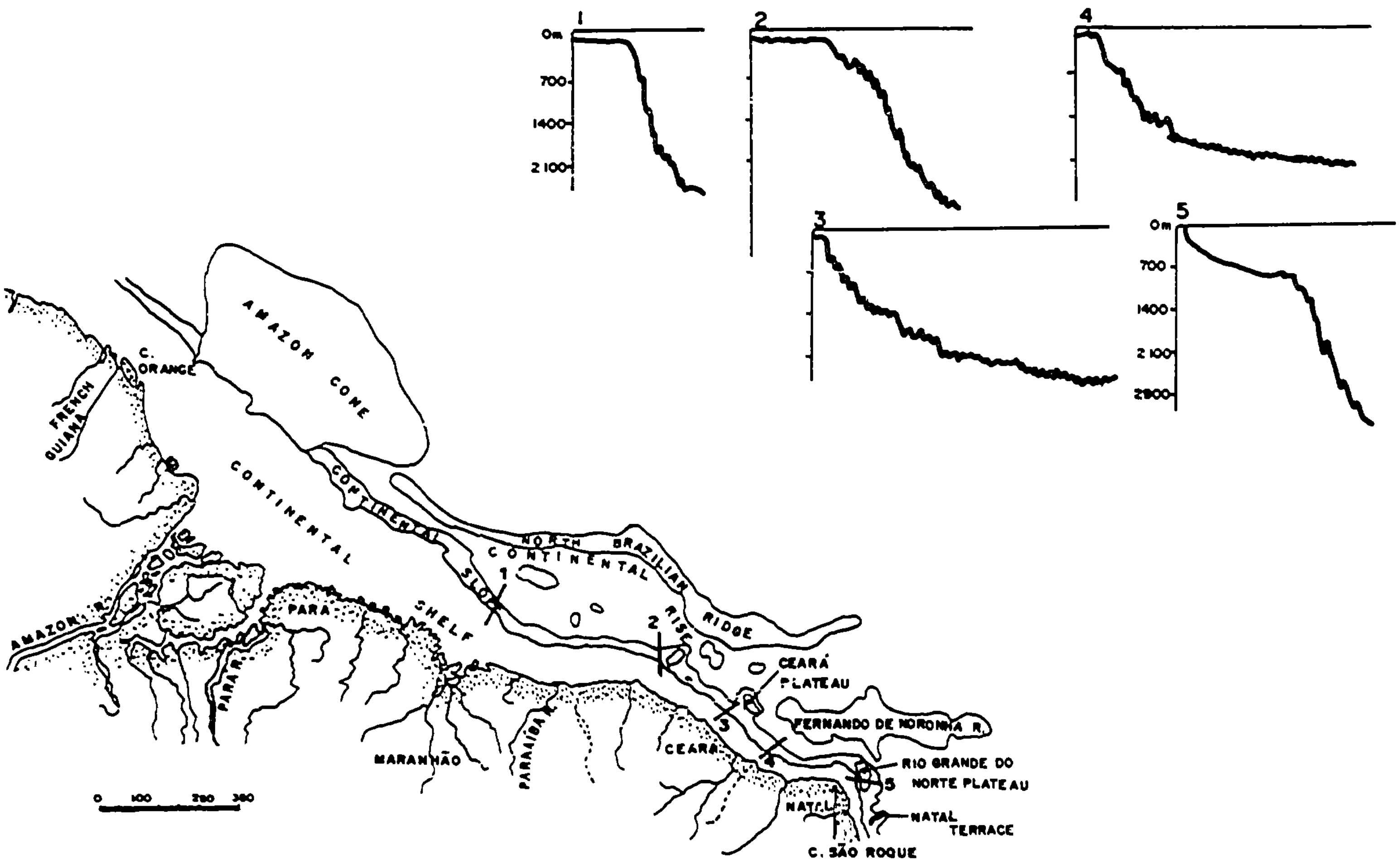
The main aspects of the Quaternary geology of the Southwestern South Atlantic can be summarized as follows.

2.1 Shelf

2.1.1 Physiography

Precision bathymetric sections and the most important physiographic units of the continental terrace are shown in Figs. 10 A to 10 E.

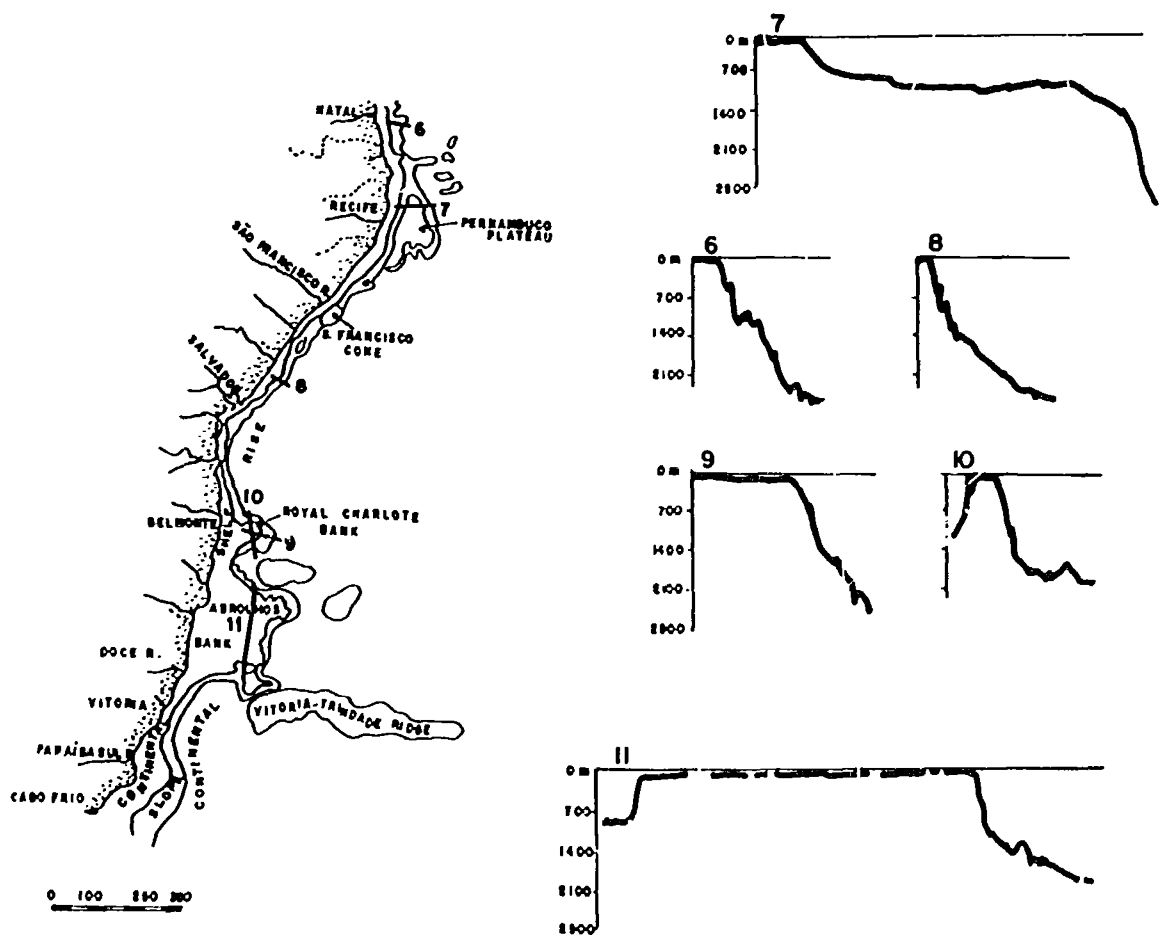
Seven physiographic provinces can be recognized and are discussed as follows:



Precision bathymetric sections (PDR) and most important physiographyc units of the continental terrace between Cabo Orange and Cabo São Roque. Observe the well-marked break and the passage to the marginal plateaus. (After Martins et al., 1975)

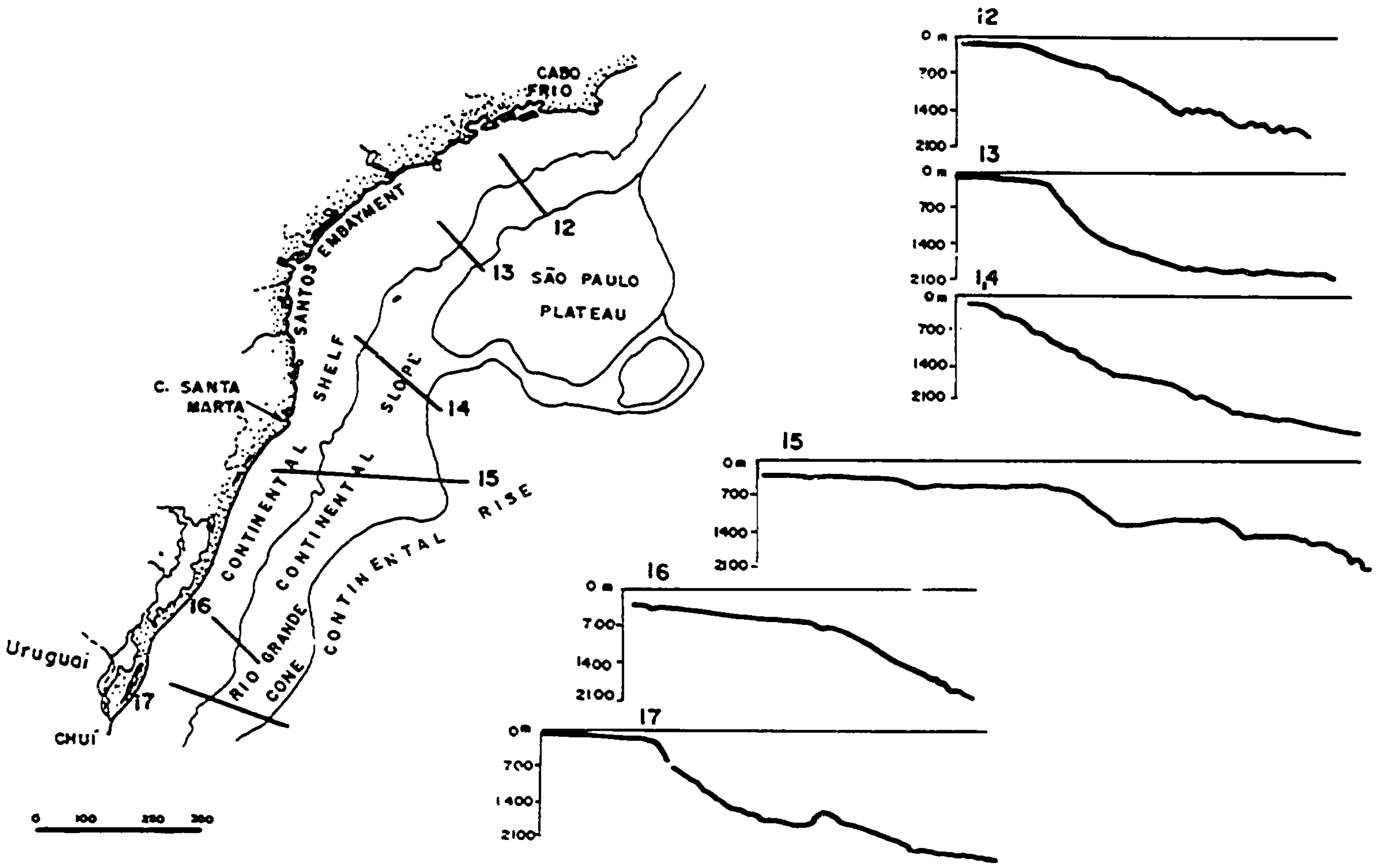
Fig. 10 A

D. Joyce Less



Precision bathymetric sections (PDR) and most important physiographic units of the continental terrace between Cabo São Roque and Cabo Frio. The narrowness of the northeastern shelf, the intermediate scarp between the shelf and the Pernambuco Plateau (section 7), and the Royal Charlote and Abrolhos Banks with their abrupt borders caused by their volcanic nuclei may be observed. (After Martins et al., 1975)

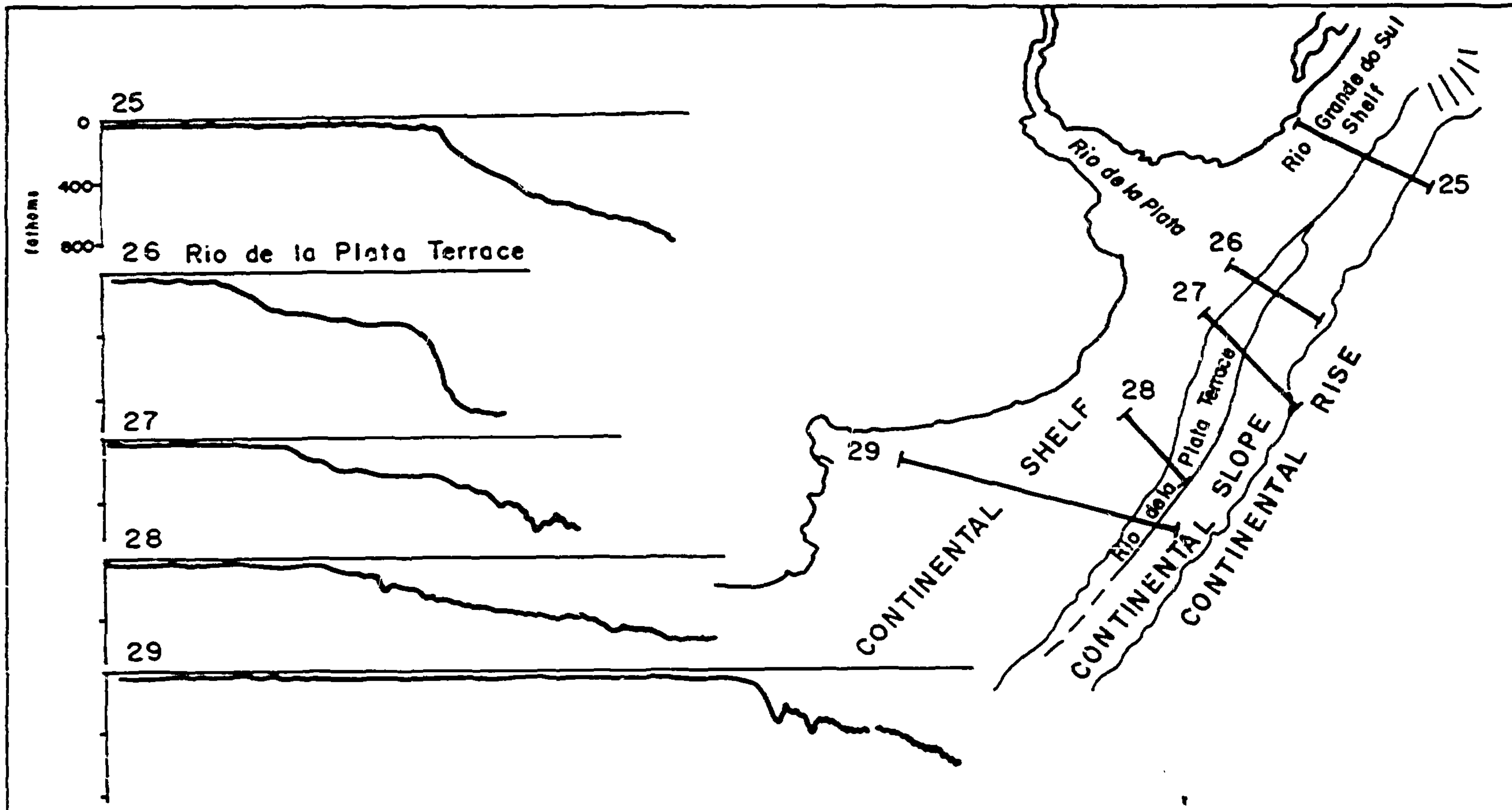
Fig. 10 B



Precision bathymetric sections (PDR) and most important physiographic units of the continental terrace between Cabo Frio and Chuí. Note the widening of the shelf from Cabo Frio southward, the gradual transition between shelf and slope without omission irregularities, the intermediate plateaus, and in section 17 the scarp at the base of the slope known as Pelotas Scarp. (After Martins et al., 1975)

Fig. 10 C

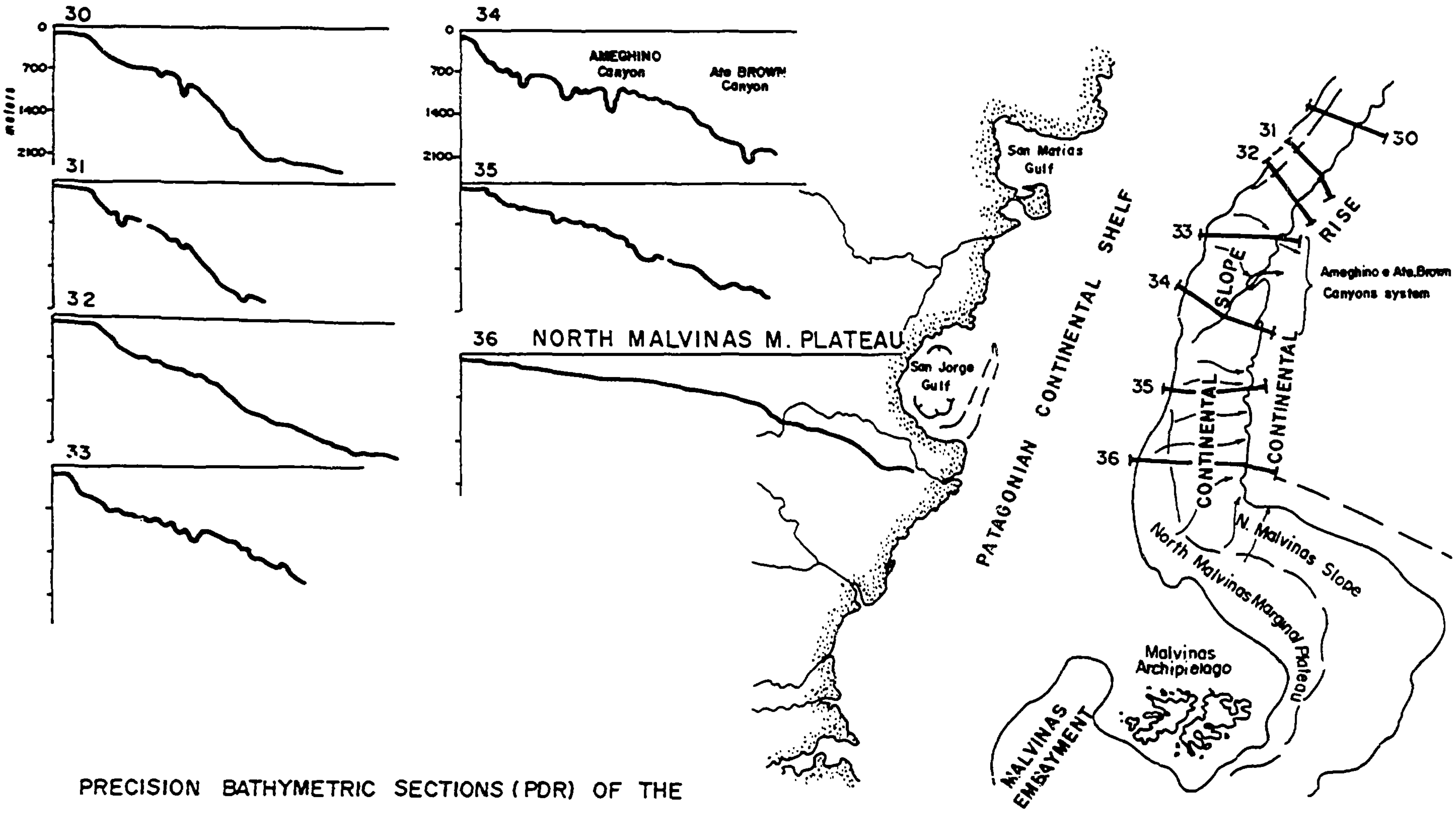
D. Joyce Loss



PRECISION BATHYMETRIC SECTIONS (PDR) SHOWING THE MAIN FEATURES OF RIO DE LA PLATA AREA. *After Martins et al., 1975.*

Fig. 10 D

D. Joyce Leon



PRECISION BATHYMETRIC SECTIONS (PDR) OF THE PATAGONIAN CONTINENTAL SHELF. *After Martins et al., 1975.*

Fig. 10 E

D. Joyce Less

Cabo Orange - Parnaiba Delta

In this region two sedimentary basins occur, the Amazonas and the Piaui-Maranhao (Parnaiba), both of them have been filled in Paleozoic times and later reactivated in response to continental rifting during the Late Jurassic and Early Cretaceous.

The Piaui-Maranhao Basin has at its northern flank two smaller and younger basins, São Luiz and Barreirinhas (MABESOONE et al., 1981).

The shelf is the widest in Brazil varying between 330 km. off the Amazon River and 100 km. near the Parnaiba river mouth. The depth of the shelf-slope break ranges from 120 m. off the Amazon to 80 m. off the extreme east of the area. Although the major part of the shelf is broad and flat, a few features are noteworthy. For instance, while the inner shelf northwest of the Pará River presents a flat surface 0 to 30 m., in depth, built up by present-day Amazon sedimentation, the major part of inner and middle shelf east of the Pará River is characterized by symmetrical and asymmetrical sand waves, 5-10 in amplitude and with average wavelengths between 100 and 500 m. The outer shelf and the upper slope are incised by numerous gullies and canyons, with those of the Amazon and the Saldanha being the most important. Probably these features represent a Pleistocene fluvial system not buried by subsequent sedimentation.

The most proeminent feature of this region is the Amazon Cone, one of the largest deep-sea fans in the world. In spite of its great sediment thickness the cone is a young feature, estimated to be 22 million years old (Early Miocene). This means that no great quantities of terrigenous sediments were supplied to the outer shelf before the Early Miocene, and this material probably remains until that time behind barriers located at the edge of the present-day shelf.

The Amazon Cone causes a discontinuity in the continental slope of the region, which is rather narrow (maximum width of 45 km) and is cut by various valleys and canyons.

Actually, delta and cone are disconnected due to the sea-level rise which covered the Amazon and Maranhao plains, although the presence of paleochannels and a system of abandoned cayons can be observed. These paleochannels permit a reconstruction of the coastal retreatment in response to the last rise of sea level.

The marked widening of the Amazon shelf is partially due to the sedimentation of the Amazon system with its complex of deltas and estuaries. Among other features one may observe buried channels normal to the shelf-break zone, beach ridges, and marine terraces with a smooth surface.

Thus, due to the voluminous recent sedimentation, there is almost no real shelf break, but a gradual transition from shelf to slope, with a few erosional steps, between the depths of 145 and 220 m.

The foot of the continental slope appears as well defined feature on both sides of the Amazon Cone, extending from the base of the slope to depths of 3660 to 4000 m., with the North Brazilian chain as its outer limit.

Parnaiba Delta - Cabo São Roque

From the Parnaiba delta up to Cabo Sao Roque, where it curves towards the south, the coast is more or less straight, with a semi-arid climate and rather high, moving coastal dunes, behind which lagoons and marshes are common. The environment is favourable for salt pans which produce the major part of the salt consumed in Brazil.

In this region the shelf becomes considerable narrower, with a width of about 30 km. near Cabo São Roque; the shelf break starts at a depth of about 80 m. and decreases in the direction of northeastern Brazil where it may attain depths of only 40 to 50 m. The most important traces of the continental terrace are the plateaus and marginal terraces off Ceará and Rio Grande do Norte states as well as a series of submarine seamounts parallel to the continental margin, separated from the shelf by a rather abrupt scarp. The presence of small terraces and remainders of ancient reefs has not yet been described.

Besides these features, the North Brazilian and the Fernando de Noronha chains play an important role in the morphology of the region. The first chain was initially described by HAYES and EWING (1970) as a continuous feature, probably of volcanic origin, extending alone the whole of the northern Brazilian shelf. Recently, KUMAR, et al., (1976) showed this ridge to be discontinuous, with at least three segments consisting of isolated seamounts. The North Brazilian chain acted as a sediment trap until the beginning of the Early Miocene. The Fernando de Noronha chain is a line of seamounts of which only Fernando de Noronha and Atol das Rocas reach the surface.

At the margin of the continental shelf, one may observe sedimentary structures of deltaic origin and zones of active abrasion formed during the Pleistocene. These represent an important factor in the modelling of the present form of the shelf and especially the upper slope where wave action left traces of a series of steps down to a depth of 150 m.

Cabo São Roque - Belmonte

From Cabo São Roque southward, the coast is characterized by Cenozoic sediments of the Barreiras Group, of semi-arid type, constituting a surface which abruptly terminates at the coast against rather steep cliffs. The most remarkable features are, however, the sandstone "reefs" (beach rocks) which occur in various lines parallel to the coast. These "reefs" form a certain protection for this coast.

The shelf of northeastern Brazil is typical for its reduced width and shallow depths when compared with other parts of the Brazilian submerged platforms. This reduced width seems to be related to the low continental erosion rate and the small zone of marine sedimentation (SUMMERHAYERS et al., 1976). The shallow depth is attributed, by some authors, to inefficient marine erosion process during the Pleistocene, acting upon a narrow and abrupt continental terrace, and to recent uplift. In addition there is the constant presence of the Brazil Current that is directed towards the southwest parallel to the shelf.

The shelf width varies from 42 km. off Maceió to 8 km. off Salvador, with an average of 30 km. Its greater part has a depth of less than 40 m. and its edge occurs at 50-60 m. Nearly all bathymetric sections show multiple breaks, corresponding to terraces at the shelf margin (BOYER, 1969).

The most important feature of this region is the Pernambuco Plateau with an irregular surface, composed of an upper level between 700 and 1250 m. and a lower terrace at 2000-2400 m. (ZEMBRUSCKI et al., 1972).

The surface of the shelf bottom is somewhat irregular, cut by a net of narrow and shallow channels and has a typical erosional hummocky topography. The hummocks are slightly rounded with reliefs of 2-6 m. and diameters of 2 km; they are particularly at the middle shelf north of the São Francisco river mouth (SUMMERHAYES et al., 1976).

On the inner shelf the presence of lines of beach rock, often covered with coralline algae, constitutes the chief topographical feature (MABESOONE and COUTINHO, 1970). From the São Francisco River southward, the topography of the inner and middle shelf becomes more regular, with disappearance of the hummocks due to increased river contribution. But north of this river shelf bottom relief is more irregular with an erosional pre-Pleistocene topography due to absence of important fluvial supply. Off the river, its sediments form a cuspidate delta with a morphology reflecting the predominant effects of high-energy waves (BACOCCOLI, 1971; COLEMAN and WRIGHT, 1972). The absence of relief irregularities on the outer shelf may point to the fact that at present the reef-forming organisms are not active in this zone. This may be because of unfavourable living conditions or because of excessive turbidity produced by the biodetrital sediments with a high mud content present in the area.

From the Pernambuco Plateau southward to Belmonte, the continental slope presents a few seamounts, and within its relief, the canyons of São Francisco, Japaratuba and Salvador. Typical are the abundant structural terraces bound to a system of faults as well as to the presence of various slump scars. The slope is generally very abrupt, with an average width of 30 km., becoming locally narrower off the canyons.

Belmonte - Cabo Frio

This eastern coast (SILVEIRA, 1964) is characterized by a great number of beach ridges. The recent sedimentation of the area is abundant. More towards the south, where the shelf becomes wider and flatter, there exists a number of coral reefs, for instance the Abrolhos Bank.

In this portion of the coast the width of the shelf is very irregular due to the development of extensive biogenic formations on top of banks of volcanic origin. The shelf is unusually shallow, often less than 60 m. deep, with its edge at a depth of only 70 m.

The innermost shelf, above a depth of 20 m., is generally smooth due to burial of the topography by Holocene sedimentation. The bottom surface of the middle and outer shelf is rougher because of the many small banks and steep-walled narrow channels which probably represent a Pleistocene drainage system (MELO et al., 1975).

On the shelf of this zone, the Doce and Paraiba do Sul river deltas developed; they are related, through almost buried channels, to a large embayment south of the banks, called Espirito Santo basin. Both deltas played an important role on the prograding shelf border where deltaic fronts alternate with submarine terraces at depths between 44 and 141 m.

The Abrolhos Bank, of great structural importance, lies at a distance of about 120 km. off the coast, with a width of 180 km. and a surface area of about 35,000 km^2. This bank of volcanic substratum presents a variable physiography with reefs, canyons, marginal terraces and a wide lagoon surrounded by pinnacles of dead corals and covered with biodetritic sediments. The Royal Charlote Bank extends 95 km. east of the coast, forming a plateau about 46 km. wide. Its top is flat, with channels up to 30 m. deep. Other seamounts, such as the Vitoria and Besnard banks, also present flat tops at depths between 50 and 80 m. The coastal reefs are absent south of the Abrolhos Archipelago.

Cabo Frio - Cabo Santa Marta

The shoreline of this region is characterized by sandy beaches with intermittent rocky headlands. Coastal lagoons bounded by barrier ridge systems are predominant off Cabo Frio. Another particular feature of the southeastern region is the small area drained by the rivers. These are short and carry only little suspended material, the major part of which is deposited in estuaries and coastal lagoons.

From Cabo Frio towards the south the coastline is convex and the continental terrace begins to widen, forming various steps as well as the Santos embayment as a response to the subsidence of the basement of the Sao Paulo Plateau. The shelf width in this region varies between 90 and 210 km; the break occurs at depths between 150 and 185 m., showing a smooth dip and a more gradual transition at greater depths that is different from the other zones. On the other hand, in the zone with marginal terraces, the break is more prominent due to the presence of a small scarp.

In this region the features of the shelf are more modern owing to the fact that the surface deposits, chiefly terrigenous, have been reworked during the Holocene transgression. The presence of elongated banks parallel to the bathymetric lines suggests the existence of ancient littoral zones. Superimposed on these banks are submarine dunes, the product of the reactivation of the bottom caused by the new hydraulic regime.

The continental slope is broad, with a weak relief and a gentle inclination, suggesting the predominance of depositional process. The same influence of sedimentation in the morphology of the continental margin of this region is observed at the foot of the continental slope which has a width of 300 km. off Cabo Frio, increasing to 400 km. southwards.

The most important morphological expression of the area is the Sao Paulo Plateau, with a complex topography, already described by BUTLER (1970). The plateau extends for some 200 km. between the isobaths of 2000 and 3000 m. and it seems not to be limited by a steep scarp at the ocean side as is suggested by some authors. On the contrary, there exists a progressive transition between the plateau and an almost flat continental rise, pierced by two large seamounts (MASCLE and RENARD, 1976).

Cabo Santa Marta - Buenos Aires

From Cabo Santa Marta southward the coast presents a set of well-developed beach ridges and wide plains within which strings of lagoons appear, some completely closed, others connected with the sea.

In the State of Rio Grande do Sul (Brazil) the dip of the continental terrace diminishes gradually, presenting a marked deltaic progradation (BUTLER, 1970). The average shelf width is 125 km, with maxima 180 and minima 100 km. The shelf break is generally transitional, without plateaus and marginal terraces. In contrast to other regions of the Brazilian continental margin, its southern part is not crossed by any important canyon except the Rio Grande Valleys (ZEMBRUSCKI et al., 1972). Another typical feature of this area is the occurrence of many depressions that run parallel to the coast on the middle shelf, apparently Late Quaternary analogues of the modern coastal lagoons (MARTINS et al., 1967; ROCHA et al., 1975).

These relic mid-shelf lagoons contain very special sediments. Some of the bathymetric records show steps near the shelf margin, possibly erosional features related to lower sea-level stands.

The shelf surface shows minor features such as ancient banks, submarine dunes and barriers parallel to the present coastline. At the shelf margin there still exists traces of channels belonging to a drainage network on a submerged coastal plain.

On the inner shelf a typical barrier coast developed with growing barriers parallel to it as a consequence of the new hydrodynamic regime (FIGUEIREDO, 1975). There also occur typical estuarine river mouths through which much fine clastic material is supplied. Bands of beach rock and buried channels have been observed south of Rio Grande, as probable relicts of the Rio de la Plata drainage on the coastal plain of Uruguay and Rio Grande do Sul (URIEN and EWING, 1974; URIEN et al., 1976).

One of the most remarkable features of the eastern South America continental margin is the gradual widening of the continental shelf south of 32°S. The structural units that control the physiography and continental margin morphology are the Brazilian shield, the Buenos Aires hills, the Patagonia massif; and post-Jurassic negative units such as Pelotas basin and the Salado-Colorado basins (URIEN, 1970). The uppermost expression of this basin group is present in the lowland and coastal plain complexes such as the Rio Grande - Rio de la Plata and the Bahia Blanca-Colorado coastal plains.

The coastal plain and continental shelf in this area have subsided slowly. During Late Tertiary times they were subject to alternate periods of transgression and regression, subsequently accumulating a considerable amount of sediment (URIEN, 1972). About 18,000 years ago, a worldwide transgression from approximately the shelf border (-140 m.) up to the present sea level took place. At that time the shoreline transgressed the coastal plain and was stabilized, after some fluctuations, approximately in its present position.

To the south the continental shelf width increases, with prominence of a new sediment source (fluvial supply of the Rio de la Plata) that represents the major depositional feature of the area.

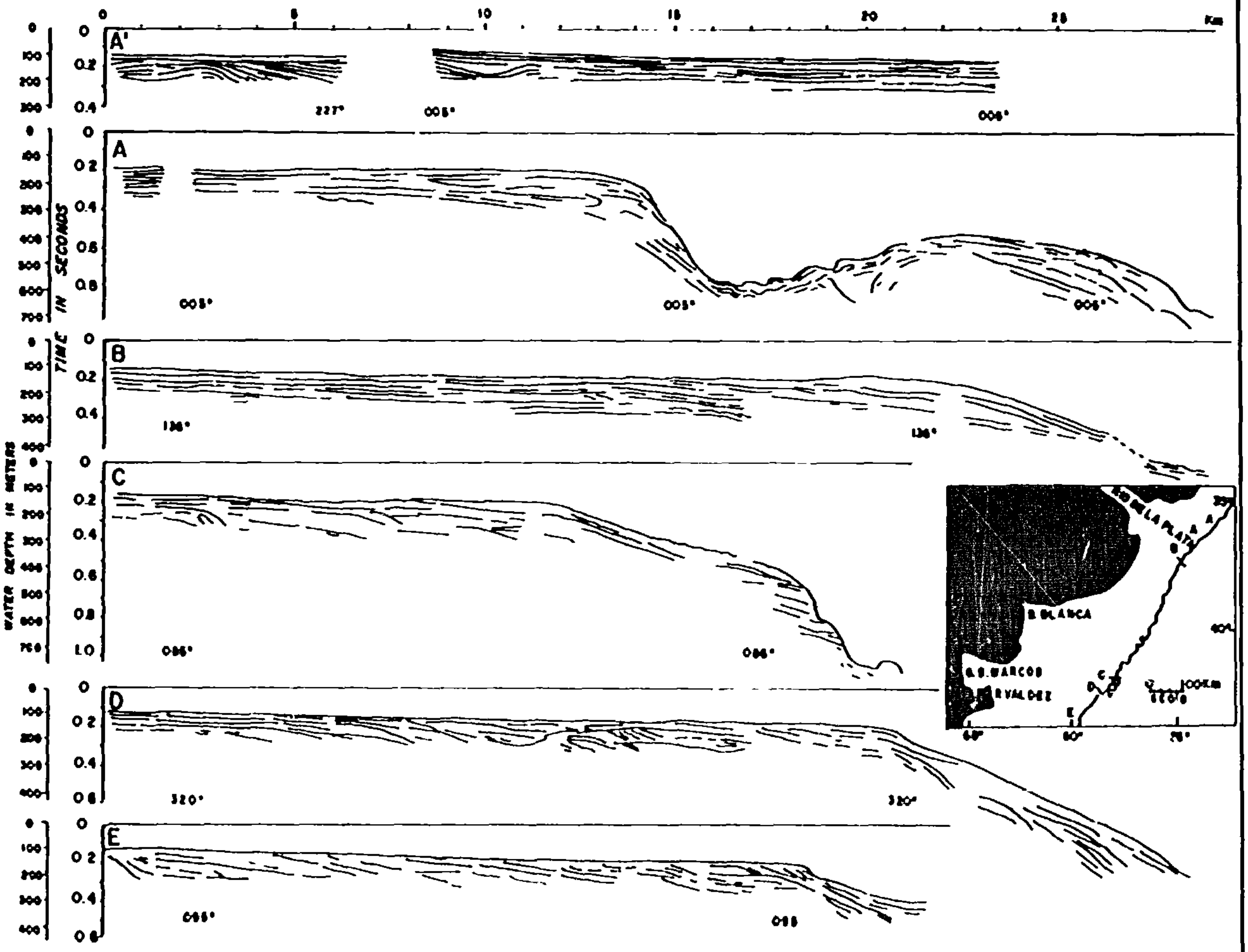
A large part of the topographic features are possible related with an old delta system that had reached the shelf border, creating a series of remarkable forms between 68 and 620 meters.

Seismic reflection lines (Fig. 11) show a series of prograding layers in th modern shelf sediments including the shelf border (LONARDI and EWING, 1971, URIEN and EWING, 1974, URIEN and MARTINS, 1980).

These patterns suggest a very modern delta front, build up during the last sea-level lowering, which overlies several overlapping Quaternary and perhaps also late Tertiary deltas.

Three principal topographic features are present on the continental shelf; ridges, steps and channels, that may be classified as depositional or erosional. (Fig. 12).

The depositional features are ridges parallel to the shelf strike, marking sea level stands.

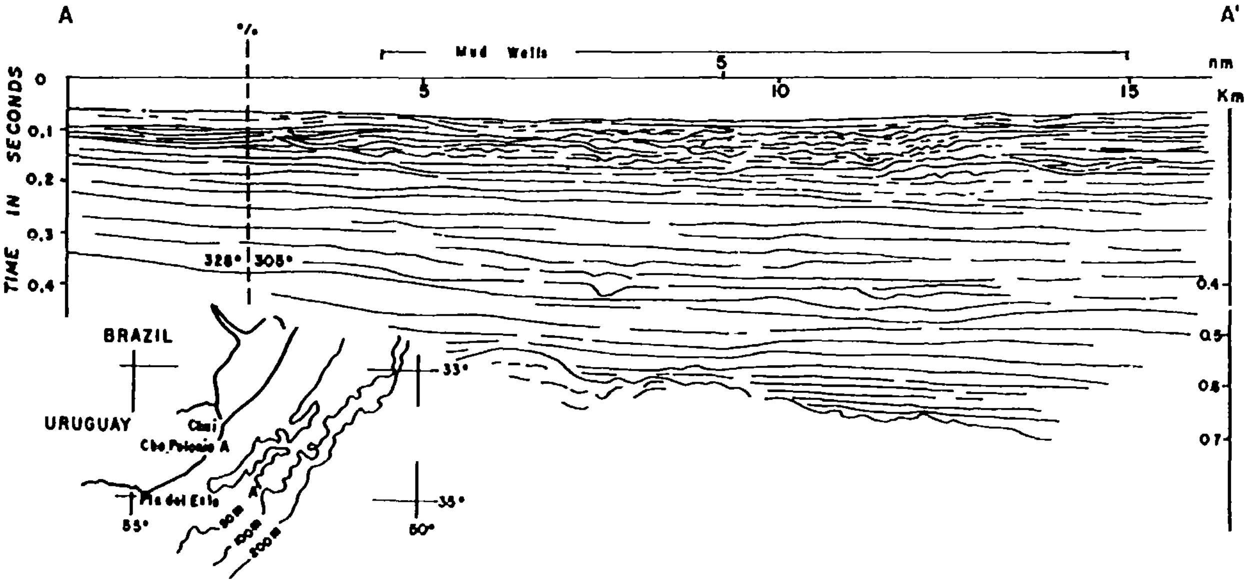


Seismic reflection records across the shelf border from off Rio de La Plata to Punta Valdez. Section A – A' parallel to the shelf edge shows a series of sediment-filled channels. Section A shows prograding layers, a delta - like front.

At km. 15 - 20, line A crosses a canyon and the Rio de La Plata terrace. The other sections also show deltaic prograding layers, some of then outcropping on the slope (Section C)

According to Urien and Ewing, 1974, Urien, Martins and Martins, 1980.

Fig. II (A)

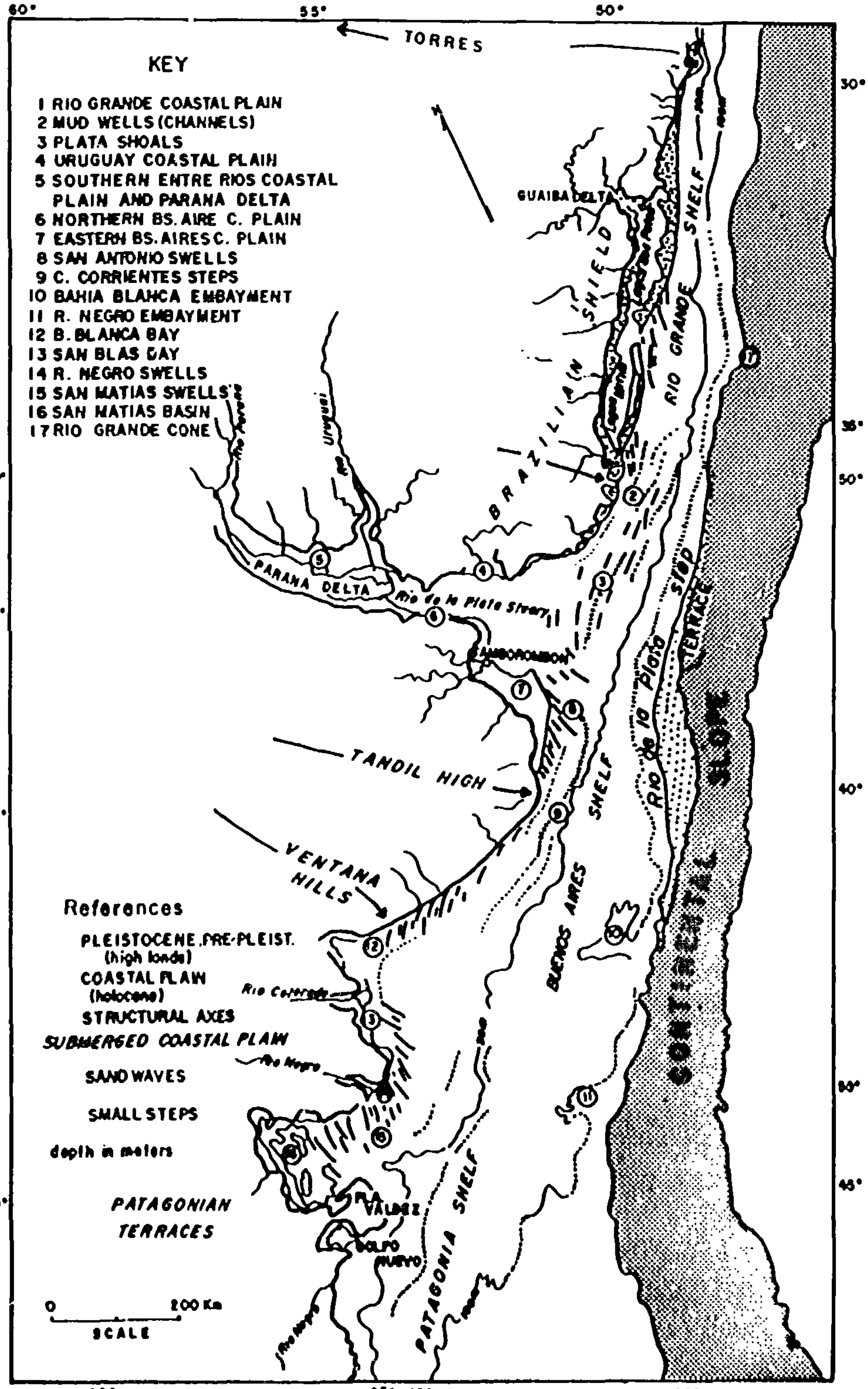


Seismic reflexion profile off Uruguay, crossing the "mud wells."
The reflectors show a series of overlapping and buried channels.

According to Urien and Ewing, 1974; Urien, Martins and Martins 1980.

Fig. II (B)

D. Joyce Loss



Main physiographic and topographic features of the Rio Grande do Sul (Brazil), Uruguay and Buenos Aires continental shelf and the salient morphos - tructural onshore units. *Modified from Urien and Ewing, 1974*

Fig. 12

The most prominent of these is close to the Rio de la Plata mouth, forming a "barrier complex" which possibly partially closed the estuary in the recent past.

Between the complex "Plata shoal" and the shore, a channel extends from the Rio de la Plata into the inner shelf.

Several reflection lines took at the latitude of Cabo Polonio (Uruguay) show a series of imbricated buried channels which shift westward, perhaps as a result of sea-level rising.

South of the "Plata shoal", close to the shore, there are a series of sand waves or submarine dunes similar to those seen in desert areas, with heights of 5 to 12 meters, some of which are oblique to the shore and more or less parallel to the tidal currents.

These forms are also found in southern Buenos Aires, close to Bahia Blanca and San Blas and are superimposed in front of the entrances to San Matias Gulf, where they are 4 to 17 meters high. (PIERCE, 1969). These waves may be active, but only in shallow areas with high tidal currents which mobilize the sand bottom as in the San Matias and San Blas shallow areas.

The erosional features are small steps, 3 to 10 meters high, most of them buried by sediments, following the topographic contours.

They are related to wave-cut abrasion platform and the most spectacular step occurs in the Rio de la Plata area at a water depth of 80 meters. It is related to a delta front, probably built up during sea-level lowering.

Buenos Aires - Patagonia

The Argentine continental platform has no marked topography, and it is possible to observe the gradual change from continental platform to continental slope and continental rise. The Malvinas Plateau is limited to the north by the Malvinas scarp and to the south by the Scotia ridge and is one of the most prominent physiographic features of the region. The Argentine coastline shows a development of large bays and gulfs, which to a certain extent reflect the underlying sedimentary basins. The change from continental flatform to continental slope is sharp close to Uruguary and South Brazil (the shelf break is around 50 m.); further to the south the plateau increases in width with a passage to the slope around 100 m. The Malvinas Plateau has an average depth of 2000 m. Its northern flank is delimited by a major scarp trending at 250^{0} and descending directly into the Argentine abyssal plain. The Malvinas chasm extends to the southern part of the plateau thus isolating the Burdwood bank from the rest of the continental platform. To the west of the Malvinas Islands is the Malvinas embayment which partially separates the Malvinas Islands from Tierra del Fuego. South of this region there is the Scotia Arc which ends abruptly at the southern limit of the Argentine margin. This structure has controlled the evolution of the southernmost part of South America.

Here the continental terrace, mainly the continental shelf presents its maximum width, (> 500 km.) and the continental slope is steep and cut by several submarine canyon systems with coalescent cones occurring along the continental rise.

According to URIEN et al., (1972) the continental margin width is not due to acrescent sedimentary process, but to the extension of two Patagonian massifs.

The sedimentary cover in the area is less than 1.000 meters, with an average of 500 meters.

The continental border is considerably distant from the actual coast line and the entire area, as a continent extension to the east like a peneplain surface rested semi-emersed since the Early Cretaceous to the Maestrichian transgression time and sunk subsequently through tilting movements, as the result of the Andean orogeny.

2.1.2 Surface Sediments

The sedimentological maps of the South Atlantic shelf show that the major part of the deposits are relict, followed by detrital, biogenic, and accessory authigenic deposits.

In fact, the surface of the eastern South American shelf underwent, during the Quaternary, phases of submersion and exposure, chiefly due to eustatic sea-level variations.

About 15.000 years BP, at the end of the Pleistocene glaciations, a rapid sea-level rise caused submergence of the coastal plain.

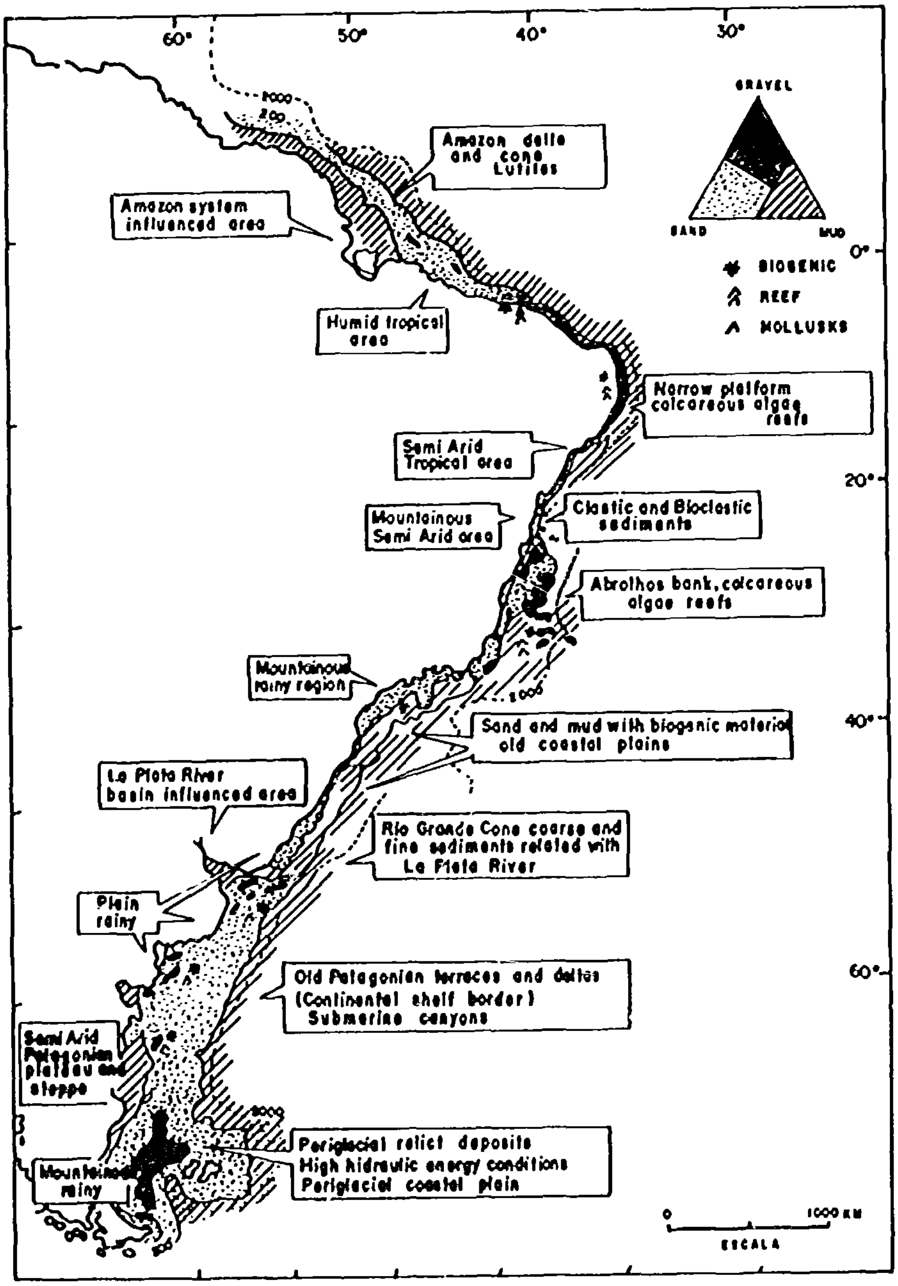
Available data suggest that the Holocene transgression stabilized about 3.000 BP and the sea-level has remained at its present position with only few oscillations.

MARTINS et al., (1973) subdivided the continental shelf into at least four domains: modern, (detrital and biogenic) relict, palimpset and glacial.

URIEN and MARTINS (1979) showed the distribution of the main sedimentary textures along the continental shelf and slope (Fig. 13).

Maps about the distribution of the sediments of the western South Atlantic were published by MARTINS et al., (1972) URIEN & MARTINS (1974) and REMAC Project (1979).

According to the physiography and sedimentary regime, the surface sediments of the region can be summarized as follows.



Distribution of the main surface sedimentary textures along continental shelf and slope. The gravel texture includes either calcarecus or terrigenous material.

Modified from Urien and Martins, 1979

Fig. 13

D Joyce Loss

Cabo Orange - Parnaiba Delta

Sedimentation in this region is chiefly terrigenous at the inner and middle shelf parts, changing gradually to biodetrital sediments of relict type towards the shelf break. The sediments near the shelf edge appear to have been derived from a series of shelf-edge reefs, as elsewhere in the world (MILLIMAN, 1974). Another characteristic of the outer Amazonian shelf is the presence of high-magnesium calcite ooids at a depth of 120 m. that were deposited during the last low-sea-level stand (MILLIMAN and BARRETO, 1975). The major part of the carbonate sediments is thus relict, although some mixture of modern and ancient material may occur.

To the northwest of the Amazon and Pará Rivers the terrigenous sediments are chiefly pelitic, occurring mainly on the inner shelf, whereas more towards the southeast this zone is chiefly sandy quartz.

The mud lens off the Amazon mouth is modern, the product of river discharge trapped in this area. Part of it is transported by the North Brazilian Coastal Current toward the Guyanas coast and differentially deposited by the physical-chemical and dynamic action of the sea water.

The sandy terrigenous sediments northwest of the Pará River contain sub-angular to subrounded quartz grains, have a subarkosic to protoquartoze composition, and contain a heavy mineral association of hornblende with enstatite and hyperstene. East of the Pará River and along the coast of Maranhão State, the sandy sediments become gradually more rounded, with an orthoquartoze composition and a fairly stable heavy-mineral association of staurolite, tourmaline and zircon. Finally, between the São Marcos Bay and the Parnaiba River delta a great quantity of kyanite occurs (BARRETO and SUMMERHAYES, 1975). The major part of the coarse terrigenous sediments of the middle and outer shelf is relict, deposited during the last low stand of sea level and the subsequent Holocene transgression.

The Amazon muds as well as the sublitoral sands are poor in $CaCo_3$, but towards the outer shelf carbonate content increases due to the presence of pebbles and sand of calcareous algae, foraminifera, bryozoans and mollusks. The rapid terrigenous sedimentation covers the carbonate grains and buries potential areas of attachment for the benthic community.

Summarizing only little modern sediment from the Amazon escapes from the coastal environment; much of it is deposited inside the estuary proper or transported toward the northwest along the shore and innermost shelf by the longshore currents.

MARTINS (1976) discussed the major sedimentary province and different from MILLIMAN et al., (1979) studies, established the transport mechanism of the Amazon modern suspension load along the inner shelf of Amapá, and Guyanas.

Offshore transport of Amazon sediments occurred primarily during glacial times, when sea level was lowered sufficiently to allow escape to the deep sea.

Parnaiba Delta - Cabo São Roque

From the Parnaiba river mouth towards Cabo São Roque, the shelf becomes gradually narrower, accompanied by a decrease of terrigenous sedimentation and an increase of biogenic and biodetrital sediments.

The terrigenous sediments are represented by quartz sands and muds, with the latter restricted to the river mouths and with some rare occurrences on the inner shelf. Patch reefs occur at depths above 20 m. (MABESOONE and COUTINHO, 1970).

The quarts sands are chiefly angular to subangular, well sorted and negatively skewed, suggesting accumulation under high-energy conditions. These sediments are orthoquartzose on the inner and middle shelf and become arkosic towards the outer shelf. The heavy-mineral association is quite mature, dominated by kyanite up to the Jaguaribe river mouth and by andalusite more to the east. The clay fraction is dominated by illite. These nearshore sands are poor in $CaCo_3$, with mollusk and occasional benthic foraminiferal assemblages. Among the latter, miliolids are the most abundant, chiefly in the muddy deposits. Apparently the sands of the inner and middle shelf are relict and completely reworked.

The biogenic carbonate sediments are represented by pebbles and sand of branching and encrusting coralline algae (Lithothamnium and Lithophyllum) and of Halimeda. The latter occurs more frequently on the outer shelf.

The carbonate sediments cover the whole of the middle and outer shelf as well as all the banks off this area when situated at depths of less than 100 m. The boundary between these deposits and the terrigenous sands of the inner shelf is fairly abrupt.

Cabo Sao Roque - Belmonte

The continental shelf of this region is extremely narrow, shallow, and almost entirely covered with biogenic carbonate deposits.

Various factors favour the development of carbonate sedimentation, such as the existence of a semi-arid climate on the continent which results in a reduced supply of terrigenous material. This permits favourable conditions of salinity, temperature and water transparency for the growth of calcium-carbonate-producing epifaunal organisms (KEMPF, 1970a). Only at the innermost part of the shelf, the high wave energy creates unfavourable conditions (COLEMAN and WRIGHT, 1972). In contrast to other tropical shelves, these sediments are very poor in corals and devoid of ooids.

The biogenic carbonates are represented by pebbles and sand composed chiefly of encrusting and branched calcareous algae, with a dominance of Halimeda at certain places. The distribution as well as the biological and geological characteristics of these sediments have been described by COUTINHO and MORAES (1968), KEMPF (1970b, 1972), KEMPF et al., (1969), MABESOONE et al., (1972), ZEMBRUSCKI et al., (1972) and SUMMERHAYES et al., (1975).

On the inner shelf there occurs lithified sediments constituting extensive bands of submerged beach rock. In the depressions and lagoons behind these "reefs", terrigenous and accumulates, rich in organic matter, and at other places lime muds in which Halimeda locally dominates.

Terrigenous muds occur at the mouth of big rivers (for instance, the São Francisco), at isolated spots which occupy depression in the shelf relief, and on the upper slope south of the São Francisco River.

The quartz sands of the inner shelf are subarkosic and include subrounded and rounded grains. They present generally two distinct heavy-mineral associations with tourmaline dominant north of the São Francisco river mouth and stauraolite south of it. The sands are also relict, with a completely reworked biogenic fraction.

Belmonte - Cabo Frio

The sediment cover in this region is quite similar to that of the region discussed above, and exhibits the same distribution. The terrigenous sands occupy the inner shelf, reaching the middle shelf at the Doce river mouth. These sands are arkosic with a fairly high hornblende content and very few resistant heavy minerals such as zircon and tourmaline. As on the rest of the northeastern Brazilian shelf, corals are rare, and oolites and other chemical carbonate precipitates absent. The few corals occur in the littoral zone on hard substratum, chiefly from the Vitoria - Trindade Ridge northward. General characteristic of the West Indies reefs are almost entirely absent (LABOREL, 1967).

Carbonate sands and pebbles occupy the outer and middle shelf parts, at some places also reaching the inner part.

The sedimentary cover of the Abrolhos Bank is biogenic, with carbonate mud derived from degradation of reefs dominant in the depression and biodetritus with modern and fossil components at the borders. North of the bank, coralline algae dominate, and south of it bryozoans.

To the south of the Abrolhos Bank the shelf again becomes narrow and terrigenous sedimentation becomes dominant, with the bioclastic fraction restricted to the outer shelf. The climate of these latitudes is more humid, resulting in a more significant supply of river material. The Doce and Paraiba do Sul Rivers form large deltas in this area, and are now restricted to the coastal zone. They supply terrigenous sediment to the inner shelf which is laterally distributed by waves and currents. The quantity of modern terrigenous sediment supplied is, however, small and consists mainly of relict subarkosic sandy and submature sandy muds. The deltas attained the shelf break in the Pleistocene, as shown, for instance, by the presence of marine terraces at depths between 150 and 200 m. related to the deltaic fronts. Several seismic reflection diagrams of the area showed a typical deltaic sedimentation sequence.

Submature terrigenous sediments are mainly confined to the inner shelf and have a relict character.

Cabo Frio - Chui

From Cabo Frio to Chui the continental shelf becomes progressively wider; and because the climate is more humid, terrigenous sediments develop southward where the carbonate deposition remains restricted to the outer most shelf part.

Cabo Frio marks the transition between the tropical realm of the north and the temperature zone of the south, considerably affecting carbonate deposition. North of this cape the sediments are rich in carbonates with coralline algae, miliolids, Amphistegina, peneroplids and bryozoans, probably derived from the extensive algal ridge system (ROCHA et al., 1975). Toward the south, the sediments are poor in carbonate, with dominant associations of mollusks, barnachles and sandy foraminifera.

The muds north of Cabo Frio contain much kaolinite and little illite and montmorillonite, whereas south of it the kaolinite content decreases rapidly with consequent increase of illite and montmorillonite.

The generally immature terrigenous sediments are distributed in zones parallel to the coast, varying between psammites on the inner shelf to pelites on the middle and outer shelf.

Near the shelf edge, biodetrital accumulations occur of a composition rather different from that of N-NE Brazil. They are normally formed by fragments and abraded and blackened shells of mollusks, bryozoans and foraminifera, mixed with variable proportions of mud. The same type of sediment reappears on the inner shelf, in the form of almost pure shell gravel distributed in elongated bodies. These banks are relict and possibly related to beach rocks similar to those found near the spits of the Mirim and Patos lagoons (MARTINS et al., 1973).

In the southernmost portion of the area MARTINS et al., (1972) distinguished new muddy facies derived from the Rio de la Plata region, composed of material coming from this river and covering the middle shelf off Uruguay. At the sehlf border the same type of mud reappears, related to an ancient distribution of sediments of the Rio de la Plata on the coastal plain of Uruguay and Rio Grande do Sul.

All terrigenous sediments from Cabo Frio southward are relict. During the Holocene sea-level rise and prior to the formation of present-day coastal barriers, shelf muds and sands were deposited by coastal rivers draining the Rio Grande highlands. The terrigenous deposits to the north of the area must have been derived from the numerous small rivers which drain the coastal ranges there. In the extreme south of the area they originate chiefly from the Rio de la Plata and are transported northward by longshore currents. Studies of suspended material indicate that little modern sedimentation is reaching the southern margin (MILLIMAN, and SANTANA, 1974).

Recent studies on heavy minerals (TOMAZELLI, 1977; ZOUAIN, 1985) confirmed the origin of these sediments.

During low sea-level, the Rio Grande highlands and Rio de la Plata drainage were responsible for the development of several coalescent deltas along the shelf border (URIEN and MARTINS, 1980) and a mud depocenter on the slope and rise identified and described by MARTINS and URIEN (1972); and MARTINS (1984).

According to ROCHA et al., (1975), mud belts which characterize the middle shelf south of São Paulo apparently were deposited as lagoonal sediments during lower stands of sea level.

Chui - Patagonia

Along the Uruguay and the Rio de la Plata area, the inner shelf shows a muddy belt that covers a channel which extends from the estuary.

The mud composed of clayey silt and sandy clay is the product of the suspension load in the estuary's runoff, most of which is deposited in this area.

The nearshore area is rocky and sandy (pocket beaches). The yellowish sand is local and a product of the erosion of the Quaternary sand deposits that maintain the littoral sand budget. In the outer Rio de la Plata estuary a series of muddy to sandy mud archs are transformed seaward into a well-sorted medium to fine sand which is the extension of the shelf sandy facies into the estuary (OTTMAN and URIEN, 1966; URIEN, 1967). This sand, designated "old sand", is the onlap facies, which constrasts with the silty fluvial deposits identified as offlap facies in the estuary evolution (URIEN, 1972). The fluvial suspended solids are deposited within the Rio de la Plata estuary and on the inner Uruguayan shelf up to near Rio Grande do Sul. On the middle shelf there appears a concentration of shells, fragments, and calcareous debris (lime and cemented sandstone pebbles 10 mm in diameter) mixed with sand and spread in an elongated patch identified as the relict of an old shoreline, perhaps a barrier island in its destructive facies.

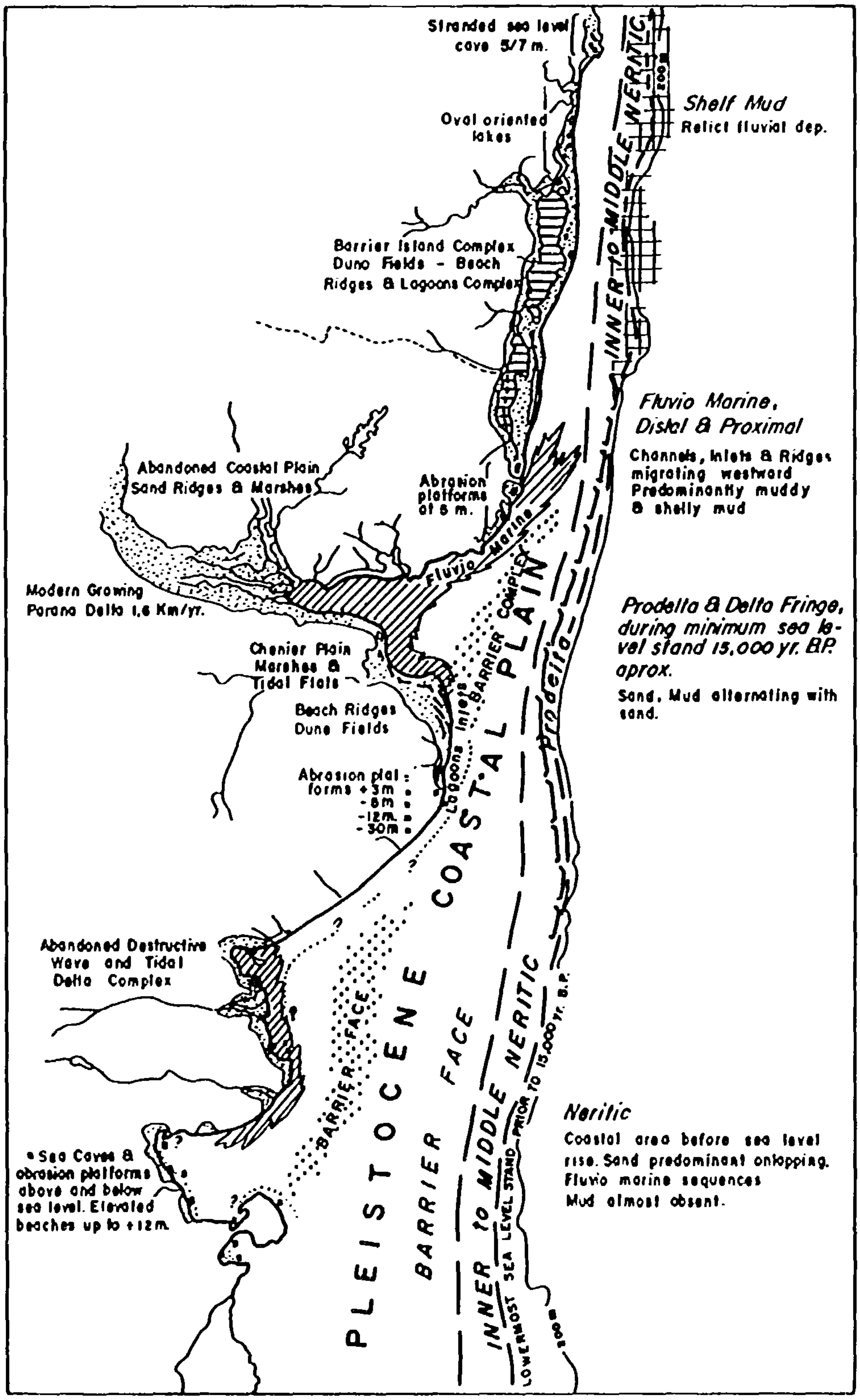
According to URIEN and EWING, (1974) in Buenos Aires area, as in almost all the rest of the southern shelf, there is a blanket sand field which covers both inner and outer shelves. This sediment is a medium to fine well-sorted yellowish-gray to brownish-gray sand which in some sectors contains small shell fragments and/or calcareous debris. No muddy sediments were found here. Shelly textures are spread in nearshore elongated patches. (Fig. 14).

On Bahia Blanca and San Blas area the river's suspended solids are trapped within the bay and nearshore areas, making these bays highly lutitic with a nearshore olive silty sand belt. Both inner and outer Bahia Blanca, arcuate shelly bodies appear (like ridges), following the bathymetry. In the southern middle shelf there is an extended shelly blanket that is perhaps related to a relict barrier island similar to the one near Rio de la Plata.

Near San Matias zone this is a wide and deep embayment with a sandy and gravelly silt which separates the sandy shelf facies from the tannish-green clay that covers the main gulf depression. The gulf nearshore belt is silty sand and gravelly. Since no rivers supply sediments to this area, it is supposed that the mud must be coming in suspension from the Rio Negro and carried by tidal currents or, alternatively, it is partially a relict of a former drainage pattern within the gulf. Sieguel (personal communication) has dated Holocene shells beneath 2 m. of homogenous clay, proving the relatively young age of these sediments.

Thus, the continental shelf in the studied area has predominantly a Recent sand cover of approximately 1-3 m. thickness. The fine textures are related to the runoff (recent of ancient) of rivers on the continental shelf, the most important river being the Rio de la Plata, with a yearly runoff of 23.000 m^3/sec (Rio Colorado, 180 m^3/sec; Rio Negro, 950 m^3/sec).

Since at the present time fluvial deposits are concentrated in the main estuaries and bays or near the shore, most of the sandy shelf facies are free of fine sediments. Nevertheless, in the Rio de la Plata-Uruguay area, suspended sediments bypass the shelf and are probably deposited on the continental slope. In its passage, some material settled, covering the bottom, but very sparsely, with a fine dash of clay, as was observed in bottom photographs and samples.



Principal deposicional environment units and the most remarkable features of the Rio Grande do Sul (Brazil), Uruguay and Buenos Aires area. Based on cores, topographic data, and seismic lines.

Fig. 14 *Modified from Urien and Ewing (1974)*

D. Joyce Lott

The region from Santa Cruz to Tierra del Fuego (Patagonia austral and Tierra del Fuego) shows the most varied occurrence of sedimentary textures of the entire area.

The littoral zone is characterized by the presence of an extensive sandy mud belt that changes direction to the coast to sand and gravel.

The middle and outer shelf presents a sand texture blanket that covers old relict conglomeratric bodies (sandy gravel with bioclastic material).

These relict sediments were expelled over the continental shelf during glacial times.

High energy hydraulic conditions were responsible by the transport and dispersion of these materials.

The slope is carpet with silty sand and sandy silt and different of other regions, with coarse conglomeratic material transported through gravity flows (turbidity, grain and debris flows).

2.2 Coastline

2.2.1 Brazil

The Brazilian coastline, lying between latitudes 4°N and 32°S, is about 9.200 km. long and shows a great diversity of geomorphological aspects as a result of different geological settings and variable hydrodynamic and climatic conditions along all its extensive length (SILVEIRA, 1964; SUGUIO & TESSLER, 1984 and CRUZ et al., 1985).

Bordering an old platform composed by Precambrian igneous and polymetamorphic complexes and Paleozoic basins with sedimentary and volcanic sequences, there are narrow and elongate coastal plains with Tertiary and Quaternary detrital sediments produced in continental, transitional and marine environments. The most developed plains are those near the principal river mouths where the sedimentary supply is more effective. On the other hand, there are some expressive sectors where the coast is rocky and scarped, prevailing erosion over deposition, like north and northeastern coastline where Tertiary formations reach the sea and in the southeast where Precambrian basement is frequently submitted to wave action.

The north, northeast and east coastlines receive waves generated by northeast trade winds. The southeast coastline is also influenced by the northeast winds but the most effective waves are those related to the southerly swell arriving from the South Atlantic. Wave energy is low in the north and increases towards the south where storms are more frequent. Tide range increases from south (microtidal) to east (mesotidal) and to northeast and north (macrotidal) where it reaches up to 12 meters.

In order to make easier the understanding of this entire coastline, it has been divided by SILVEIRA (1964) in five sectors which will be described briefly, below. (Fig. 15).

Amazonic region - From Cabo Orange to Baia de São Marcos

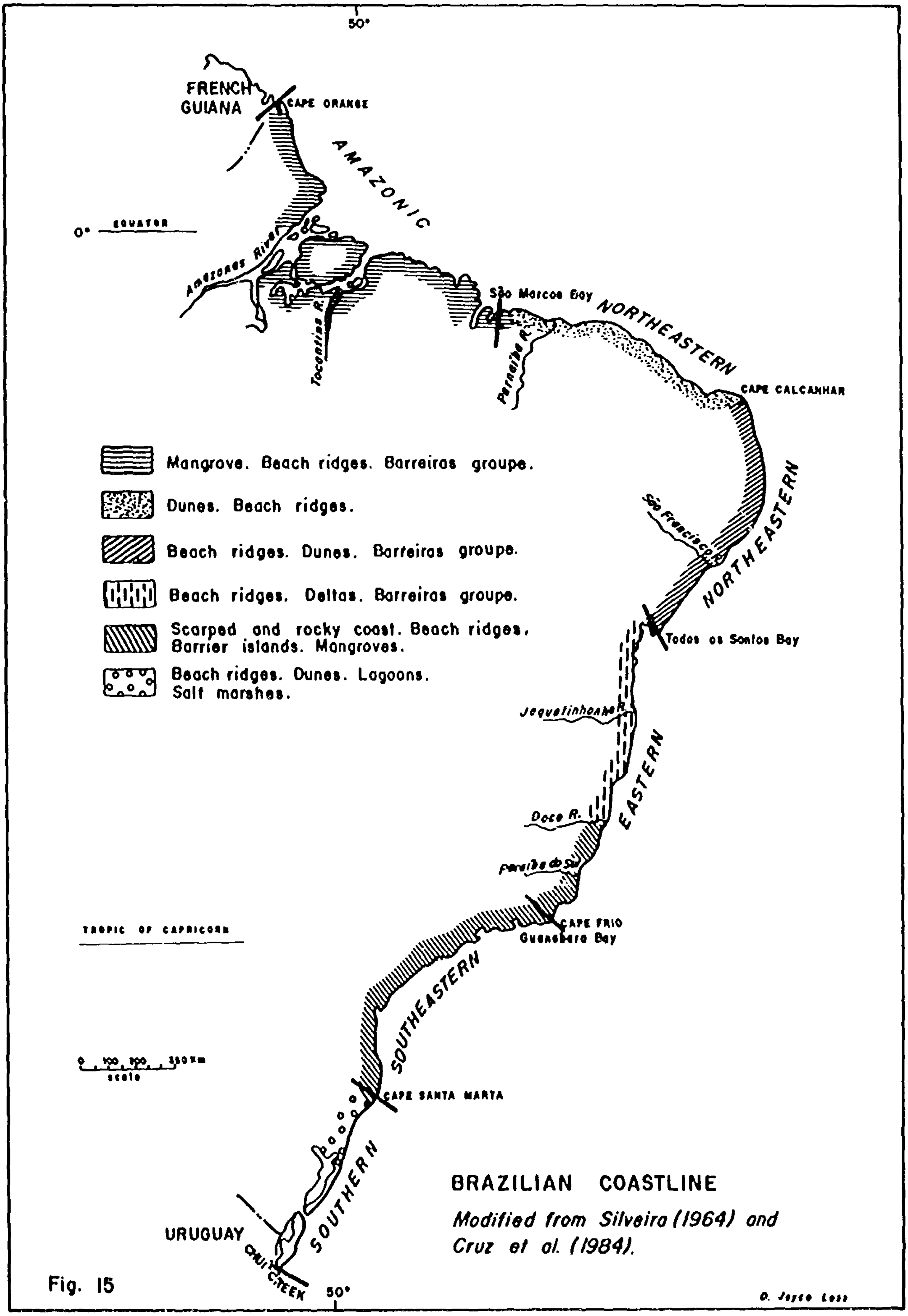
Due to its shape, dynamic marine conditions and differences in precipitation, this sector can be divided in three parts.

The first one, between the Amazon river mouth and French Guyana, is a low lying muddy coast, plentiful with mangrove swamps, with a smooth coastline, probably the result of accretion by Amazon sedimentation (EISMA & Van Der MAREL, 1971; MARTINS, 1976; RINE and GINSBURG, 1985). The second part is the so called Amazon Gulf, with an extremely unstable coastline due to the influence of waves, tidal and coastal currents and river runoff. The third part corresponds to the Eastern Amazonian Coast, characterized by a great number of small estuaries and by low cliffs. Mangrove swamps occur at some protected places, helping to accentuate the coastline. Fig. 16 shows many estuaries bordered by mangroves and tidal flats backed by a low plateau of Tertiary Barreiras Group and early Quaternary sedimentary rocks which reach the coast in several localities as small cliffs, as demonstrated by FRANZINELLI (1982).

Northeastern coastline - Baia de Sao Marcos to Baia de Todos os Santos

This sector of the Brazilian coastline is characterized by Tertiary deposits of Barreiras Group which constitute a flat and low altitude surface that reaches the coast where it is being reworked since Pleistocene to Recent. Differences in climatic and oceanographic conditions along this region let it to be divided in two parts.

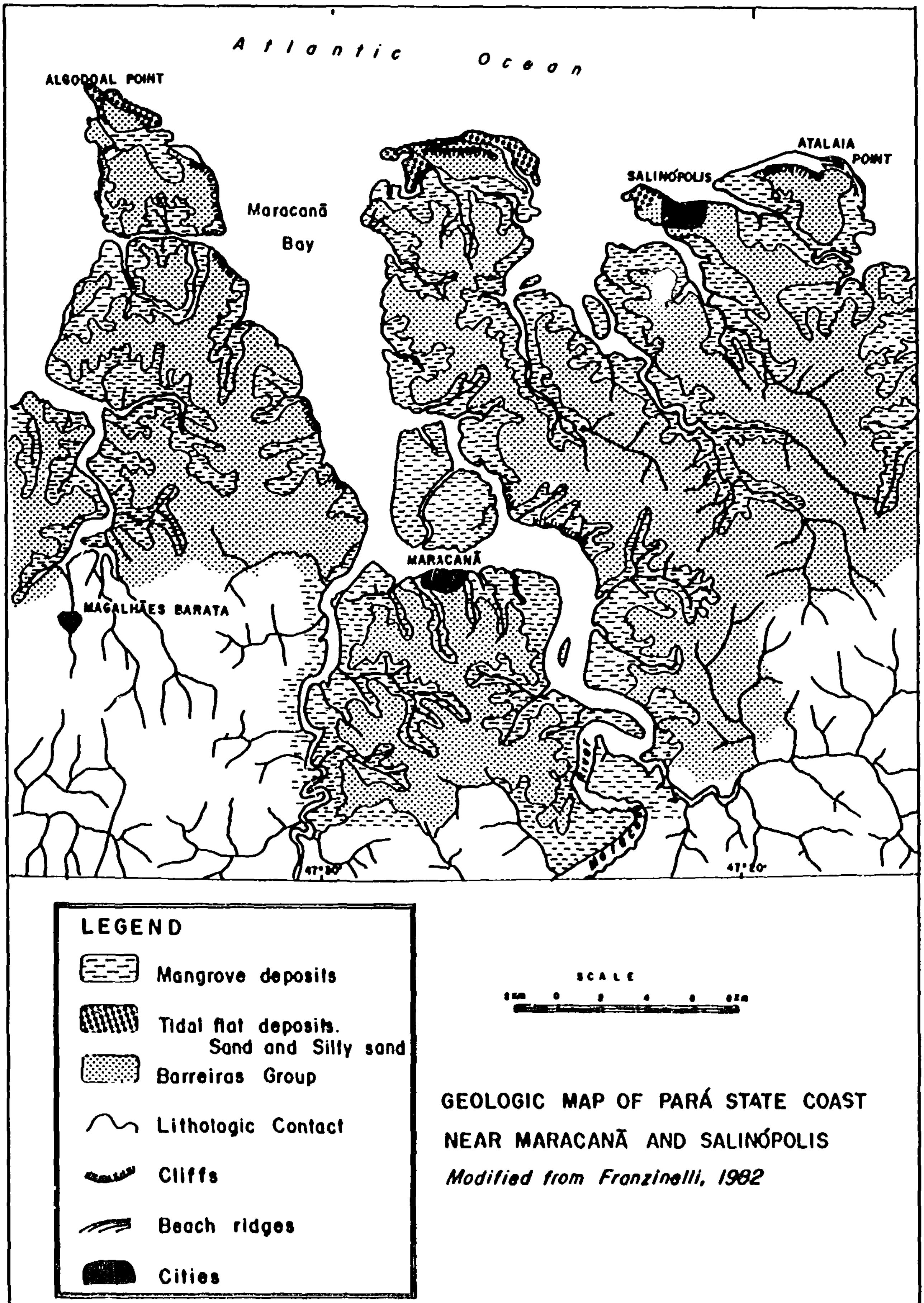
The first part, from Baia de São Marcos to Cabo Calcanhar is submitted to a semiarid climate. The coast is more or less straight and depositional with beach ridges and sand dunes alternating with lagoons and salt marshes. Near the Delta do Parnaiba there are long sandy beaches backed by extensive dune fields. Some aspects of this coast were discussed by SMITH & MORAIS (1984). Along the second part, from Cabo Calcanhar to Baia de Todos os Santos, under humid tropical conditions, the coast shows cliffs cut into Barreiras Group and beach ridge plains with some sand dunes. The straight coastline is bordered offshore by beach rocks in parallel zones and calcareous reef sandstones. CUNHA (1982) and DOMINGUEZ et al., (1981 and 1983), describe the main geological aspects of this area. Fig. 17, by BITTENCOURT et al., (1983), is a geological map of the coast of Sergipe and Alagoas (in part) States, showing the main depositional features of the delta of Sao Francisco River, fringed by beach ridge plains and dune fields.



BRAZILIAN COASTLINE

Modified from Silveira (1964) and Cruz et al. (1984).

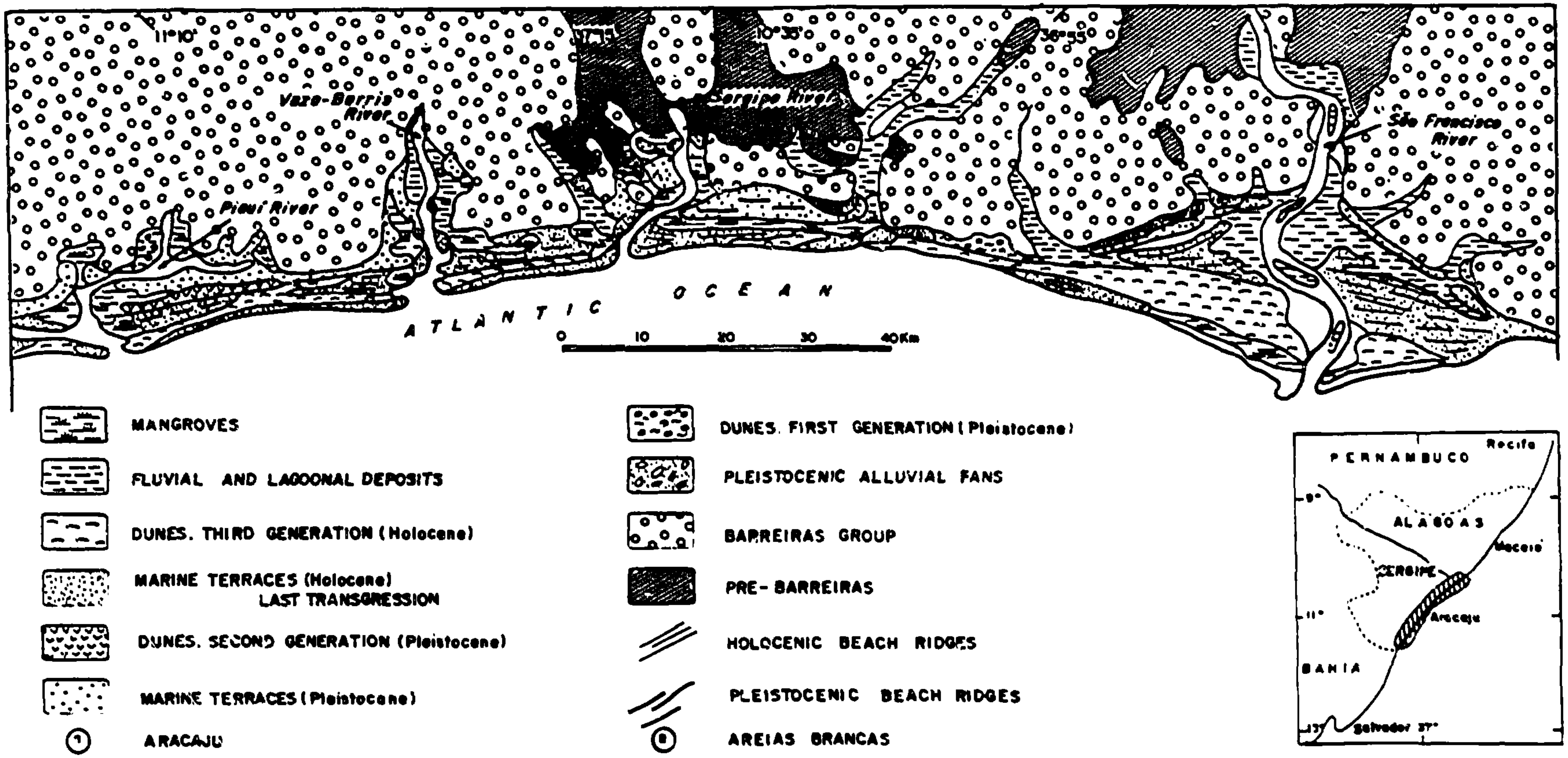
Fig. 15



GEOLOGIC MAP OF PARÁ STATE COAST NEAR MARACANÃ AND SALINÓPOLIS

Modified from Franzinelli, 1982

Fig. 16



GEOLOGIC MAP OF SERGIPE AND ALAGOAS (SOUTH) STATES.
Modified from Bittencourt et al., 1983.

Fig. 17

B. Joyce Loss

Eastern coastline - From Baia de Todos os Santos to Cabo Frio

In this sector, many peculiarities of the northeastern coastline still persist, as the Barreiras Group flat surface, the beach rocks and the coral reefs. The crystalline headland scarps are very far from the present shoreline, unless near Vitora when they reach to the ocean. Coastal plains with beach ridges are extensive and well developed at the mouth of the main rivers as in Jequitinhonha, Doce, Paraíba do Sul and many others where deltaic complexes were built which were described by DOMINGUEZ (1982), DOMINGUEZ et al., (1981, 1982 and 1983), BANDEIRA Jr. et al., (1979), MARTIN et al., (1980) and AMADOR (1980).

Southeastern coastline - Cabo Frio to Cabo Santa Marta

If the northeastern and eastern coastlines were characterized by the presence of the Barreiras Group, in the southeastern coast the main aspect is related to the Precambrian gnaiss-granitic headlands face where high and rocky promontories alternate with valley-mouth inlets, small coastal plains with beach ridges, sand dunes, mangrove swamps, and some elongated sandy beach barriers with coastal lagoons developed in the reverse side of the barriers.

From Cabo Frio to Baia de Guanabara former embayments have been sealed by Holocene barrier deposition to form a series of coastal lagoons. In some places there is an inner barrier related to a higher Holocene sea-level phase and an outer barrier developed at the present sea level. MUEHE (1984) has shown that sea level rise and shortage of sediment supply are causing now a landward migration of the younger barrier.

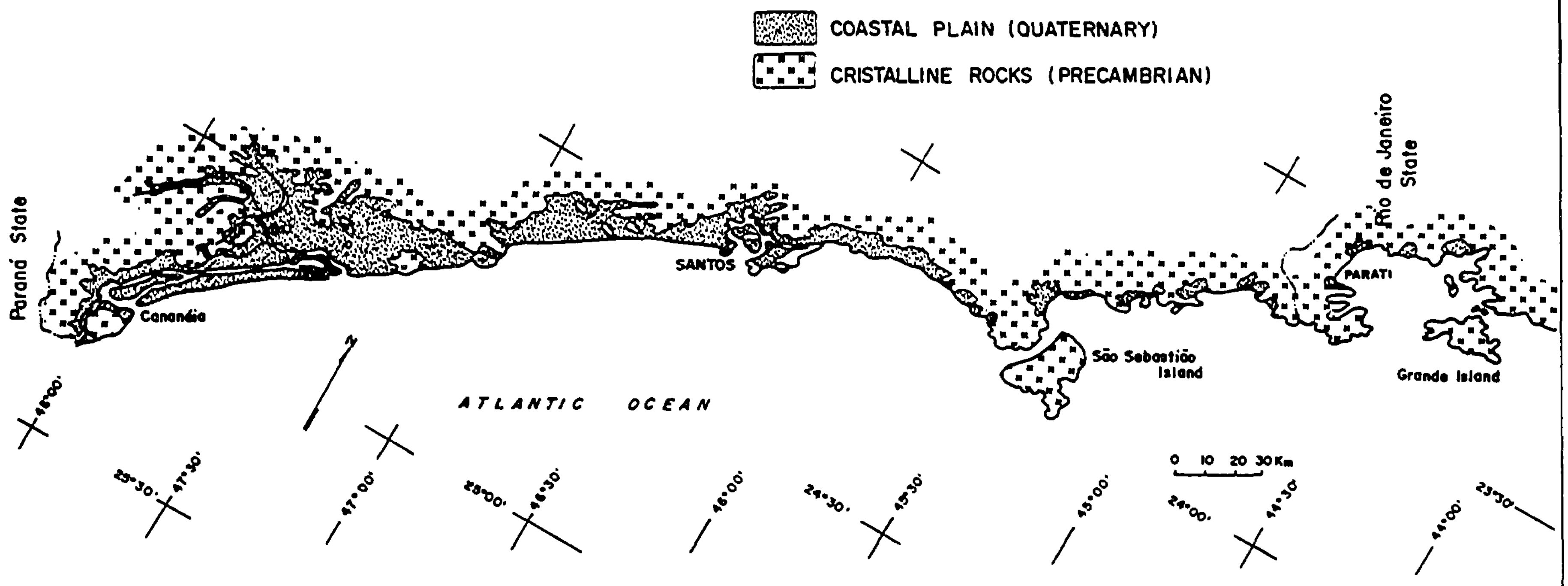
Sandy barriers are interrupted by steep promontories of crystalline rocks, including the sugarloafs of Rio de Janeiro alongside a major marine inlet, the Baia de Guanabara, occupying a tectonic depression, having its inner margins fringed by mangroves.

To the west, from Baia de Ilha Grande to Cananéia the main geological aspects can be seen in Fig. 18. Studying the Quaternary deposits of this area, MARTIN et al., (1979), have observed at least two transgressive phases (Cananéia and Santos transgressions) and have outlined sea level fluctuation curves for the last 8,000 years.

From Cananéia to Cabo Santa Marta the same general geomorphic features can be seen. Detailed descriptions have been made by BIGARELLA (1965 and 1975) and DUARTE (1981).

Southern coastline - From Cabo Santa Marta to Arroio Chuí

The southern coastline is characterized by a wide coastal plain where multiple sandy barriers encloses a giant lagoonal system (Mirim and Patos Lagoons) and a series of other water bodies isolated or connected with the sea through narrow and shallow inlets. Salt marshed and



SÃO PAULO STATE COASTLINE. *Modified from Martin et al., 1979.*

Fig. 18

extensive dune fields are observed over the sandy barrier. Sedge swamps can be seen along the lagoonal margins. From Tramandaí to Cape Santa Marta coastal plain becomes narrow, holding a necklace of small lagoons, backed by the scarped edges of sedimentary and volcanic sequences of Paraná Basin, which reach to the present shoreline in Torres. This region was described by DELANEY (1965) and VILLWOCK (1984). See Fig. 19.

2.2.2 Uruguay

The wide coastal plain observed in the southern segment of the Brazilian coastline extends to the northern part of Uruguay, bordering Mirim Lagoon as far as parallel 33°S. From there towards the south the coastline shows narrow coastal plains alternating with rocky points. In these coastal plains, sandy beaches and dunes are associated with small lagoons, swamps and salt marshes. Tertiary and Pleistocene sediments are present in the inner part of them.

From Montevideo to the west, the coastal plain widens and the pampean flat lowlands which border the Rio de la Plata estuary becomes the main characteristic geomorphological feature.

Further details about this region can be seen in PROST (1982) and JACKSON (1984). PROST (1979) has shown three transgressive phases present in the Quaternary deposits of the Uruguayan coastline, named Chuy (10-13 m. above the present sea level), Villa Soriano (5 m.) and, the younger, Punta de los Loberos (1,5-2 m.) the latest sea level maximum.

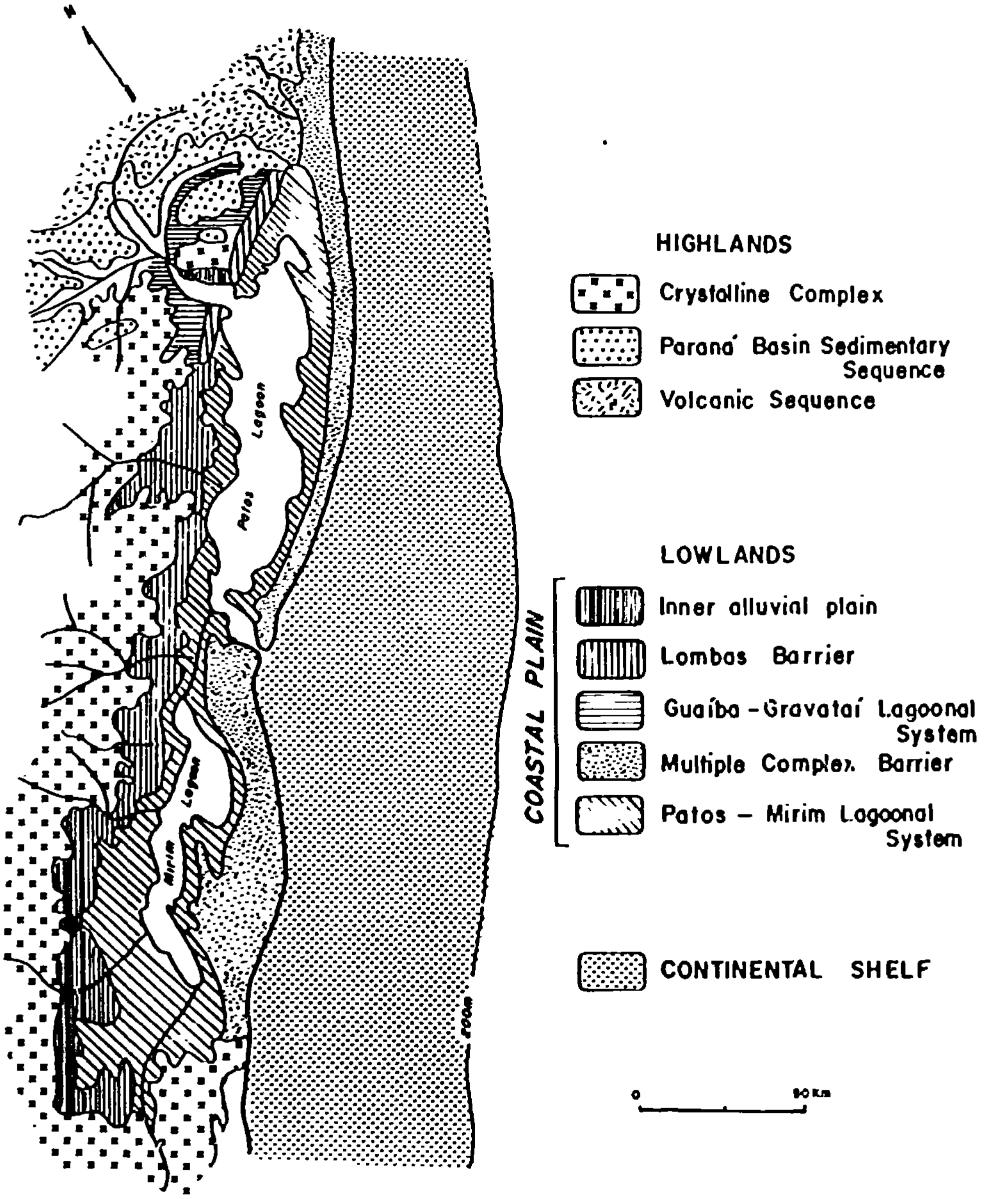
2.2.3 Argentina

As described by SCHNACK (1985), the coastline of Argentina is about 5,700 km. long, excluding Malvinas islands and the Antarctic sector. Open marine and semi enclosed coastal waters are associated to varying tidal regimes, from micro to macrotides, minimum values at the northern part and maximum ranges in the south, along the Patagonian sector.

Main coastal landforms are deltas, estuaries, marshes, cliffs and wave cut terraces, sandy and pebbly shorelines, and ice-fringed coastlines. Sandy shorelines are typical from Cabo San Antonio to Laguna Mar Chiquita. Pebbles are a common component of the Patagonian shores. Brackish and salt marshes along the coast, the former in the northeastern sector of Buenos Aires Province (Samborombón, Mar Chiquita), and the latter, most macrotidal, in Patagonia and Tierra del Fuego. The Patagonian coast is predominatly cliffy, while the Buenos Aires coastline alternates low lying and cliffy areas, see Fig. 20.

A variety of geological settings can be encountered along the coast of Argentina, from a fairly stable area in the north to an isostatically affected coastline at the extreme south. Tectonic activities may also affect coastal development in some places.

Evidences of a higher than present relative sea level stand reached during the Holocene are well represented in the Argentine coastline as shelley or pebbly beach ridges, estuarine deposits and marine terraces.

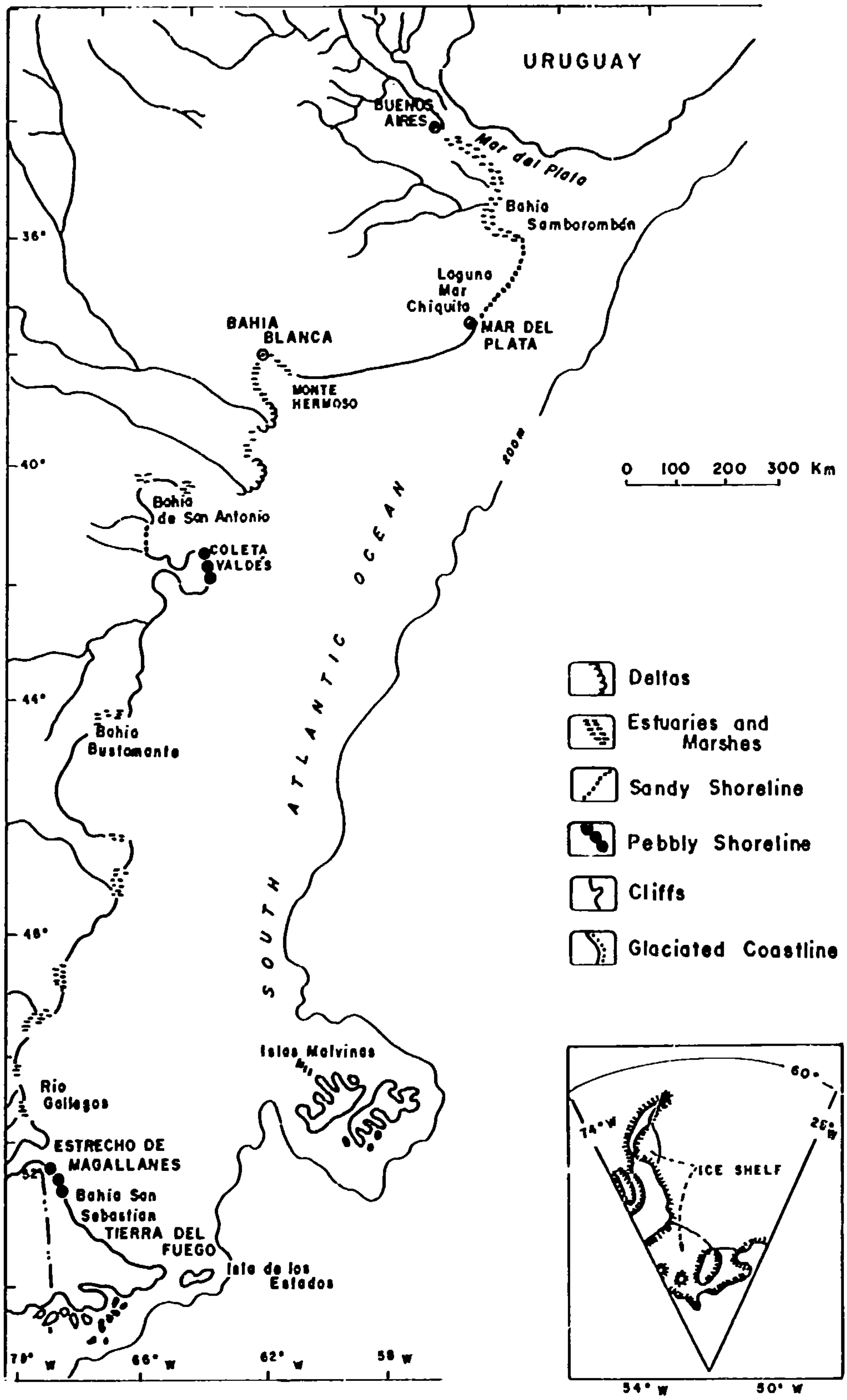


GEOMORPHOLOGY OF THE RIO GRANDE DO SUL
COASTAL PROVINCE

Modified from Villwock, 1984

Fig. 19

D. Joyce Loss



PREDOMINANT LAND FORMS OF THE ARGENTINA COAST.

Modified from Schnack, 1985

Fig. 20

D. Joyce Lass

QUATERNARY SHORELINE CHANGES (Case examples)

Some models of Quaternary shoreline changes and continental shelf paleogeographic evolution along the studied area, were prepared by several authors.

In this brief summary some of these studies are present:

3.1 Jequitinhonha River Coastal Plain

The Jequitinhonha coastal plain is one of the best studied areas along the coast of the State of Bahia Brazil and is quite representative of the geologic evolution of the Eastern Brazilian coastline. This area was studied in detail by DOMINGUEZ (1982) and additional information can be found in DOMINGUEZ et al., (1982). DOMINGUEZ et al., (1981 and 1983) discussed comparatively this area with several other coastal plains associated to other river mouths along the eastern and northeastern coastline.

Quaternary sea level fluctuations, according to DOMINGUEZ (1982), played an important role on the development of the Jequitinhonha coastal plain whose main geological features can be seen in Fig. 21.

Nine stages were recognized representing the paleogeographic evolution of this plain. (See Fig. 22). They can be summarized as follows:

Stage I - Pliocene - Deposition of Barreiras Group as a series of alluvial fans;

Stage II - Pleistocene - The Most Ancient Transgression, which erode, during its course, the external front of the Barreiras Group;

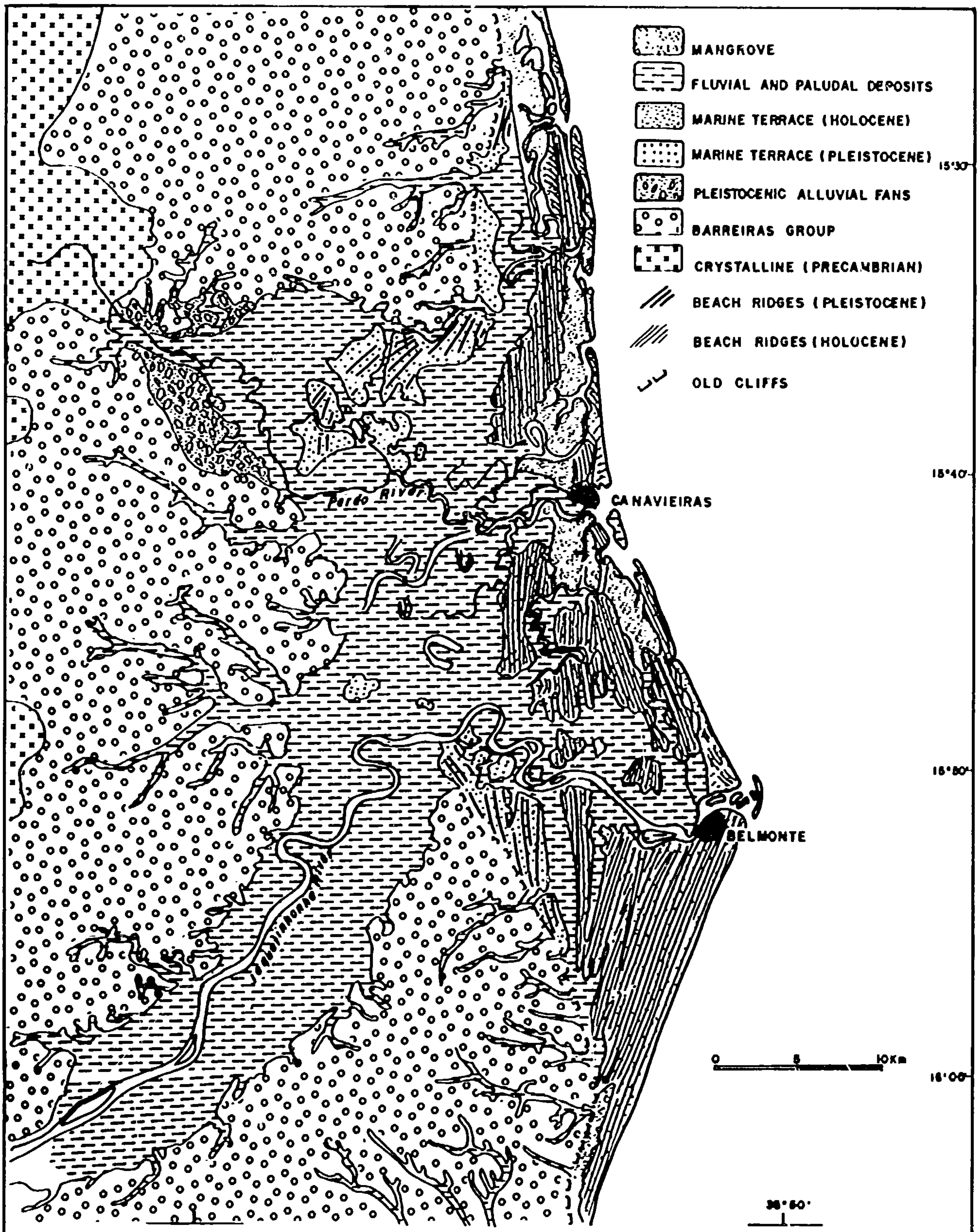
Stage III - Pleistocene deposition of coalescing alluvial fans, at the foot of the coastal cliffs, carved by the Most Ancient Transgression, onto the Barreiras sediments;

Stage IV - 120,000 years B.P. - The Penultimate Transgression partially eroded the Pleistocene alluvial fans;

Stage V - Descent of the sea level, leading to the construction of a coastal plain similar to those that exist today;

Stage VI - 5,100 years B.P. - The Last Transgression partially eroded the Pleistocene coastal plain which became, in part, isolated from the open sea by barrier islands;

Stage VII - 5,100 - 3,800 years B.P. - a new regression, enabled the development of the first holocenic Jequitinhonha river progradational zone. Coastline progradation was interrupted by another rise of sea level at 3,800 - 3,500 years B.P., which also caused lateral shifting of the river course;

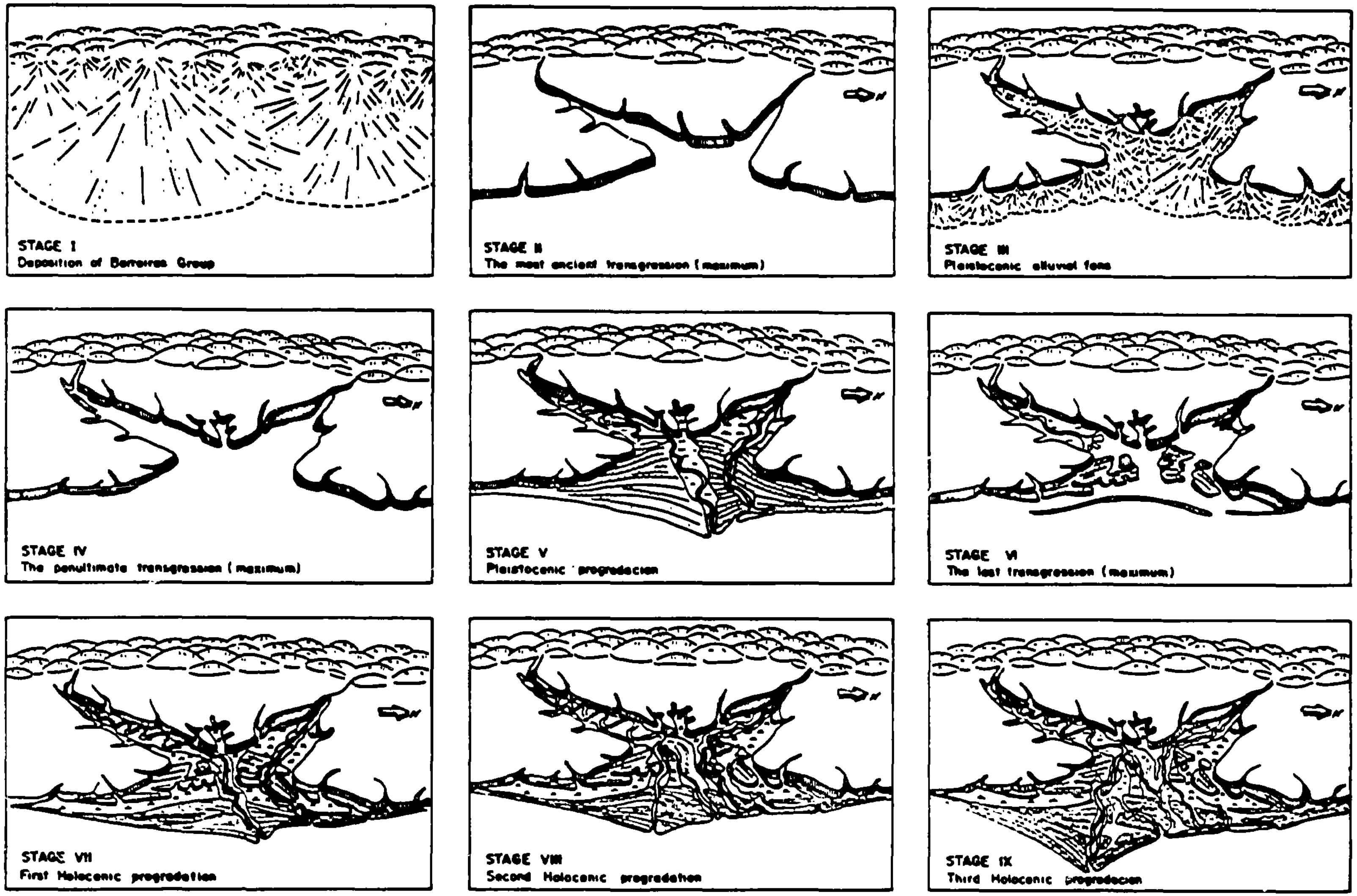


GEOLOGICAL SKETCH OF JEQUETINHONHA RIVER COASTAL PLAIN.

Modified from Domingues, 1982.

Fig. 21

D. Joyce Lees



PALEOGEOGRAFIC EVOLUTION OF THE JEQUITINHONHA RIVER COASTAL PLAIN *Modified from Dominguez.*

Fig. 22

Stage VIII - 3,500 - 2,700 years B.P. - at the new river mouth the second holocenic Jequitinhonha river progradational zone was constructed and again drowned during a rising sea level between 2,700 - 2,500 years B.P. This new event was the course of a new shifting of channel to its present position.

Stage IX - After 2,500 years B.P. - the present day progradation zone started its development.

3.2 Rio Grande do Sul (Brazil) - Uruguay coastal plain

Contributions from VILLWOCK (1972, 1984) that established the paleogeographic scheme on the morphological features of the emerged area, and from MARTINS and URIEN (1979) and URIEN et al., (1980a, 1980b) that prepared the same based on the submerged morphological features and in the characteristics of the sedimentary deposits of the continental shelf, are the more important contributions of this region.

The greatest problem which still persists, in setting up the various stages of paleogeographic evolution, lies in the scarcity of geochronological data, and in applying the classical eustatic variation curves, which are inadequate for this region.

It become obvious that sedimentation and morphological edification of the studied areas was controlled by the succession of transgressive and regressive events, and this sense, after a large Miocene transgression, all successive cycles left their marks imprinted on the surface of the coastal plain and continental shelf.

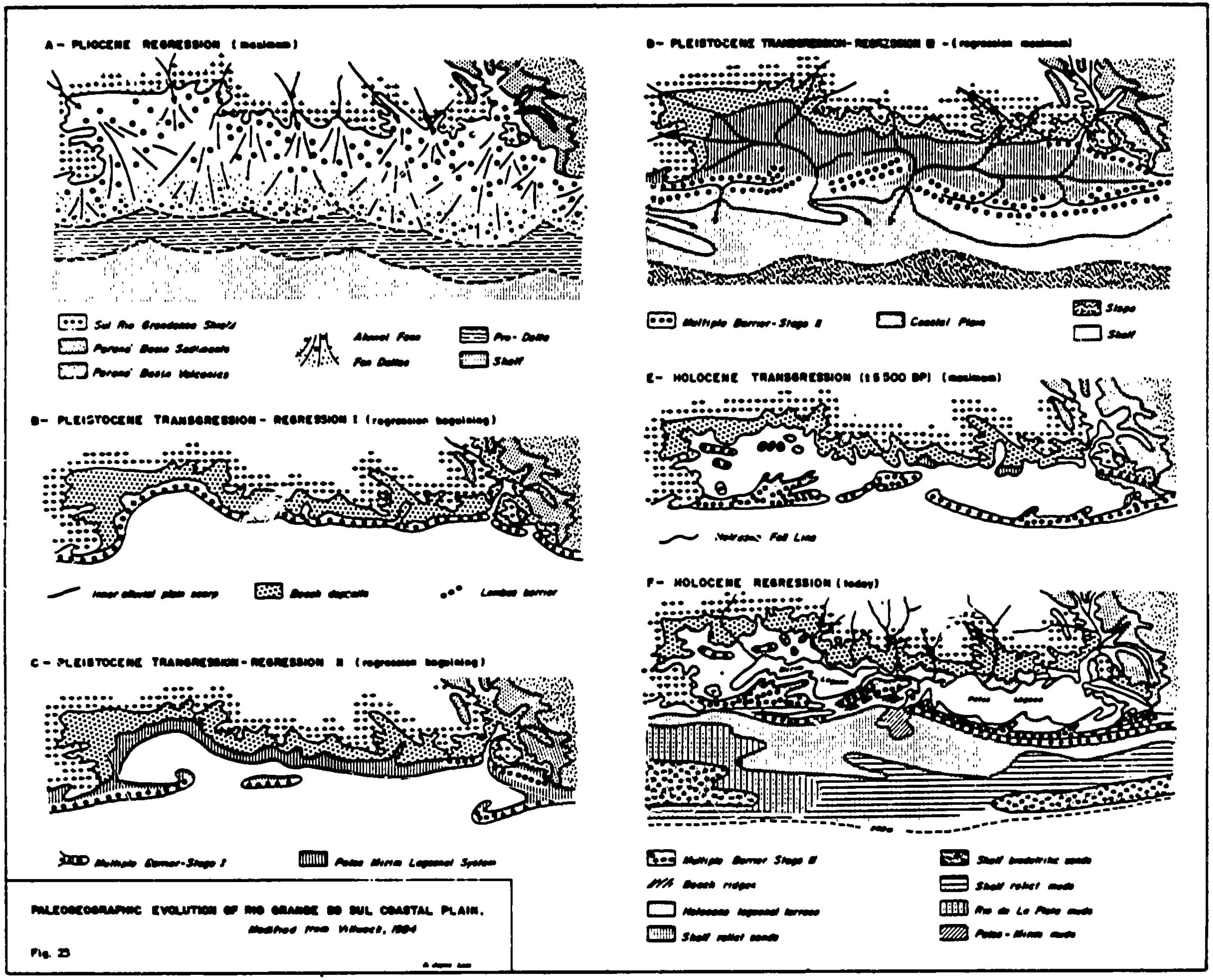
The evolution scheme can be presented as shown in Figs. 23 and 24.

The tentative paleogeographic evolution can be summarized as follows:

a) During Pliocene regression, large deltaic fans, linked to a system of a braided channels system, covered wide areas with coarse clastic deposits, in a continental sequence.

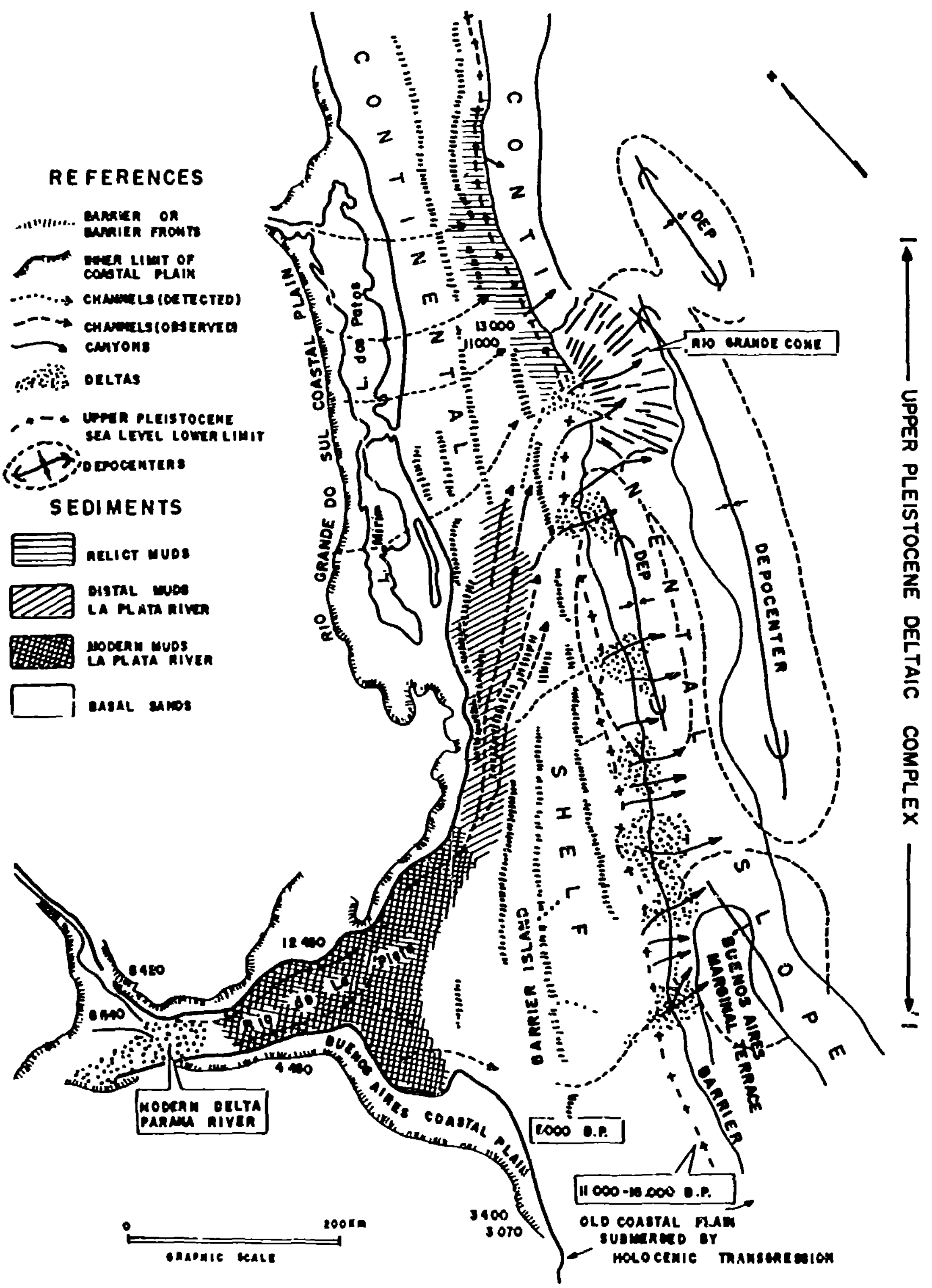
b) The first Pleistocene (Lower Pleistocene) transgression-regression cycle beach barrier and lagoon system was developed along the coast.

c) After the second Pleistocene (Middle Pleistocene) transgression-regression cycle started the construction of the first barrier of the multiple barrier, which began to isolate the Patos-Miriam Lagoon System.



PALEOGEOGRAPHIC EVOLUTION OF RIO GRANDE DO SUL COASTAL PLAIN.
Modified from Villwock, 1984

Fig. 23



PALEOGEOGRAPHIC EVOLUTION OF RIO GRANDE DO SUL (BRAZIL) URUGUAY AND BUENOS AIRES PROVINCE (ARGENTINA) AREA.

Main morphological features and dominant sediments, according Urien, Martins and Martins, 1980

Fig. 24

D. Joyce Less

d) At the end of the third Pleistocene (Upper Pleistocene) transgression-regression cycle the multiple barrier continued to grow (adding the second barrier) and later the alluviation of the Patos-Miriam Lagoon system, allowing the formation of an enormous coastal plain which extended up to the present 140/150 meters isobath, which was the sea level at the time ± 14.000 years BP, according to MARTINS and URIEN (1979).

In this extensive sandy coastal plain, numerous meandering rivers, lagoon and wetlands were present.

During this stage, along the fluvial and coastal plain the La Plata River and Rio Grande do Sul Rivers, built several coalescent deltas and generating several mud depocenters along the continental slope and contributed to the last partial development events of the Rio Grande Cone.

e) Between 1,000 and 6,000 BP, the sea level started to change in a transgressive motion, with a consequent lateral migration of the coast line toward the continent. The La Plata and Rio Grande do Sul River channels started to displace to the west, but maintaining its connections with submarine channels and valleys along all shelf break. During this motion, the sea level had a brief stabilization at -100 and -60 meters, recorded by bioclastic carbonate sand and gravel and erosive terraces.

At the end of this interval, during the last stabilization, a barrier island complex developed and partially closed the La Plata entrance and forcing the river discharge to inflect to the north.

Between 6,000 and 4,000 BP the sea level covered the remainder lowlands and the La Plata River valley. In the Uruguayan coast several shallow bays were developed. During the high point of Holocene transgression which caused the formation of a sea cliff, the multiple barrier and the abrasion of the Holocene lagoon terrace in the Patos-Mirim system.

f) Starting the Holocene regression to the present sea level position, sandy bars and spits closed partially these bays and added a third barrier to the multiple barrier Patos-Mirim system, forming the Mangueira lagoon and the coastal plain.

From 4,000 BP to the present the new stabilization of the sea level creates a regressive microphase.

The coast is now an accretion zone with the development of beach ridges and dune fields.

The La Plata River starts its accretionary stage building the Paraná delta and the fluvial facies progrades over old transgressive sand facies.

Suspended load of Rio Grande do Sul systems is almost entirely trapped along the Patos-Mirim lagoon system and just a few amount is transmitted to the continental shelf through the Rio Grande inlet.

The La Plata River discharge affects the Uruguay inner shelf.

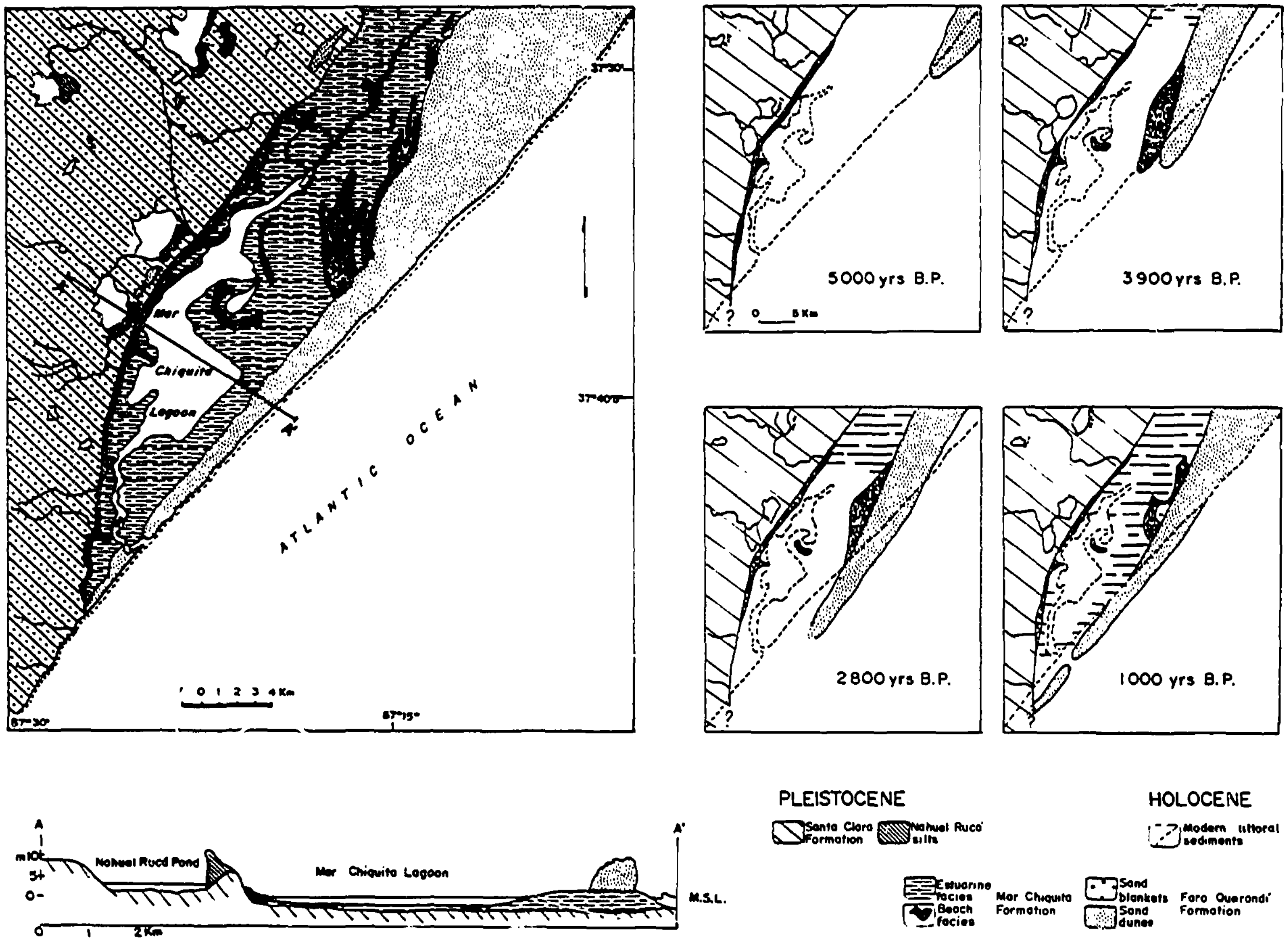
Hydraulic conditions and the presence of a sand stock on the continental shelf allow the development of bars parallel to the present coastline, along its inner part. Although this is a brief description, the tentative depicted evolution is not much different from what has been presented for other sections of the Brazilian coast, especially DOMINGUEZ et al., (1981).

It is certain that the continued geological mapping working in this region will add important data to what has been written, describing the geological evolution of the Cenozoic terrains along the coast and margin.

3.3 Mar Chiquita Lagoon Coast, Buenos Aires Province, Argentina

The paleogeographic evolution of the coastal plain in the area of Mar Chiquita Lagoon, south of Buenos Aires, was presented by SCHNACK et al., (1982). See Fig. 25. According to the authors this coastal plain shows clear evidence of a high sea level stand reached during the last deglacial hemicycle. Marine and estuarine sediments were deposited as a result of a transgressive-regressive sequence of events. At about the time of the maximum sea level stand, the "first generation" shelly beach ridges were formed reaching an altitude of 4.3 m. above the present mean sea level. Topographic surveys made on these ridges and their comparison with the present beach forms in the vicinities would indicate a maximum sea level stand of about + 2.5 m. at the transgressive peak. A regressive phase implying a minor fall in the sea level and the development of a barrier prograding southward on the eastern part of the area, gave origin to a large estuarine environment: - the "proto" Mar Chiquita lagoon. Radio carbon dates of 8 well preserved shell samples collected from these deposits range between 3,850 ± 60 and 1,350 ± 50 years B.P.

Erosion is today the chief process at the coastline south of the lagoon inlet - located at the southern end of Mar Chiquita lagoon -, where cliffs and wave cut terraces are the dominant features. North of the inlet, an accretionary coastline with well developed beaches and sand dunes extends on a strip enlarging northward. However, a few signs of erosion do exist along the southern part of this segment. Southeasterly storms are primarily responsible for coastal erosion in this area.



GEOLOGICAL SKETCH AND EVOLUCIONARY STAGES OF MAR CHIQUITA COASTAL PLAIN IN THE LAST 5.000 YEARS.

Fig. 25 *Modified from Schnack et al., 1982.*

PROCESS AND FACTORS

From the evidence available along the coastal plain and adjacent continental margin, it is possible to analyse the main process and factors that were responsible for the geological evolution of the area during the Quaternary.

According to MARTINS et al., (1967) and SUGUIO and TESSLER, (1984) the principal factor in this evolution was the sea level fluctuations, availability of sandy sediments, wave and longshore currents dynamics and coastal features propitiating entrapment of sediments.

More work is needed in the area, on sedimentary, fauna/flora, datings and geomorphological aspects in the light of environmental process, with the purpose to compare with present day littoral models, and prepare a more or less accurate picture of the history of the entire region.

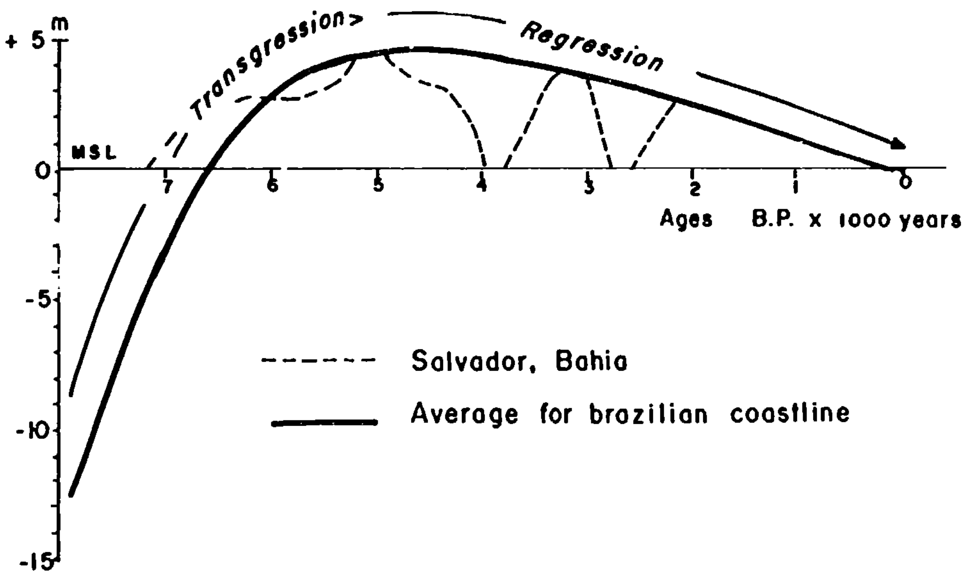
FLEXOR et al., (1984) discussing data obtained by several authors along the central part of the Brazilian coast concluded that this area was submitted to important sea level fluctuations and identified three marine levels higher than the present coastline.

The most ancient was identified in Sergipe (BITTENCOURT et al., 1983), Bahia (MARTIN et al., 1980, DOMINGUEZ, 1982) and Rio Grande do Sul (VILLWOCK, 1984). It seems to be related to Early Pleistocene and the level reached, was quite the same as the present one. The two last ones, reached levels of 8 ± 2 m. (120,000 years B.P.) and 4,5 ± 0,5 m. (5,100 years B.P.), left a series of marks along the coastline and were studied and dated.

SUGUIO and TESSLER (1984) have presented an integrated mean sea level fluctuation curve for the last 7,000 years for the Brazilian coast. It can be seen in Fig. 26. The development of the Holocene deposits along the coastal plain is directly related with sand supply from continental origin (sedimentary and hard rock cliffs, river discharge) and marine sources like the sand blanket from the continental shelf.

The dynamic aspects related with the longshore currents, has an important role on the nearshore transport and in the building up of spits, bars and barriers, that are responsible for the growth of regressive sand deposits. Some morphological features (bays, inlets, offshore shoals and deltas) work as sediment entrapment and promote the sand stock to be reworked along the coastal area.

The western south Atlantic shelf shows several Quaternary stillstands of sea level that can be identified based on studies of the sediments and geomophological aspects. Based on this type of study it is possible to follow the interruptions during brief periods of the Holocene transgression. During these short periods, terrigenous sediments were



Sea level fluctuation integrated curve for brazilian coastline compared with that obtained for the region north to Salvador (Ba.). Based in Suguio e Tessler (1984).

Fig. 26

D. Joyce Less

furnished to the continental shelf and these reworked as coarse deposits during the following step. Using this method, KOSSMAN and COSTA (1975) indicated sea level stillstands along the Brazilian continental shelf at 170, 100 and 60 meters.

There are other evidences like the occurrence of oolitic sediments on the Amazon - Amapá outer shelf, described and dated by MILLIMAN and BARRETO (1975) who inferred a hypersaline coastal lagoon environment of deposition, based on the anomalous original magnesian calcite composition of the ooids. They occur in a depth of 80 and 150 meters and show 14C ages ranging from 14,310 ± 250 years to 21.250 ± 400 years.

The southern Brazil outer shelf is covered by mollusk sand and gravel (MARTINS 1985) characteristic of a shallow shelf environment, concentrated as a shallow marine/beach deposit, under high energy conditions.

Radiocarbon datings, several a late Wisconsin age of 17,628 ± 320 years and 17,827 ± 240 years (MARTINS, et al., 1985) corresponds to the shoreline position at the glacial maximum sea level stillstand 15,000 years ago (URIEN & MARTINS, 1980).

Various morphological features mapped through detailed bathymetry and shallow seismic profiles of 3 KHz (mainly used to identify Pleistocene depositional or erosional features) showed evidences of sea level fluctuations, mainly related with the Holocene transgression. Scaps and erosional terraces as a morphological sea level stillstand marker, were also identified along the western Atlantic continental shelf. Based on 3.5 KHz profiles, CORREA et al., (1980) described various sea level stillstands along the southern Brazilian continental shelf at the levels of 80-90 (± 11,500 years B.P.) 60-75 (± 11,000 years B.P.) 50 (± 10,000 years B.P.) 32-45 (9,000 years B.P.) 20-25 (± 7,500 B.P.). Linear shoal retreat massifs off Rio Grande do Sul (MARTINS et al., 1967, FIGUEIREDO, 1975), cuspate shoal retreat massif off deltaic cuspate foreland, such as the ancestral of Paraiba do Sul River (KOWSMAN e COSTA, 1975) La Plata River region (URIEN et al., 1980) are other examples of diagnostic features.

The main problem to develop studies that can be useful to build the Quaternary paleogeographic evolution of the coastal plain and continental shelf is the lack of information on datings, shallow seismic profile lines, and basic maps in a good scale that permits to work on trustful documents and data. Geological mapping in a scale of 1:50.000 and faciological studies, actually developed by various Quaternary research groups in Brazil, Uruguay and Argentina, will be helpful to the development of this goal.

REFERENCES

ALMEIDA, F.F.M., HASUI, Y., FUCH, R.A. 1981. Brazilian structural provinces: an introduction, Earth Science Reviews, vol. 17 (1/2) p. 1-30.

AMADOR, E.S. 1980. Traços gerais da evolução quaternária da Bacia do Rio São João (RJ). Anais de XXXI Congresso Brasileiro de Geologia, Balneário de Camboriú, Santa Catarina, Vol. 1, p. 542-556.

ASMUS, H.E. 1979. Conocimiento actual del margen continental brasileño. 4o Congresso Latino-Americano de Geologia. Puerto España, Trinidade/Tobago. (manuscript).

ASMUS, H.E. 1984. Geologia da margem continental Brasileira. In: Geologia do Brasil, 443-472, DNPM, Rio de Janeiro.

ASMUS, H.E. and PORTO, R. 1972. Classificação das bacias sedimentares brasileiras segundo a tectônica de placas. Anais XXVI Congresso Brasileiro de Geologia, Vol. 2, p. 67-90, Belém, Pará.

ASMUS, H.E. and PONTE, F.C. 1973. The Brazilian marginal basins. In: Nairn, A.E.M. and Stehli, F.G. (ed). "The Ocean Basins and Margins, p. 87-133.

BACOCCOLI, G. 1971. Os deltas marinhos holocênicos brasileiros - uma tentative de classificação. Bol. Téc. Petrobrás, 14, p. 5-38.

BANDEIRA Jr., A.N. PETRIS, S. and SUGUIO, K. 1979. The Doce River Delta: An example of a "highly destructive wave-dominated" Quaternary delta on the brazilian Atlantic Coastline, State of Espirito Santo. In: Suguio, K.; Fairchild, R.R.; Martin, L. & Flexor, J.M. (eds), Proceedings of the 1978 International Symposium on Coastal Evolution in the Quaternary, São Paulo, p. 275-295.

BARRETO, H.T. and SUMMERHAYS, C.P. 1975. Oceanography and suspended matter off northeastern Brazil. J. Sedimen. Petrol., 45; p. 822-833.

BIGARELLA, J.J. 1965. Sand ridge structures from Paraná coastal plain. Marine Beology, Amsterdam, 3 p. 269-278.

BIGARELLA, J.J. 1975. Lagoa dune field State of Santa Catarina, Brazil, a model of eolian and pluvial activity. Boletim Paranaense de Geociências, UFP, Curitiba, 33, p. 133-67.

BITTENCOURT, A.C.S.P., MARTIN, L., DOMINGUEZ, J.M.L. and FERREIRA, Y.A. 1983. Evolução Paleogeográfica Quaternária da Costa do Estado de Sergipe e da Costa Sul do Estado de Alagoas. Revista Brasileira de Geociências, Vol. 13 (2), p. 93-97.

BOYER, P.R. 1969. Structure of the Continental Margin of Brazil, Natal to Rio de Janeiro. Thesis, University of Illinois, Urbana, IU., 93 p.

BUTLER, L.W. 1970. Shallow structure of the continental margin, southern Brazil and Uruguay. Geol. Soc. Am. Bull., 81, p. 1079-1096.

COLEMAN, J.M. and WRIGHT, L.D. 1972. Delta morphology in relation to the discharge/wave power climate. Anais do XXVI Cong. Bras. Geologia, Belém, Pará, Vol. 2 p. 145-156.

CORREA, I.C.S., PONZI, V.R.A., TRINDADE, L.A.F. 1980. Níveis marinhos Quaternários da Plataforma Continental do Rio de Janeiro. Sociedade Brasileira de Geologia, XXXI Congresso, Camboriú, Anais, Vol. 1: 578-587.

COUTINHO, P.N. and MORAES, J.J.O. 1968. Distribucion de los edimentos en la plataforma continental norte-nordeste del Brasil. Symp. Invest. Res. Caribbean and adjacent regions Curaçao p. 273-284.

CRUZ, O., COUTINHO, P.N., DUARTE. G.M., and GOMES, A.M.B. 1985. Brazil, In: Bird E.C.F. & Schwartz, M.L. (eds.), The world's Coastline Van Nostrand Reinhold Co., New York, p. 85-91.

CUNHA, E.M.S. 1982. Caracterização a planejamento ambiental de estuário Potengi. Porto Alegre, Instituto de Geociências da UFRGS, Dissertação de Mestrado, 210 p.

DELANEY, P.J.V. 1966. Geology and Geomorphology of the coastal plain of Rio Grande do Sul, Brazil and northern Uruguay. Baton Rouge, Luisiana State University. South American Coastal Studies Technical Report 18, 58 pp.

DOMINGUEZ, J.M.L., BITTENCOURT, A.C.S.P. and MARTIN, L. 1981. Esquema evolutivo da sedimentação quaternária nas feições deltáicas dos rios São Francisco (SE-AL), Jequitinhonha (BA), Doce (ES) e Paraiba do Sul (RJ). Revista Brasileira de Geociências, Vol. 11(4) p. 227-237.

DOMINGUEZ, J.M.L. 1982. Evolução quaternária da planicie costeira associada à Foz do rio Jequitinhonha (BA): influência das variações do nível do mar e da deriva litorânea de sedimentos. Dissertação de Mestrado, 73 p.

DOMINGUEZ, J.M.L., BITTENCOURT, A.C.S.P., MARTIN, L. LIMA, R.C.C. and COSTA, I.V.G. 1982. Roteiro de Excursão Geológica à planície costeira do rio Jequitinhonha (BA) e às turfeiras associadas. XXXII Congr. Bras. Geologia, Salvador, Boletim No. 3, Roteiro das Excursões, p. 201-235.

DOMINGUEZ, J.M.L., BITTENCOURT, A.C.S.P. and MARTIN, L. 1983. O papel da deriva litorânea de sedimentos arenosos na construção das planícies costeiras associadas às desembocaduras dos rios São Francisco (SE-AL), Jequitinhonha (BA), Doce (ES) e Paraiba do Sul (RJ). Revista Brasileira de Geociências, Vol. 13(2): 98-105.

DUARTE, G.M. 1981. Estratigrafia e evolução do quaternário do plano costeiro norte da Ilha de Santa Catarina - Porto Alegre, Instituto de Geociências UFGRS, Dissertação de Mestrado, 279 p.

EISMA, D. and van der MAREL, H.W. 1971. Marine muds along the Guyana coast and their origin from the Amazon basin. Cont. Mineral. Petrology, Vol. 31, p. 321-324.

ESTRELA, G.O. 1972. O estágio "rift" nas bacias marginais do leste brasileiro. Anais do XXVI Cong. Bras. Geologia, Belém, Pará, Vol. 3 p. 29-34.

EVANS, R. 1975. Origin and significance of evaporites around Atlantic margin. AAPG Bull. Vol. 62 (2), p. 223-234.

FIGUEIREDO Jr., A.G. 1975. Geologia dos depósitos calcários biodetríticos da plataforma continental do Rio Grande do Sul. Dissertação de Mestrado. Universidade Federal do Rio Grande do Sul, Porto Alegre, 72 p. (manuscript).

FLEXOR, J.M., MARTIN, L., SUGUIO, K. and DOMINGUEZ, J.M.L. 1984. Gênese dos cordões litorâneos da parte central da costa brasileira. In: Restingas: Origem, Estructura, Processos. (Lacerda, L.D., Araújo, D.S.D., Cerqueira, R. & Turcq, B. Orgs). CEUFF, Niterói. p. 35-45.

FRANZINELLI, E. 1982. Contribuição à geologia da costa do Estado do Pará (entre a Baia de Curaça e Maiaú). In: Suguio, K.; Meis, M.R.M. e Tessler, M.G. ed. Atas IV Simpósio Brasileiro do Quaternário no Brasil. Rio de Janeiro, p. 305-322.

HAYES, D.E. and EWING, M. 1970. North Brazilian Ridge and adjacent continental margins, Am. Assoc. Pet. Geol. Bull. Vol. 54, p. 2120-2150.

JACKSON, M. 1984. Contributions to the Geology and Hydrology of Southeastern Uruguay Based on Visual Satellite Remote Sensing Interpretation. Münchener Geographische Abhandlungen, Band 31. München, 71 p.

KEMPF, M. 1970. A plataforma continental da costa leste brasileira entre rio São Francisco e a Ilha de São Sebastião (10º30'-25º Lat. S): nota sobre os principais tipos de fundo, XXVII Cong. Bras. Geologia, Belém, Pará, Vol. 2, p. 211-234.

KEMPF, M. 1972. Prospecção de fundo realizadas na plataforma continental do norte, nordeste e leste do Brasil pelo Laboratório de Ciências do Mar - UFPe ou com sua participação. Anais do XXVI Congr. Bras. Geologia, Belém, Pará, Vol. 2, p. 245-259.

KEMPF, M., MABESOONE, J.M. and TINOCO, I.M. 1969. Estudos da plataforma continental na área de Recife (Pernambuco). Univ. Fed. Pernambuco, Trabalhos Oceanogr., 9/11, p. 125-148.

KUMAR, N., BRYAN, G., GORINI, M.A. 1976. Evolution of the continental margin off northern Brazil: sediment distribution and carbon potential. An. Acad. Brasil. Ciên., 48 (Supl), p. 131-143.

LABORIEL, J.L. 1967. A revised list of Brazilian scleractinian corals and description of a new species. Postilla, Peabody Museum Natural History, Yale University, 107: 14 p.

LONARDI, A.G., EWING, M. 1971. Sediment transport distribution in the Argentine basin. 4 Bathymetry of the continental margin. In: Ahrens, L. et al., (eds) Physics and chemistry of the Earth: Elmsford, N. York, Pergon Press, Vol. 1, p. 79-121.

MABESOONE, J.M. 1971. Fácies sedimentares da plataforma continental brasileira. Estud. Sedimentol., 1(1) p. 55-71.

MABESOONE, J.N. and COUTINHO, P.N. 1970. Littoral and shallow marine geology of northern and northeastern Brazil. Univ. Fed. Pernambuco, Trabalhos Oceanogr., 12, 214 pp.

MARTIN, L., SUGUIO, K. and FLEXOR, J.M. 1979. Le quaternaire marin du littoral brésilien entre Cananéia (SP) e Barra de Guaratiba (RJ). In: Suguio, K.; Fairchild, R.R.; Martin, L. 6 Flexor, J.M. (eds), Proceedings of the 1978 International Symposium on Coastal Evolution in the Quaternary, São Paulo, p. 296-331.

MARTIN, L., BITTENCOURT, A.C.P.S., VILASBOAS, G.S. and FLEXOR, J.M. 1980. Texto explicativo para o mapa geológico do Quaternário costeiro do Estado da Bahia 1:250.000. CPM, SME, Salvador, (BA), 60 pp.

MARTINS, I.R. 1984. Modelo sedimentar do Cone do Rio Grande. Pesquisas, Vol. 16, p. 91-189.

MARTINS, L.R., URIEN, C.M. and EICHLER, B.B. 1967. Distribuição dos sedimentos modernos da plataforma continental sul-brasileira e uruguaia. Anais do XXI Congr. Bras. Geologia, Curitiba, Paraná, p. 29-43.

MARTINS, L.R., URIEN, C.M. and BUTLER, L.W. 1972. Províncias fisiográficas e sedimentos da margem continental atlântica da América do Sul. Anais do XXVI Congr. Bras. Geologia, Belém, PA, 2, p. 105-114.

MARTINS, L.R., MARTINS, I.R. and URIEN, C.M. 1973. Sedimentos modernos e relíquias da plataforma continental sul-americana oriental. Anais do XXVII Congr. Bras. Geologia, Aracajú, SE, Vol. 1 p. 212-213. (abstract).

MARTINS, L.R., URIEN, C.M. and MARTINS, I.R. 1975. Morfologia e Sedimentos da plataforma continental Atlântica sul-americana entre Cabo Orange e Chui (Brasil). An. Hidrogr., Vol. 23. p. 83-109.

MARTINS, L.R. and COUTINHO, P.N. 1981. The Brazilian continental margin Earth-Science Reviews, Vol. 17(1/2) p. 87-108.

MASCLE, J. and RENARD, V. 1976. The marginal São Paulo Plateau, comparison with the southern angolan margin. In: Continental margins of Atlantic type. Anais da Academia Brasileira de Ciências, Vol. 48, Suplemento, p. 179-190.

MELO, U., SUMMARHAYES, C.P. and ELLIS, J. 1975. Upper continental margin sedimentation off Brazil. Part IV - Salvador to Vitória, southeastern Brazil. Contr. Sedimentl., p. 78-116.

MILLIMAN, J.D. 1974. Marine carbonates. Springer-Verlag, Berlin, 375 p.

MILLIMAN, J. and SANTANA, C.I. 1974. Oceanography and suspended matter in the surface waters off southern Brazil, November-December, 1972. Anais do XXVIII Congr. Bras. Geologia, Porto Alegre, RS, abstract manuscript.

MUEHE, D. 1984. Evidências de recuo dos cordões litorâneos em direção ao continente no litoral do Rio de Janeiro. In: Restingas: Origem, Estrutura, Processos. (Lacerda, L.D.; Araújo, D.S. D.; Cerqueira, R. & Turcq, B. Orgs.), CEUFF, Niteroi, p. 75-80.

OJEDA, H.A.O. 1982. Structure, stratigraphy and evolution of the Brazilian marginal basins. Am. Assoc. Pet. Geologists Bull. 66 (6): 732-749.

OTTMANN, F. and URIEN, C.M. 1966. Sur quelques problèmes sédimentologiques dans le Rio de la Plata; Rev. de Géogr. Physique et de Géol. Dynamique, V. fasc. 3, p. 209-224.

PIERCE, J., URIEN, C.M. and SIEGUEL, F. 1969. Topografia submarina del golfo de San Matías: Argentina, Journadas Geologicas Mendoza, (abstract).

PONTE, and ASMUS, H.E. 1976. The Brazilian Marginal basins: current state of knowledge In: Continental Margins of Atlantic type. Anais da Academia Brasileira de Ciencias, Vol. 48, Suplemento, p. 215-240.

PROST, M.T. 1979. Quelques observations sur les oscillations du niveau de la mer au quaternaire dans le SE de l'Uruguay (étude géomorphologique). In: Suguio, K.; Fairchild, R.R.; Martin, L. & Flexor, J.M. (eds.), Proceedins of the 1978 International Symposium on Coastal Evolution in the Quaternary, São Paulo, p. 426-448.

PROST, M.T. 1982. Heritages quaternaires et evolution geomorphologique des bords du Rio de la Plata en Uruguay. These de Doctorat, Paris, VII, 577 p.

REYMENT, R.A.; BENGTSON, P. and TAIT, E.A. 1976. Cretaceous transgressions in Nigeria and Sergipe-Alagoas (Brasil). In: Continental margins of Atlantic Type. Anais da Academia Brasileira de Ciências, Vol. 48, Suplemento, p. 253-264.

RINE, J.M. and GINSBURG, R.N. 1985. Depositional facies of a mud shoreface in Suriname, South America, a mud analogue to sandy, shallow-marine deposits: Jour. Sed. Petrology, V. 55, p. 633-652.

ROCHA, J. 1973. Domos de sal e possibilidades de ênxofre (Plataforma continental Bahia Sul/Espirito Santo). Companhia Pesquisas e Recursos Minerais, Rio de Janeiro, internal report, 32 pp.

ROCHA, J.; MILLIMAN, J.D.; SANTANA, C.I.; VICALVI, M.A. 1975. Upper continental margin sedimentation off Brazil, Part V, Southern Brazil. Contribution Sedimentology, Vol. 4, p. 117-150.

SCHNACK, E.J. 1985. Argentina, In: Bird, E.C.F. & Schwartz, M.L. (eds.) The world's coast line. Van Nostrand Reinhold Co., New York, p.

SCHNACK, E.J.; FASANO, J.L. and ISLA, F.I. 1982. The evolution of Mar Chiquita Lagoon coast, Buenos Aires Province, Argentina. Proc., International Symp. on "Sea level changes in the last 15.000 years, Magnitude and causes, Columbia, S. Carolina, April, 1981, p. 143-145.

SMITH, A.J. and MORAIS, J.D. 1984. Estudos preliminares sobre a geologia ambiental costeira do Estado de Ceará, Nordeste do Brasil. Arquivos de Ciências do Mar, Fortaleza, Volume XXIII, p. 85-96.

SUGUIO, K. and MARTIN, L. 1976. Brazilian coastline Quaternary formations. The States of Sao Paulo and Bahia littoral zone evolutive schemes In: Continental Margins of Atlantic type. Anais da Academia Brasileira de Ciências, Vol. 48, Suplemento, p. 325-334.

SUGUIO, K. and TESSLER, M.G. 1984. Planícies de cordões litorâneos quaternários do Brasil: origem e nomenclatura. In: Restingas: origem, Estrutura, Processos. (lacerda, L.D.; Araujo, D.S.D.; Cerqueira, R. & Turcq, B. Orgs.) CEUFF, Niterói, p. 15-25.

SUMMARHAYES, C.P.; COUTINHO, R.N.; FRANCA, A.M.C. and ELLIS, J.P. 1975. Upper continental margin sedimentation off Brazil, Part III - Salvador to fortaleza, northeastern Brazil, Contrib. Sedimentology, 4, p. 44-78.

TOMAZELLI, L.J. 1977. Minerais pesados da plataforma continental do Rio grande do Sul. Thesis, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS.

TORQUATO, C.M. and CORDANI, V.G. 1981. Brazilian - Africa geological links Earth-Science Reviews, Vol. 17(1/2) p. 155-176.

URIEN, C.M. 1967. Los sedimentos modernos del Rio de la Plata exterior: Bol. Servicio Hidrografia Naval, Buenos Aires, V.4, (2) p. 113-213.

URIEN, C.M. 1970. Les rivages et le plateau continental de Sud de Brésil, de l'Uruguay y de l'Argentine: Quaternaria, Vol. 12, p. 57-69.

URIEN, C.M. 1972. Rio de la Plata estuary environments, in Nelson, B.W., ed., Environmental framework of coastal plain estuaries; Geol. Soc. America Mem. 133, p. 213, 234.

URIEN, C.M. and ZAMBRANO, J.J. 1973. The geology of basins of the Argentine continental margin and Malvinas plateau. In: The Oceans Basins and Margins (Nairn, A.E.M. and Stehli, F.G. (editores) p. 135-169.

URIEN, C.M.; MARTINS, L.R. and BUTLER, L.W. 1973. Fisiografia y sedimentos de la margem continental sulamericana. 2 Congr. Latinoam. Geologia, Caracas, resumo comunicaciones, 1 p. 5-6.

URIEN, C.M. and EWING, M. 1974. Recent sediments and environments of southern Brazil, Uruguay, Buenos Aires and Rio negro continental shelf. In: The geology of Continental Margins (Burk, C.A. and Drake, C.L. (ed.): 157-177.

URIEN, C.M. and MARTINS, L.R. 1979. Sedimentacion marina en America del Sur Oriental. Memorias del Seminario sobre Ecologia Bentonica y Sedimentacion de la Plataforma Continental del Atlantico Sur, UNESCO/ROSTLAC: 5-28.

URIEN, C.M.: MARTINS, L.R. and ZAMBRANO, J.J. 1976. The geology and tectonic framework of southern Brazil, Uruguay and northern Argentina continental margin: their behaviour during the southern Atlantic opening. In: Continental Margins of atlantic type. Anais Acad. Bras. Ciências, Vol. 48, p. 365-376.

URIEN, C.M.; MARTINS, L.R. and MARTINS, I.R. 1980. Aspectos sedimentares do Quaternãrio Costeiro do Rio Grande do Sul. Notas Técnicas, Porto Alegre, 2, p. 7-12.

URIEN, C.M.; MARTINS, L.R. and MARTINS, I.R. 1981a. Evolução geológica do Quaternãrio do Litoral Atlântico uruguaio, plataforma continental e regiões vizinhas. Notas Técnicas, Porto Alegre, 3, p. 7-43.

URIEN, C.M.; ZAMBRANO, J.J. and MARTINS, L.R. 1981b. The basins of southern South America (southern Brazil, Uruguay & Eastern Argentine) including the Malvinas Plateau. Cuencas Sedimentarias del Jurassico y Cretacico de America del Sur, Bueno Aires, 1, p. 45-125.

URIEN, C.M. and MARTINS, L.R. 1985. Southern South America Continental Margin: structural map, South Atlantic opening episodes and basis. CECO/UFRGS, Porto Alegre, Séries Mapas 06.

VILLWOCK, J.A. 1984. Geology of the coastal province of Rio Grande do Sul, southern Brazil. In: A synthesis. Pesquisas, Vol. 16, p. 5-50.

VALENCIO, D.A. and vilas, J.F.A. 1976. Sequence of the continental movements occurred prior to and after the formation of the South Atlantic. In: Continental margins of Atlantic type. Anais Acad. Bras. Ciências, Vol. 48, p. 377.

ZEMBRUSCKI, S.G.; BARRETO, H.T.; PALMA, J.C.: MILLIMAN, J.D. 1972. Estudo preliminar das provincias geomorfológicas da margem continental brasileira. Anais do XXVI Congr. Bras. Geologia, Belém, Pará, Vol. 2, p. 187-209.

ZOUAIN, R.N.A. 1985. Areas fonte e dispersão dos minerais pesados da margem continental sul-brasileira e uruguaya. Anais do II Simpósio Sul-Brasileiro de Geologia, Florianópolis, p. 1:362-378.

QUATERNARY EVOLUTION OF THE CENTRAL PART OF THE BRASILIAN COAST

THE ROLE OF RELATIVE SEA-LEVEL VARIATION AND OF SHORELINE DRIFT

Louis MARTIN - ORSTOM/CNPq, Departamento de Geofìsica, Observatòrio Nacional, Rua General Bruce 586, (20921) Rio de Janeiro (Brésil);
Kenitiro SUGUIO - Instituto de Geociências, Universidade de Sào-Paulo, C.P. 20890, (01498) Sào-Paulo (Brésil);
Jean-Marie FLEXOR - Departamento de Geofìsica, Observatòrio Nacional, Rua General Bruce 586, (20921) Rio de Janeiro (Brésil);
José Maria Landim DOMINGUEZ - Programa de Pesquisa e Pòs-Graduaçào em Geofìsica e Instituto de Geociências, Universidade Federal da Bahia, (40000) Salvador (Brésil);
Abilio Carlos da Silva Pinto BITTENCOURT - Programa de Pòs-Graduaçào em Geofìsica e Instituto de Geociências, Universidade Federal da Bahia, (40000) Salvador (Brésil).

ABSTRACT

The central part of the Brasilian coastline experienced considerable relative sea-level fluctuation during the Quaternary. It has been possible to identify three high marine levels. The last two of these, during which the sea-level was at a maximum 8 $\pm$ 2 m (120,000 years B.P.) and 4.8 $\pm$ 0.5 m (5,100 years B.P.) above the current level, have left substantial records, whose identification was possible due to numerous absolute datings. The fact that this coast was submerged until about 5,100 years B.P., when it emerged above water, is crucial for an understanding of Holocene littoral sedimentation mechanisms. In fact, starting in 5,100 years B.P., relative sea-level decline supplied large amounts of sand from the nearby platform. Deposited on the beach, these sands were taken up by littoral drift and moved on until they encountered an obstacle or a trap that would allow them to accumulate. It seems quite clear that waterways played an important role as obstacles (damming littoral transport), but only a secondary one in the supplying of sand. This accounts for the existence of progradation zones, whether linked or not to the mouth of a river.

1. INTRODUCTION

Until recent years, the old shorelines of so-called stable regions (for example, Brasil) were considered to be records of the world's ocean level. One of the goals of the "Sea-level" project (PICG N° 61, 1974-1982) was to determine a worldwide eustatic curve for the Holocene. However, field studies conducted all over the planet very quickly showed that this was not a realistic undertaking, and all the specialists now accept that it is not possible to define a general curve, but only local or regional curves. Thus it is evident that so-called eustatic curves, such as that of Fairbridge (1961), cannot be used as models of relative sea-level variation over recent millennia.

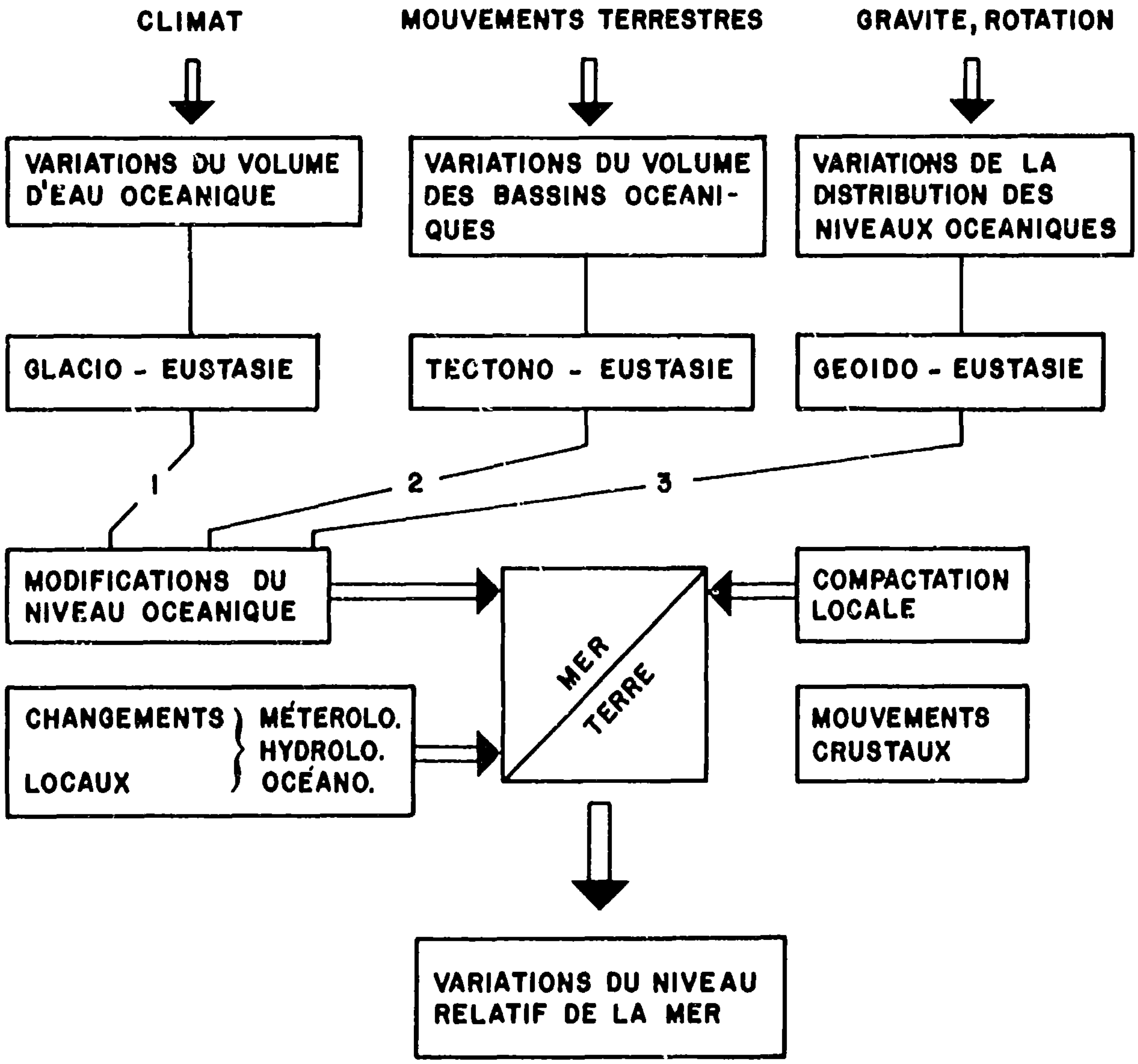


Fig. 1 - Complexity of mechanisms governing the sea-level (according to MORNER, 1980)

It is just as evident that, during the same age, coastal zones can be stable, submerged or emerged. Consequently there can be no general model of coastal sedimentation.

1.1. THE COMPLEXITY OF FACTORS GOVERNING RELATIVE SEA-LEVEL VARIATION

Relative sea-level fluctuations are the result of actual variation of the sea-level (eustatics) and of changes in the level of continents (tectonics and isostatics), as illustrated in the diagram of Figure 1. Obviously, then, whenever we reconstruct an old position of the sea--level, we are talking about a relative level.

Changes in the level of continents are controlled by:

a) tectonic movements, whether horizontal or vertical, which affect the earth's crust by mechanisms with a time scale ranging anywhere from the long-term to the instantaneous (seismic movements);

b) isostatic movements related to load variations connected with: the formation and disappearance of ice caps; the erosion of continents and accumulation of sediments in sedimentary basins; transgressions and regressions on continental platforms (hydro-isostatics);

c) deformations of the continental geoid (the latter constitutes our current reference).

Changes in the level of the ocean surface are also controlled by a number of factors:

a) fluctuations of the total volume of oceanic basins, as a consequence of plate tectonics (tectono-eustatics);

b) fluctuations of the volume of water in oceans, connected with glaciation and deglaciation (glacio-eustatics);

c) deformations of the ocean surface.

The height of the marine surface has an oceanic component and a geophysical component. The oceanic effects, capable of influencing the height of the sea, are mainly tides, major currents and associated whirlpools, and slope variations due to wind, pressure, water temperature and salinity. The overall effect of these does not exceed 1 to 2 m, and thus is quite small compared to the enormous marine surface hollows and humps caused by density heterogeneities within the planet. This geophysical component corresponds to the geoid, which is essentially the average sea-level. Starting in 1975, altimeters on board the GEOS 3 and SEASAT satellites made it possible to measure the position of the marine surface with extreme precision. This resulted in the demonstration of the existence of undulations, with very long wavelengths and with amplitudes of several dozen metres (up to 100 m to the South of India). Arguments based on the absence of correlation between these undulations and the surface topography on the one hand, and their amplitudes and wavelengths on the other, generally conclude by attributing them to

Fig. 2 - Orientation map

density differences in the lower mantle, or even at the core-mantle interface. At shorter wavelengths, the marine geoid exhibits a highly varied spectrum of anomalies.

The geoid surface is an equipotential surface of the gravity field, determined by the forces of rotation and gravity that affect the planet earth. These forces, and hence the geoid shape as well, vary as a function of the core and mantle composition (the origin of paleomagnetic crises) and of the relationship between the astenosphere and the lithosphere, but also as a function of several orbital phenomena and their interactions. It seems that geoid surface modifications can occur rapidly: MORNER (1984) quotes rates of 10 mm/yr, with gradients of several metres per km. A one milligal change in the force of gravity can deform the ocean surface by 3.3 m, and the surface of the earth's crust by 1.7 m.

Thus the ocean level at a given point on the coast is the instantaneous product of complex interactions between the surfaces of the ocean and the continent. Fluctuations of the volume of ocean basins (tectono--eustatics) and variations of the volume of oceans (glacio-eustatics) exert their effects on a global scale. On the other hand, geoid surface area changes (geoido-eustatics) and continental level changes exert their influence on a local or regional scale.

Therefore, it is quite logical that there exist inconsistencies among reconstructions of the sea-level position in the same age but at different points of the globe. This is particularly noticeable over the last 7,000 years. Indeed, before 7,000 years B.P., the rate of glacio-eustatic rise was too fast, masking components due to local or regional factors.

1.2. RECONSTRUCTION OF OLD RELATIVE SEA-LEVEL POSITIONS

THE VARIATION CURVE

To reconstruct an old relative sea-level position, it is necessary to define a marker for it in space and in time. In order to define the position of this marker in space, it is necessary to know its present altitude with respect to its original altitude; that is, to know its position with respect to sea-level at the time of its formation or deposit. In order to define the marker in time, it is necessary to know the age of its formation or deposit (isotopic, archaeological or other dating methods). A marker thus defined gives a relative position of the sea-level at a certain age. If we manage to establish a sufficiently large number of old relative sea-level positions, satisfactorily covering a certain period of time, we can then plot a variation curve for this period. It is quite obvious that only information originating from one coastal sector, where the local phenomena are always the same, can be utilised. Hence we are often confronted with the following dilemma: a) to construct a curve based on a large number of reconstructions covering the time period in question, but this often involves using data from a relatively large coastal sector, with the risk that local factors may not be the same throughout the sector; b) to consider only a restricted sector of the coast, but in this case the number of reconstructions may be insufficient to yield a precise or complete curve.

2. QUATERNARY VARIATIONS OF THE RELATIVE SEA-LEVEL ALONG THE CENTRAL PART OF THE BRASILIAN COAST

2.1. HISTORY

The important role played by relative sea-level variations in the evolution of Brasilian coastal plains was observed very early. Quite a number of authors (HARTT, 1870; BRANNER, 1904; FREITAS, 1951; BIGARELLA, 1965) have described the record of these sea-level oscillations. The evidence, mostly morphological in nature, was considered to be Tertiary by the first to study it, but was subsequently attributed to the Quaternary. Nevertheless, until the beginning of the seventies, systematic studies of relative sea-level variation along the Brasilian coast were fairly rare (SUGUIO, 1977). Only the work of VAN ANDEL and LABORAL (1964), on high Holocene levels, was based on Carbon-14 datings. Starting in 1974, relative sea-level variations in the Quaternary were studied by a group of researchers of the University of Sào-Paulo, of the Federal University of Bahia and of the national observatory in Rio de Janeiro, in conjunction with ORSTOM (French Research Institute for Co-operative Development). This team completed studies of the coastal Quaternary of the State of Sào-Paulo and the southern half of that of Rio de Janeiro (MARTIN and SUGUIO, 1975, 1976 a and b, 1978; SUGUIO and MARTIN, 1976, 1978 a and b, 1980 a and b; MARTIN et al., 1979 a and b, 1980 a), of the States of Bahia, Sergipe and Alagoas (BITTENCOURT et al., 1979 a and b; MARTIN et al., 1978, 1979 b, 1980 a and b, 1982; VILAS-BOAS et al., 1982; DOMINGUEZ, 1982; DOMINGUEZ et al., 1982, 1983 a and b), of the northern half of the coast of the State of Espirito--Santo (SUGUIO et al., 1982), and of the northern part of the coast of the State of Rio de Janeiro (MARTIN et al., 1984). Similarly, research work was carried out in the States of Parana and Santa-Catarina (SUGUIO et al., 1986; MARTIN and SUGUIO, 1986). Moreover, the same team systematically studied sedimentary deposits at the mouths of the Paraìba do Sul, Doce, Jequitinhonha, Sào-Francisco and Parnaìba Rivers, with a view to determining the role played by relative sea-level variation and by littoral drift in the construction of these coastal plains.

2.2. EVIDENCE FOR QUATERNARY MARINE LEVELS ALONG THE CENTRAL PART OF THE BRASILIAN COAST

Sedimentary evidence

Littoral sandy formations, whose peaks are very much above the present equivalent deposit zone, provide indisputable evidence for Quaternary old marine levels positioned above the present sea-level.

Thanks to some detailed cartography, together with absolute datings, it has been possible to distinguish between two principal generations of sandy terraces, recording two periods of high Quaternary marine levels. The nature of the sedimentary structures found in these terraces makes it possible spatially to reconstruct the sea-level position with fairly good precision.

Biological evidence

Along almost all the rocky part of the Brasilian coast, there is biological evidence for old marine levels higher than the present level. It generally consists of deposits of limpets (gastropoda), oysters and of sea-urchin holes, situated above the living zone of these organisms. Since the distribution zone of limpets is very narrow (0.5 m), the presence of a fossil deposit of these organisms makes it possible to reconstruct an old sea-level position with good precision. All along the north-eastern part of the Brasilian coast, there are numerous dead reefs made up of calcareous algae and coral. The position of these reefs' peaks provides evidence for old sea-levels higher than the present level. Finally, in the sandy terraces, one can find fossilised burrows of Callichirus major (marine arthropode) above the present living zone of these organisms.

Archeological evidence

Numerous "sambaquis" (artificial accumulations of shells), built by ancient inhabitants of the coastal zones, can be found in various parts of the Brasilian coast. The position of some of these "sambaquis" can be explained only by a lagoon extension significantly greater than the present one, and hence a higher than present marine level. Moreover, the "sambaquis" whose bases are below the present high tide level could have been built only at a time when the sea-level was lower than at present.

2.3. HIGH QUATERNARY MARINE LEVELS ALONG THE CENTRAL BRASILIAN COAST

The oldest known high marine level on the Brasilian coast has been demonstrated only on the coast of the states of Bahia and Sergipe. It is known by the name of Old Transgression (BITTENCOURT et al., 1979). This event is not well defined, because there are no outcrop deposits that can be associated with it with certainty. The only record we know of its existence consists of cliffs cut through continental Pliocene sediments of the Barreiras Formation, and probably of a non-outcrop reef formation in the south of the State of Bahia (CARVALHO and GARRIDO, 1966). The peak of this formation was found on the islet of Coroa Vermelha, 11 metres below present sea-level.

High marine level at 120,000 years

The Old Transgression was followed by a new transgressive phase, during which the relative sea-level, about 120,000 years B.P., was

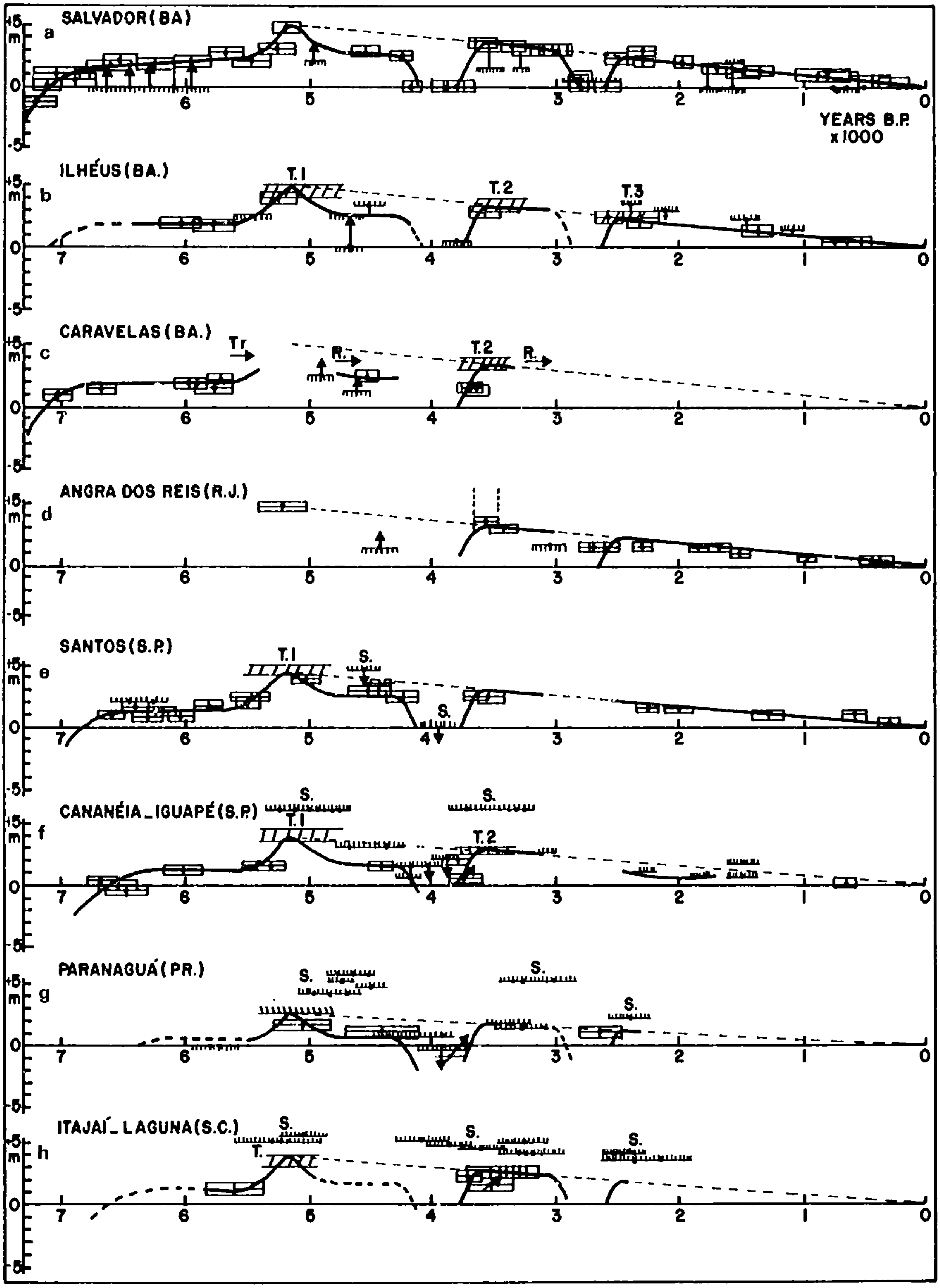


Fig. 3 - Relative sea-level variation curves for the last 7,000 years along several sectors of the Brasilian coast

at 8 ± 2 m above the present level. The age of 120,000 years was established by means of Io/U dating of 5 samples of coral (MARTIN et al., 1982; BERNAT et al., 1983). This transgression is known as the Cananeia Transgression along the São-Paulo coast (SUGUIO and MARTIN, 1978), and as the Second-Last Transgression on the coasts of the States of Bahia, Sergipe and Alagoas (BITTENCOURT et al., 1979). The record of this high level consists essentially of substantial sandy terraces, extending more or less continuously throughout the region in question. On the basis of sedimentary structures and fossilised burrows of Callichirus major, it is possible to reconstruct the spatial sea-level position. However, in the absence of datings (with the exception of the five Io/U determinations), it is not possible to do a temporal reconstruction, or to establish relative sea-levels in the vicinity of 120,000 years B.P., and to compare altitudes of the same age at different points of the coast.

High marine level in the Holocene

The most recent high marine level is very well known, thanks to a very large number of determinations of old relative sea-level positions in time and space, carried out on the basis of more than 700 Carbon-14 datings. Moreover, the position of a number of "sambaquis", together with dating of the shells they contain, and with the delta 13C(PDB) values of carbonates of these same shells, have given us interesting complementary information about relative sea-level oscillations over the last 5,500 years (MARTIN et al., 1985). On the basis of all these data, it has been possible to plot or at least to sketch relative sea--level variation curves for several sectors of the Brasilian coast. In order to obtain homogeneous curves, we have used data originating from littoral sectors of limited dimensions and exhibiting uniform geological characteristics.

2.4. RELATIVE SEA-LEVEL VARIATION OVER THE LAST 7,000 YEARS ALONG THE CENTRAL PART OF THE BRASILIAN COAST (Fig. 3)

Sector to the North of Salvador (Bahia)

In this sector of some fifty km length, about sixty determinations of old relative sea-level positions, covering the last 7,000 years very regularly, have been made. These data have made it possible to plot a very precise curve which shows that:

- the present zero (mean level) was exceeded for the first time in the Holocene at about 7,100 years B.P.;

- about 5,100 years B.P., the relative sea-level went through a first maximum of 4.8 ± 0.5 m above the present level;

- after this maximum, there was a rapid regression until 4,900 years B.P., slowing down until 4,200 years B.P., and speeding up again until 3,900 years B.P. At about this time the marine level passed through a minimum, probably below the present level;

- between 3,900 and 3,600 years B.P., a rapid transgression occurred, and at about 3,600 years B.P., the relative sea-level passed through a second maximum of 3.5 $\pm$ 0.5 m above the present level;

- between 3,600 and 3,000 years B.P., the relative sea-level fell slowly and regularly. Starting at 3,000 years B.P., the decline became very rapid, and at about 2,800 years B.P., the relative sea--level must have been slightly below the present level;

- between 2,700 and 2,500 years B.P., the relative sea-level rose very rapidly, passing through a third maximum of 2.5 $\pm$ 0.5 m above the present level at about 2,500 years B.P.;

- since 2,500 years B.P. the relative sea-level has fallen regularly to its present position.

This very well defined curve can be used as a reference for coastal sectors, where the number of reconstructions is insufficient to allow a complete curve to be plotted. In this type of sector, it is possible to compare the available reconstructions with the Salvador curve, and to see whether or not they fit on the curve.

Sector of Ilheus (Bahia)

In this sixty km sector, the number of reconstructions of old relative sea-level positions over the last 7,000 years is insufficient for a complete curve to be drawn. However, the available determinations exhibit no shift with respect to the Salvador curve. It has been possible to demonstrate the presence of 3 sandy terraces, witnessing the existence of 3 high level periods, positioned between 5 and 4, 4 and 3, and 3 and 2 metres above the present level. It is logical to conclude that these 3 terraces correspond to the 3 maxima determined in the Salvador sector.

Sector of Caravelas (Bahia)

It was possible to do only 11 reconstructions in this thirty km sector. However, 7 of them fit into the range between 7,000 and 5,700 years B.P., so this part of the curve has been established with good precision. All the available data are in accordance with the Salvador curve.

Sector of Angra dos Reis (Rio de Janeiro)

In this sector of some 60 km, only 17 old relative sea-level positions could be reconstructed. However, the segment of the curve running from 0 to 2,500 years B.P. is fairly well defined. We also managed to obtain indications that there were two maxima, one slightly above 3 m between 3,650 and 3,450 years B.P., and the other in the vicinity of 4.8 m at about 5,200 years B.P.

Sector of Santos (Sào-Paulo)

About thirty reconstructions, resulting in a fairly complete curve, were made in this sector of about 60 km length. It is interesting to note that the present zero was exceeded for the first time in about 6,800 years B.P., that is, considerably later than in the Salvador sector. The parallel maxima of 5,100 and 3,600 years B.P. were positioned at 4.5 $\pm$ 0.5 m and at 3.0 $\pm$ 0.5 m above the present level.

Sector of Cananeia (Sào-Paulo)

Only 10 old relative sea-level positions could be reconstructed along these approximately 100 km of coast. However, as 7 of them fell into the range between 6,650 and 5,300 years B.P., that part of the curve was drawn up satisfactorily. Moreover, "sambaquis" datings in this region, associated with delta 13C(PDB) variations of the carbonates of their shells, provided additional information. It seems that the present zero was exceeded for the first time in about 6,600 years B.P., and that the maximum of 5,150 years B.P. (whose age was established with great precision by means of the 13C(PDB) variation curve) was no higher than 4 m above the present zero.

Sector of Paranagua (Parana)

Not much good data is available from this fifty km long sector. Nevertheless, a few bits of precise information bring to light the major trends of relative sea-level variation over the last 7,000 years. For instance, in Paranagua Bay the peak of the outer part of the Pleistocene marine terrace is at 2.5 m above the present high tide level. Given that on the surface of this terrace there are traces of old Pleistocene littoral belts, it is clear that the terrace was not submerged during the Holocene, and consequently that, at the time of the maximum of 5,100 years B.P., the relative sea-level could not have been more than 2.5 m above the present level. "Sambaquis" datings provide us with interesting additional information. It seems that the Paranagua curve is comparable in shape to that of Salvador, but shifted downwards by a substantial amount.

Sector of Florianopolis (Santa-Catarina)

The information available on the Quaternary of the coast of Santa-Catarina State provides us with an understanding of the major sea-level variation trends over the last 7,000 years. The resulting curve again has the same shape as that of Salvador, and it is also shifted downwards, but certainly not as much as the Paranagua curve.

The coast of Alagoas State

It was not possible to plot a relative sea-level variation curve for the length of coast in Alagoas State, because precise reconstructions are too few in number, and because the sector in question is relatively long. However, when compared with the Salvador curve, the available data exhibit no significant differences. Thus it is reasonable to believe that relative sea-level variations along the coast of Alagoas State were much the same as in the coastal sector to the North of Salvador.

2.5. GENERAL REMARKS ABOUT THESE CURVES

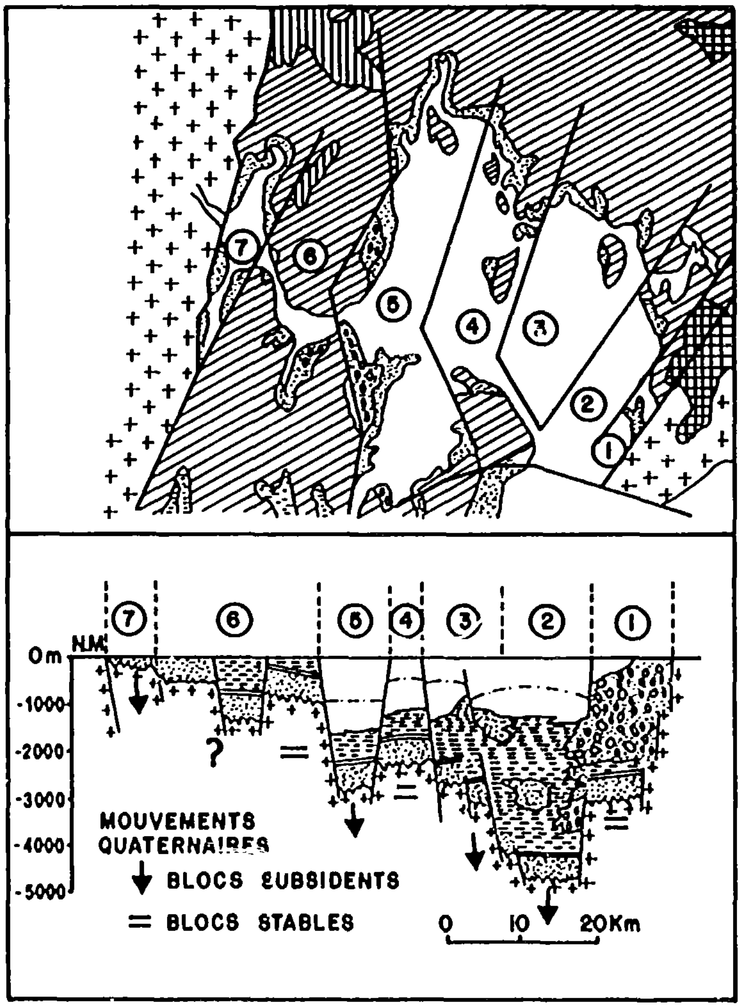
The first important fact is that, in all the sectors, the relative sea-level has been higher than the present level, with an elevation maximum always occurring at about 5,100 years B.P. Moreover, all the curves have the same general shape, but some are shifted vertically. Finally, all the sectors seem to have experienced, after 5,100 years B.P., two rapid relative sea-level oscillations of 2 to 3 metres. These are too large to be glacio-eustatic in origin.

On the Salvador curve, plotted with more precision than the others, the 17 reconstructions of old relative sea-level positions, used to establish the curve between 0 and 2,500 years B.P., fit onto a straight line segment. Moreover, 6 other reconstructions, used to establish the curve between 3,000 and 3,600 years B.P., are situated on the extension of the same straight line segment. Finally, if one extends this segment all the way to 5,100 years B.P. (age of the maximum), one obtains a relative sea-level position in the vicinity of 5.0 m above the present level. Now the experimental reconstruction yields an old relative sea-level position of 4.8 $\pm$ 0.8 m above the present level at 5,150 $\pm$ 110 years B.P. Thus we have, between 0 and 5,100 years B.P., a large number of points on the same straight line, too large, in fact, for this to be accidental. But during certain shorter periods of time, the experimental curve moves away from this straight line. It looks very much as if, since 5,100 years B.P., a first phenomenon caused a regular decline of the relative sea-level, and a second phenomenon, superimposed on the first, generated very rapid oscillations of this same sea-level.

Comparing the entire set of curves, it seems that those of Salvador, Ilheus and Caravelas are not shifted with respect to one another. On the other hand, the Anga dos Reis curve is shifted slightly downwards. This shift becomes accentuated in the curves of Santos, Cananeia and Paranagua, where it is maximal; but the Florianopolis curve, albeit shifted with respect to that of Salvador, is less so than the Paranagua curve.

2.6. NATURE OF THE PHENOMENA

In some well delineated sectors of the coast, it has been possible to demonstrate Holocene beach-line shifts, as a consequence of vertical tectonic movements. For instance, in the Bay of Todos os Santos (Bahia),



COUPE E.-W. A-TRAVERS LE BASSIN DO RECONCAVO
(Filho at al, 1982)

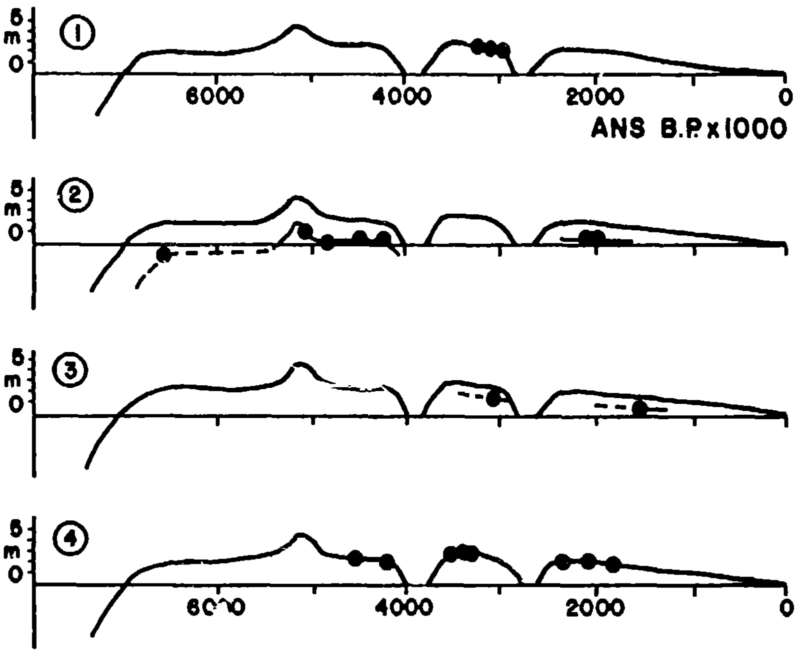


Fig. 4 - Tectonic sectioning of Reconcavo Basin. Positions of a number of reconstructions of old ocean levels in various sections of the Basin, plotted against the Salvador curve

lying on the Reconcavo trough fault, vertical movements of massifs have resulted in pronounced shifts of Holocene shorelines (Fig. 4) (MARTIN et al., 1984, 1986). The same is true for parts of the coast of Rio de Janeiro State, lying on the Guanabara trough fault (MARTIN et al., 1980), and to the South of Cap de Sào-Tomé (MARTIN et al., 1984). It is also possible that some parts of the coast were affected by a continental flexure mechanism, but this phenomenon does not seem to have had a very great influence at the time of the Holocene (MARTIN et al., 1976).

In all the sectors chosen for determination of a curve, with the exception of Angra dos Reis, there is a record of the marine terrace of 120,000 years B.P. Nowhere do the most inner parts of this terrace (of roughly the same age) exhibit significant altitude differences. If the shift of almost 2.5 m, in the maximum altitude of 5,100 years B.P., between the sectors of Salvador and Paranagua were tectonic in origin, the records of the high marine level of 120,000 years B.P. would be shifted very greatly (almost 60 metres), which is not at all the case. Thus it is likely that the shifts observed between certain sector curves are the result of geoid surface deformations.

An examination of the geoid map of Brasil (MARTIN et al., 1985) shows that the East of the country lies over a geoid protuberance, whose equal elevation lines run approximately North-South (Fig. 5). One also sees that the West of Brasil lies over another protuberance, centred on Bolivia, and that between these two protuberances there is a depression that cuts across the South-East and North coast of Brasil. The part of the coast of Bahia State, containing the sectors having provided data for the Salvador, Ilheus and Caravelas curves, and running approximately N-S, is more or less parallel to the lines of equal geoid height. On the other hand, the part of the coast containing the sectors having provided data for the Angra dos Reis, Santos, Cananeia and Paranagua curves, and running approximately NE-SW, cuts obliquely across the lines of equal geoid height. A horizontal displacement of the geoid relief, in an approximately N-S or E-W direction, would have no effect on the first three curves, but would trigger a shift of the others.

If one accepts that geoid relief changes on a regional scale are partly responsible for the Holocene high marine levels found along a large part of the coast, the shifts described above can be explained by the fact that these changes are not identical everywhere. For example, one could suppose that the submersion phase, which affected a major part of the Brasilian coast before 5,100 years B.P., is due partly to a temporary elevation of the geoid relief, and the following emersion, on the other hand, due to a lowering of the same relief. In fact, a slight displacement of the central depression's axis to the East, during the lowering of the geoid relief, could explain the shifts observed between the curves of Angra dos Reis, Santos, Cananeia and Paranagua, as shown schematically in Figure 6. If this hypothesis is correct, Holocene marine levels in the North of Brasil should be shifted with respect to corresponding levels from the Salvador region. Unfortunately, we have no numerical data for this part of the coast. Nevertheless, it is interesting to note that the coast between Sào-Luis and Belem (Fig. 2) exhibits distinct submersion characteristics: broken coast, sharp cliffs cut into the sediments of the Barreiras Formation, lower parts of waterways transformed into rias.

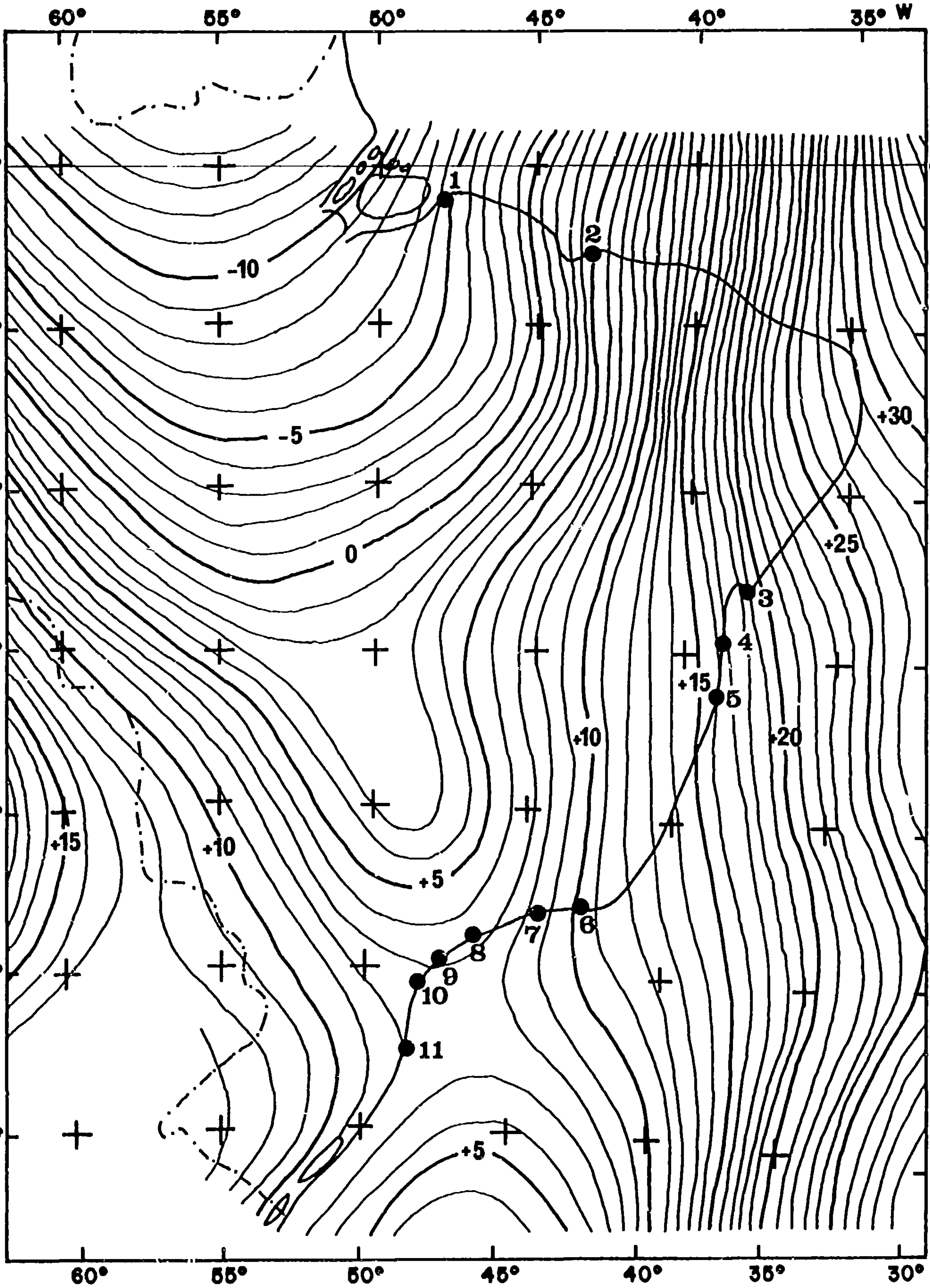


Fig. 5 - Geoid map of Brasil. 1) Belem 2) Sào Luis 3) Salvador 4) Ilheus 5) Caravelas 6) Rio de Janeiro 7) Angra dos Reis 8) Santos 9) Cananeia 10) Paranagua 11) Florianopolis

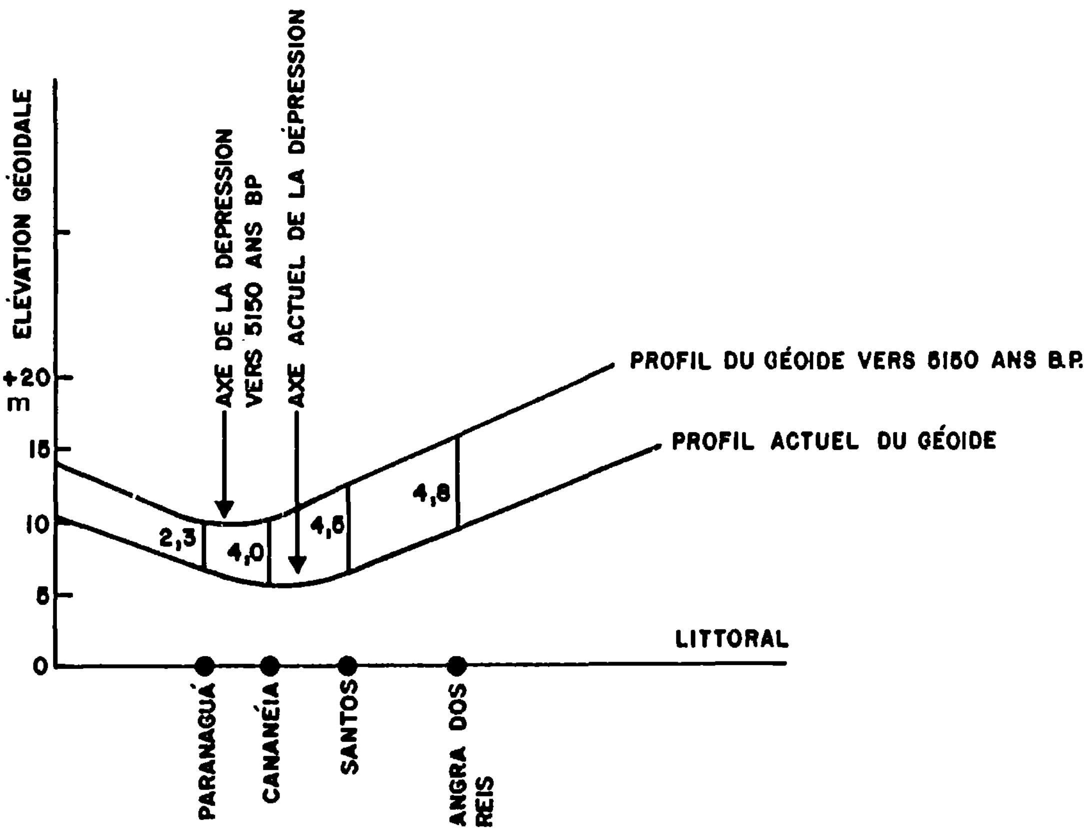


Fig. 6 - Present geoid profile between Paranagua and Angra dos Reis compared to the geoid profile in about 5,150 years B.P. The vertical dislocations can be obtained by a simple lowering of the geoid relief in conjunction with a slight horizontal displacement towards the East

To conclude, it does seem that the Holocene high marine levels of Brasil (which can be neither glacio-eustatic nor tectonic in origin) can be explained, at least in part, by a regional uplift of the overall geoid relief until about 5,100 years B.P., followed by a sinking and a minor horizontal displacement to the East. Similarly, regional sinking of the overall geoid relief, followed by an uplift on a scale of centuries, can explain the rapid oscillations that have occurred since 5,100 years B.P. (oscillations which also can be neither glacio-eustatic nor tectonic in origin).

3. CONSEQUENCES OF RELATIVE SEA-LEVEL VARIATION FOR LITTORAL SANDY SEDIMENTATION

Schematically speaking, it can be said that (whatever the causes) most of the Brasilian coast under study was submerged until about 5,100 years B.P., and, disregarding the two rapid oscillations, emerged since then. This is by no means an universal circumstance. For example, along the Atlantic Coast of the United States of America, the relative sea--level did not rise above the present level at all during the Holocene (Fig. 7). Thus it is obvious that coastal zone evolution could not have been the same in Brasil and in the United States over the last 7,000 years. Submerged coasts (the United States case) are characterised by the existence of barrier island/lagoon systems, while emerged coasts (the case of Brasil for 5,000 years) present vast sandy expanses covered by alignments of old littoral belts. A reconstruction of the situation prevailing in the Rio Doce mouth region before 5,100 years B.P. (based on Carbon-14 datings) shows a remarkable resemblance to the current appearance of Cap Hatteras in the United States (Fig. 8).

3.1. THE ROLE OF RELATIVE SEA-LEVEL VARIATION IN SANDY LITTORAL SEDIMENTATION

A sandy littoral zone has an equilibrium profile that is a function of dynamics and granulometry. The dynamics vary incessantly (tides, surge, etc.), so the profile is constantly being destroyed. However, if one considers a sufficiently long period of time, one can presume the existence of a mean equilibrium profile. It is quite obvious that a relative sea-level fall or rise destroys this equilibrium. The rule of BRUUN (1962) states that a sea-level rise destroys this equilibrium, which is then re-established by a displacement of the profile in the direction of the continent, manifested by erosion of the beach prism, and transfer of the eroded material in the direction of the outer beach. This causes the outer beach bottom to rise by a height equal to that of the sea-level rise (Fig. 9). Field and laboratory tests (SCHWARTZ, 1965, 1967; DUBOIS, 1976, 1977) have demonstrated the validity of the BRUUN rule. Even though this rule was established for the sea-level rise situation, it is logical to suppose that a sea-level fall causes destruction of the equilibrium profile, manifested by erosion of the outer beach bottom, and by transfer of the eroded sand towards the

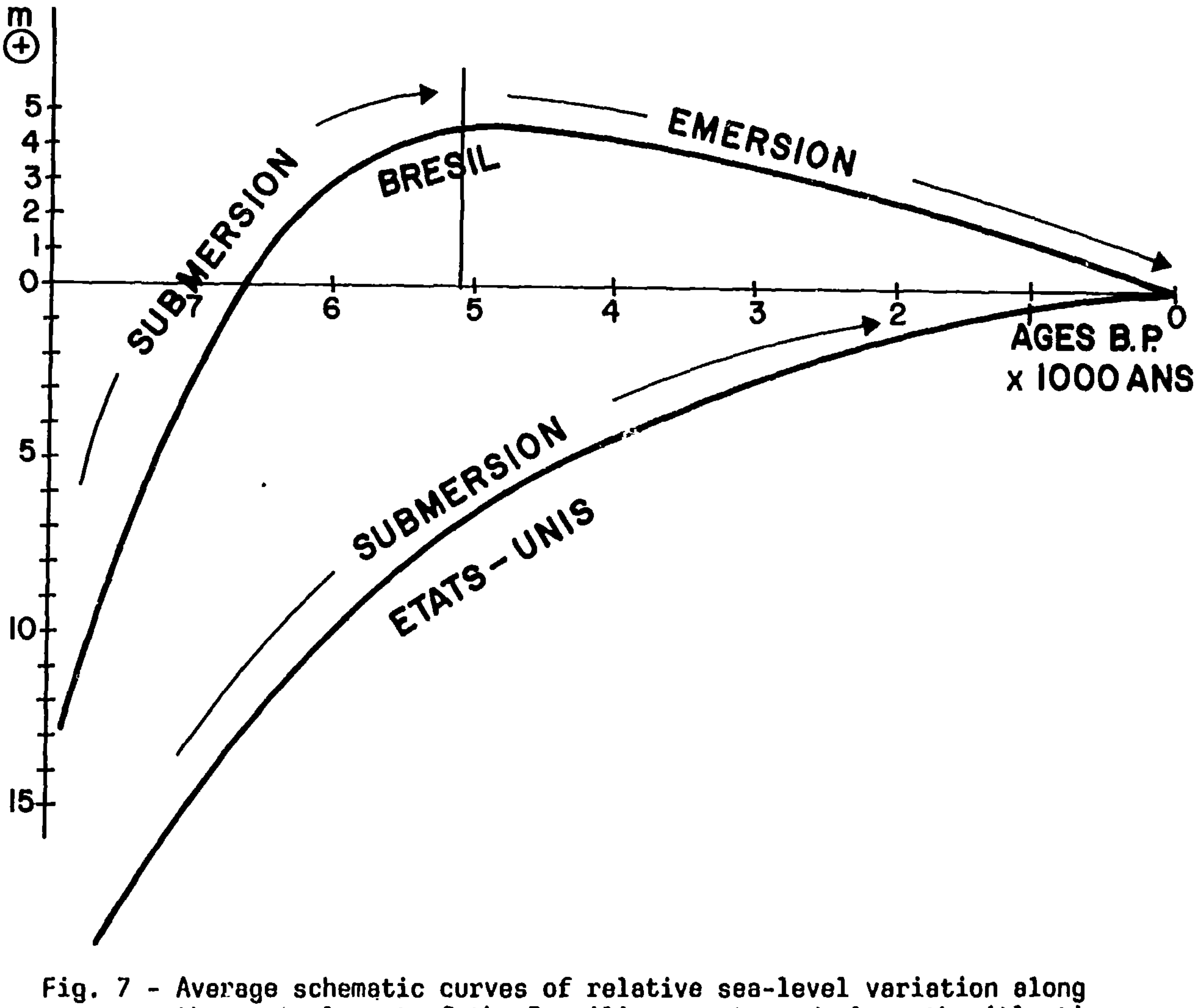


Fig. 7 - Average schematic curves of relative sea-level variation along the central part of the Brasilian coast, and along the Atlantic Coast of the United States of America, over the last 8,000 years

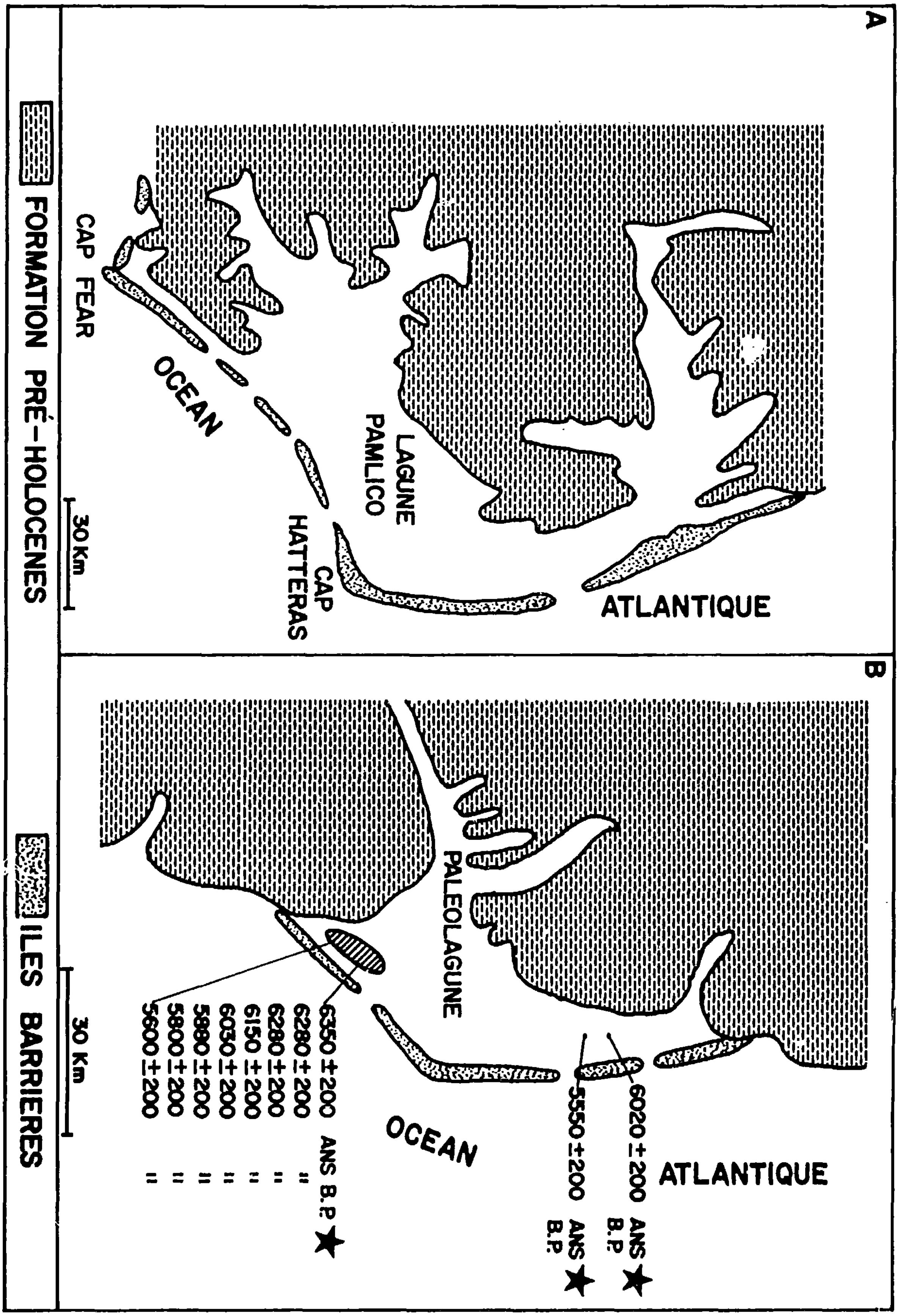


Fig. 8 - Comparison between the present situation in the Cap Hatteras region (USA) and that of the Rio Doce coastal plain before 5,100 years B.P.

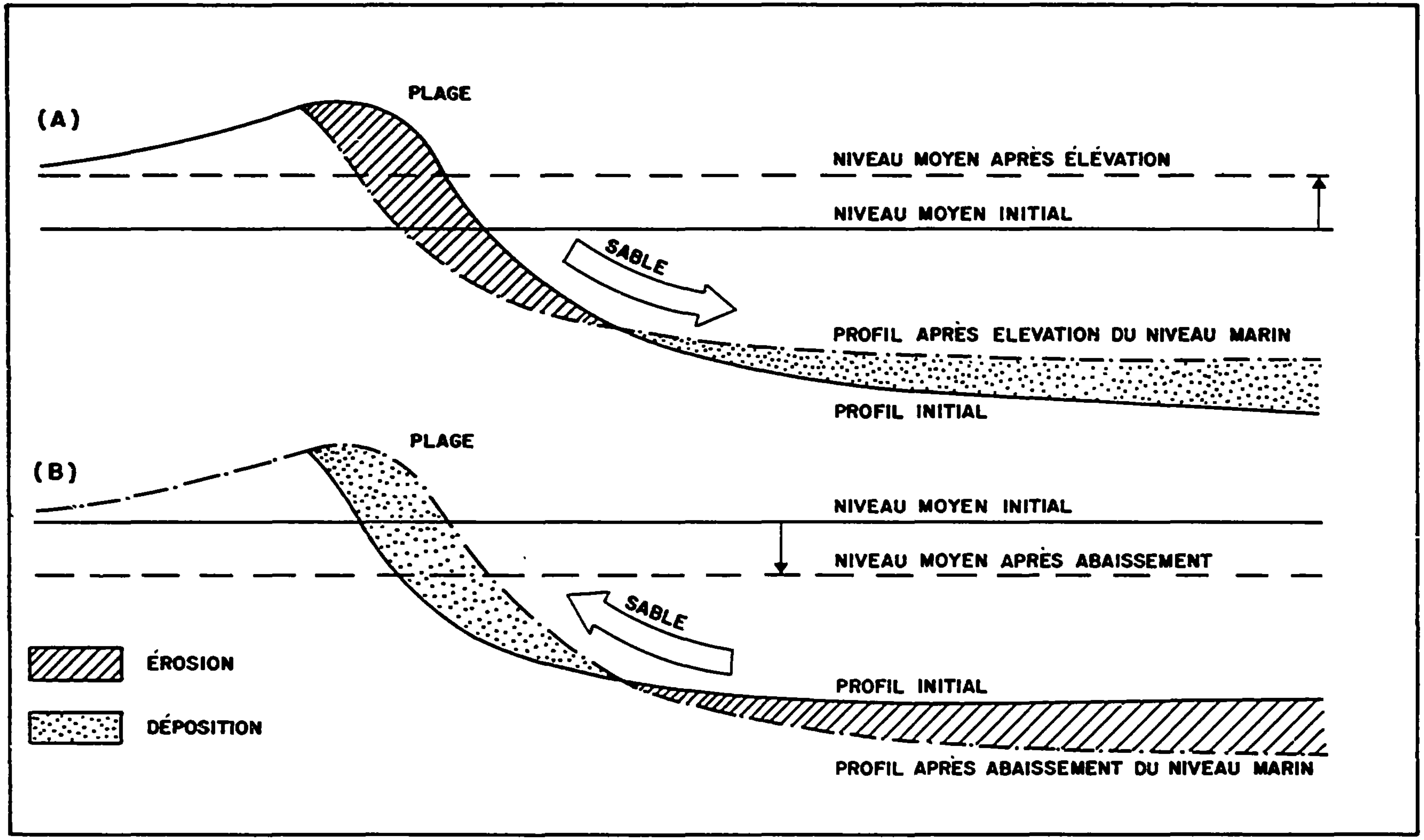


Fig. 9 - A) Behaviour of the equilibrium profile of a sandy littoral zone as resulting from a sea-level rise (BRUUN's Rule, 1962)
B) Behaviour as resulting from a sea-level fall

coast. This transfer from the outer beach towards the beach prism ends when the original depth is re-established (Fig. 9 B). This mechanism is quite similar to the one that occurs when the beach profile is re-established after a storm, by sand transfer from the outer beach to the beach prism, which is very well documented in the literature (DAVIES, 1972; KING, 1972; KOMAR, 1973; SWIFT, 1976). Moreover, this mechanism can be ideally observed during a monthly cycle of tides. During running water tides (corresponding to a small transgression), there is erosion of the beach prism and accumulation on the outer beach; on the other hand, during dead water tides (corresponding to a small regression), there is beach prism accumulation and outer beach erosion.

Hence it is clear that, on gently sloped sandy coasts, lowering of the relative sea-level generates a substantial flow of sand from the inner shelf to the beach. If the littoral transport is zero, this then results in substantial "progradation" of the coastline, by the successive adjoining of littoral belts.

3.2. THE ROLE OF LITTORAL DRIFT IN COASTAL SANDY SEDIMENTATION

As they approach the shore, waves break when the depth is not sufficient for them to continue moving. This breaking involves liberating a great amount of energy, which is taken up partly by putting sand grains into suspension, and by the formation of a current parallel to the coast, known as the longshore current. Naturally, this current appears only if the wave-fronts strike the coast obliquely. The longshore current has a slow speed, but because its action takes place in the zone where sand grains have been suspended by breaking, the volume of sand transported can be substantial. In addition, the splashes of water from breaking waves generate saw-tooth pulses of sand transport (shore casting). Obviously, the direction of the transport is a function of the direction at which the wave-fronts reach the shoreline.

It is clear, then, that during a period of relative sea-level decline, part of the sand brought in to the beach prism will be moved along the beach by the longshore current. This transport continues until the sand is taken up in a trap or blocked by an obstacle. This explains the great differences that can exist between two regions having been subjected to an equivalent lowering of the relative sea-level. Sandy deposits are small or even absent in transit regions, and very large in regions where a trap or an obstacle causes sand accumulation. Such traps or obstacles come in different forms: recesses of the coastline, islands or shallow bottoms forming low-energy zones, rocky points, mouths of waterways, etc.

3.3. BLOCKING OF LITTORAL SEDIMENTARY TRANSPORT BY THE FLOW OF A WATERWAY

Under certain conditions, the flow of water from a river-mouth can constitute an obstacle tending to block sand transport, in the manner of an artificial groyne built on a beach. These well-anchored

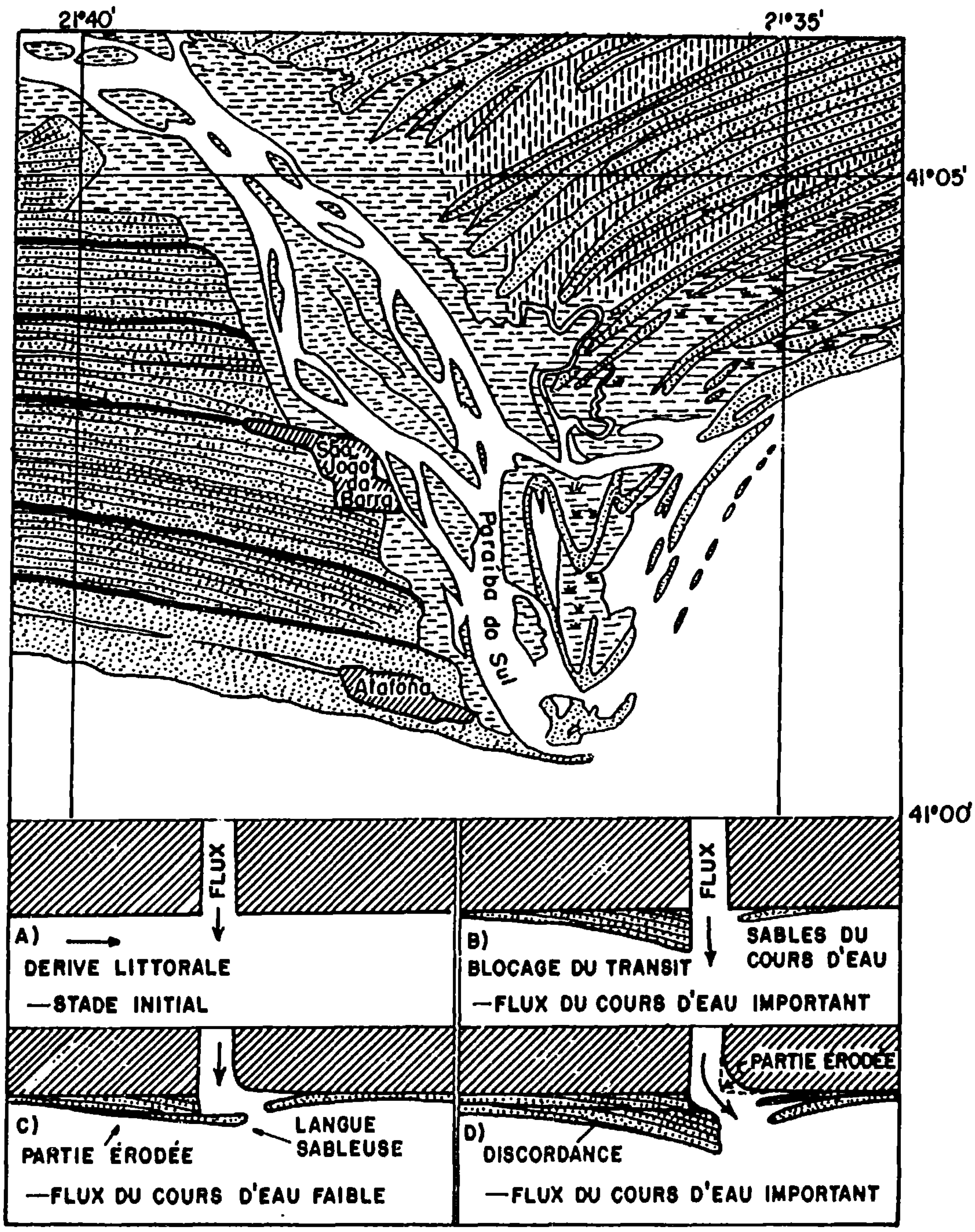


Fig. 10 - Schematic diagram of littoral transport blocking by the flow of a waterway. Map of the Rio Paraíba do Sul mouth illustrating this mechanism

works are generally built so as to extend beyond the wave breaking zone. They completely interrupt the littoral transport of sandy sediment, which leads to an accumulation on the longshore current side, so that the coastline advances there. On the other hand, on the side of the groyne lying below the longshore current, this current continues to remove sand, which leads to erosion and coastline retreat.

When there is a dominant littoral drift, the mechanisms operating at the mouth of a waterway can be described schematically as follows (Fig. 10):

a) in a period of high river discharge, the flow of water near the mouth constitutes an obstacle tending to block the transport of sand by littoral drift. This results in sand accumulation on the longshore current side, with possible erosion on the side below the current. However, this erosion is usually compensated by deposits of the waterway itself (Fig. 10 B).

b) in a period of low discharge, the obstacle formed by the waterway's flow tends to disappear, and the littoral drift causes partial erosion of the deposit formed during the preceding period. A neck of sand, tending to close off the mouth, is then formed. This mechanism is recorded in the coastal plain by lines of discordance in the alignment of littoral belts (Fig. 10 C). If the low-energy period lasts long enough, the neck of sand achieves a width that allows it to resist the following high-energy period. In some cases, only its tip is destroyed, and the dam set up by the waterway's flow is displaced in the direction of the current, with the beginning of another accumulation (Fig. 10 D). This displacement is marked by a series of stages, underscored by the discordances in the alignment of belts.

As a consequence of the groyne effect exerted by the flow of a waterway opening onto a sandy coast, one observes distinct dissymetry between the parts of the coastal plain on the two sides of the mouth. Whereas the coastline on the drift current side advances because of sand deposition by the littoral drift, the coastline below the longshore current advances mainly because of sand deposited by the waterway. The latter advance is generally less pronounced, and takes place starting from sandy points anchored on the side below the drift current, or by reshaping of mouth banks, which evolve into "moon islands" as a result of wave action. Once these sandy points and islands are constructed, protected zones form behind them, and are quickly colonised by mangroves. Thus the coastal plain on the side of the mouth that is in the drift current will consist of a fairly regular piling up of littoral belts, whose sand is not deposited by the waterway. On the other hand, the coastal plain area below the drift current will be formed by an alternation of clayey-sandy low zones and sandy zones, whose material is partly brought in by the waterway.

In order to check whether this scheme is well founded, we carried out a study of the degree of rounding of beach sand on both sides of the mouth of the Rio Paraiba do Sul (Rio de Janeiro), which is a virtually perfect model of the mechanisms we have just described (Fig. 10). In the region of the Rio Paraiba do Sul mouth, there are two types of surge. The first, coming from the S-SE and especially frequent in autumn and in winter, is related to the penetration of polar air masses over

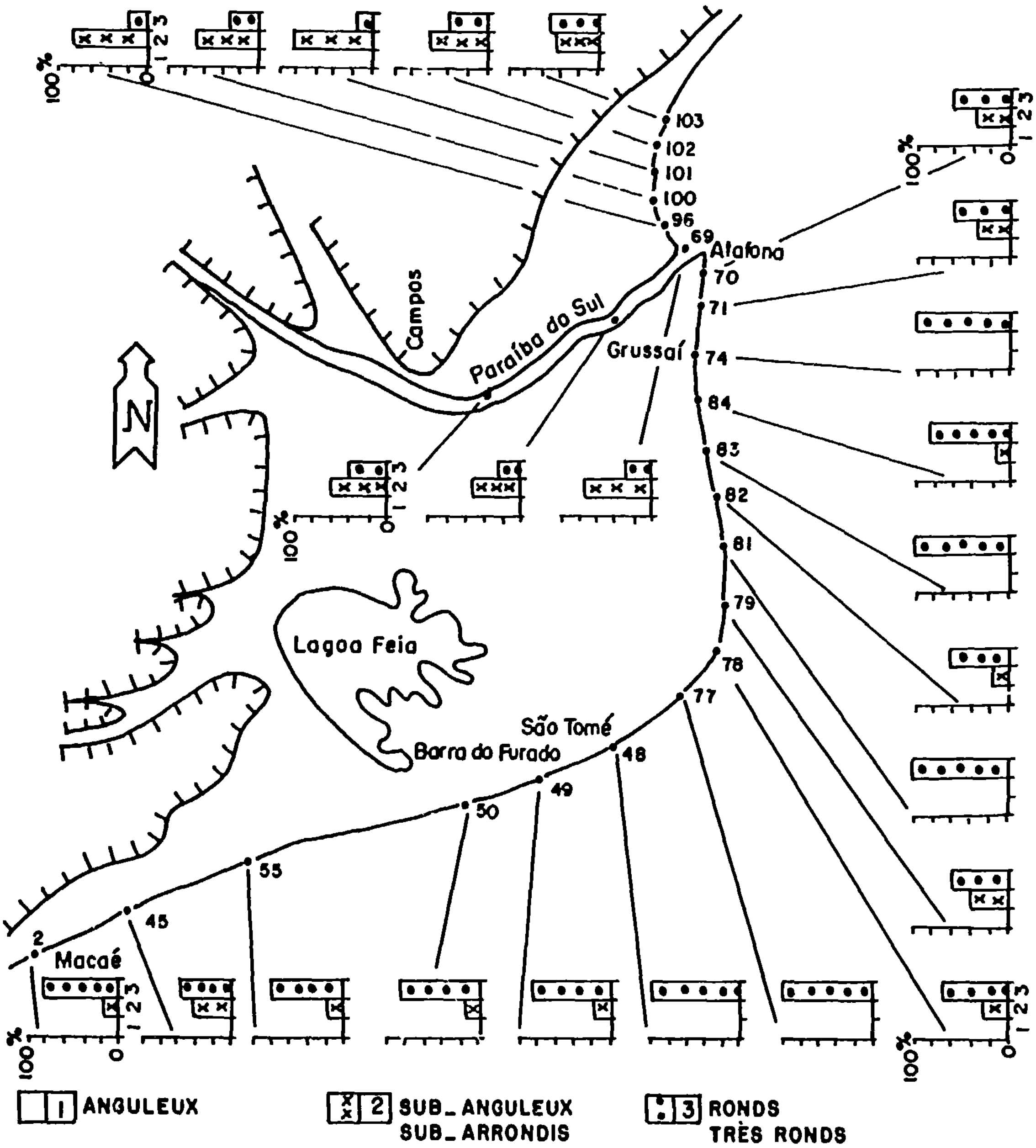


Fig. 11 - Histograms of the degree of rounding of sand grains from the present beach of the Paraíba do Sul coastal plain on both sides of the mouth, and from the present river bed

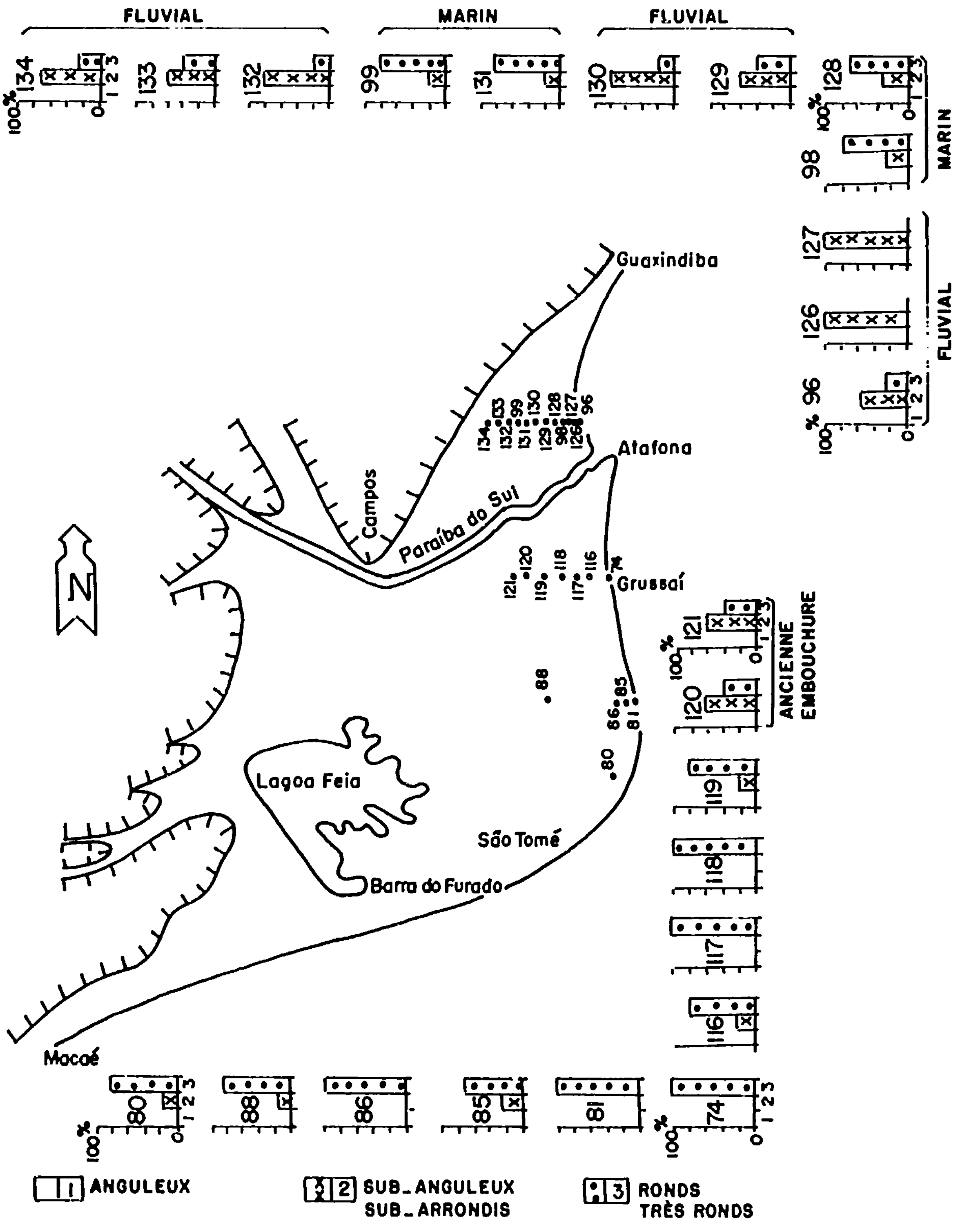


Fig. 12 - Histograms of the degree of rounding of sand grains from Holocene marine terraces on both sides of the Rio Paraiba do Sul mouth

the South American continent. The second, NE in direction, is associated with the tradewinds. But the S-SE surge, being much stronger than the NE surge, plays the dominant role in littoral transport (MARTIN et al., 1984). All the morphological indicators of littoral transport direction show that it is now occurring from the South to the North, and that this has been the case for the last 5,000 years (DOMINGUEZ et al., 1983). To begin with, 21 samples were taken between the southern and northern extremities of the coastal plain. Moreover, for the purpose of comparison, 3 samples of sand were taken from the bed itself of the Rio Paraìba do Sul. The results, represented in the form of histograms (Fig. 11), indicate that there are 2 quite distinct categories of sand. To the south of the mouth, the sand is characterised by the presence of 20% to 60% very rounded and rounded grains, and by the absence of angular and sub-angular grains. On the contrary, sand to the north of the mouth is characterised by the absence of very rounded grains and the presence of sub-angular grains. Finally, the 3 samples taken from the Rio Paraìba do Sul bed itself exhibit exactly the same characteristics as those from the northern beach. We also studied the degree of rounding of sand grains from 24 samples taken along 2 profiles cutting across terraces on both sides of the mouth. All the samples from the southern terrace exhibit the characteristics of sand from the present southern beach: presence of very rounded grains and absence of sub--angular grains. On the other hand, the northern terrace samples exhibit the characteristics of sand either from the northern beach or from the southern beach (Fig. 12). The terrace situated to the north of the mouth consists of a roughly regular alternation of sand deposited by the Rio Paraìba do Sul, and of sand originating from the inner shelf and deposited by the littoral drift. It is quite clear, then, that all the coastal plain area to the south of the mouth could not have been built up by sand deposited by the Rio Paraìba do Sul.

4. MAIN STAGES OF THE FORMATION OF COASTAL PLAINS

Relative sea-level variations, associated with climatic changes, have been the principal factors in the formation of Brasilian littoral plains. An evolutionary model has been established fairly precisely for the coast of Bahia State (MARTIN et al., 1980; DOMINGUEZ et al., 1982) (Fig. 13). This model remains valid for the entire coast lying between Macaé (Rio de Janeiro) and Recife (Fig. 2) (all this region is characterised by the presence of Barreiras Formation continental sediments). On the other hand, in the southern half of the coast of Sào-Paulo State, and along the coastline of the States of Santa Catarina and Parana, this model is only partly applicable for local reasons.

4.1. THE GENERAL MODEL

Stage 1: Deposits of Barreiras Formation continental sediments

During the Pliocene, the climate must have been hot and humid for a long period of time, which resulted in the formation of a very thick alteration mantle. At the end of the Pliocene, as the climate became drier (typically semi-arid with infrequent but driving rains),

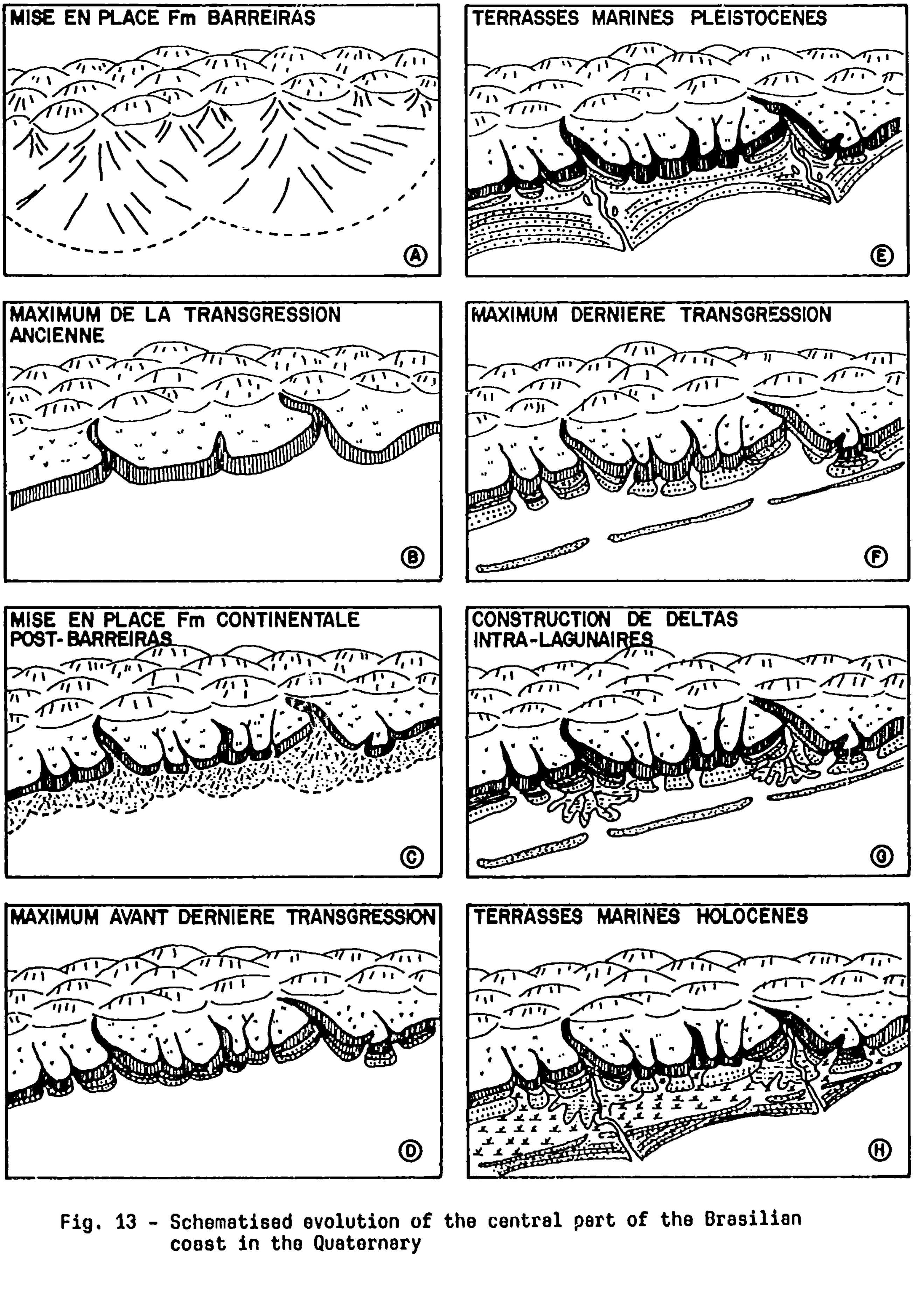


Fig. 13 - Schematised evolution of the central part of the Brasilian coast in the Quaternary

the vegetation cover tended to disappear, and the alteration mantle was exposed to erosion. This erosion was facilitated by a simultaneous upthrust of the continent (GHIGNONE, 1979). The products of the erosion were deposited at the foot of rises in the form of coalescent alluvial cones (Fig. 13 A). These deposits, which cover a considerable geographical area (from Rio de Janeiro to the mouth of the Amazon), are known as the Barreiras Formation. When they were put in place, the relative sea-level must have been quite a bit below the present level, since these deposits covered part of the continental shelf (BIGARELLA and ANDRADE, 1964).

Stage 2: The Old Transgression

The return to a humid climate, coinciding with a relative sea-level rise (Old Transgression), marked the end of the deposition of Barreiras Formation sediments. The limit reached by the maximum of this transgression is indicated by a line of dead cliffs cut through the Barreiras Formation sediments (Fig. 13 B).

Stage 3: Deposit of post-Barreiras continental sediments

A new climatic change occurred in conjunction with a lowering of the relative sea-level. The climate once again became semi-arid in type, which led to a substantial vegetation cover reduction and partial erosion of Barreiras Formation sediments. This resulted in a new continental formation being put in place at the foot of rises, and in particular of the cliffs cut through the Barreiras Formation sediments at the time of the Old Transgression. This took place under conditions quite similar to those prevailing when the Barreiras Formation was deposited (Fig. 13 C). These deposits, recorded only on the coasts of the States of Bahia and Sergipe, are known as the Post-Barreiras Continental Formation (VILAS-BOAS et al., 1980). In some regions, the surface of these deposits has been reshaped by wind, leading to the formation of large dune fields, whose vestiges have been found to the North of Salvador and on the coast of Sergipe State (MARTIN et al., 1980; BITTENCOURT et al., 1982). We know that the Post-Barreiras Continental Formation, and the dunes that sometimes cover it, are older than 120,000 years B.P., since they were partially eroded during the maximum of the second-last transgression.

Stage 4: Maximum of the second-last transgression

In about 120,000 years B.P., the relative sea-level was 8 $\pm$ 2 m above the present level. During this transgression, the continental deposits formed during the preceding stage were partially or totally eroded (Fig. 13 D). The lower reaches of waterways and valleys dug out of Barreiras Formation sediments were inundated and transformed into estuaries or lagoons.

Stage 5: Construction of Pleistocene marine terraces

A new regression started and sandy terraces covered with littoral belts were formed, either in the presence or in the absence of waterways (Fig. 13 E). Between 120,000 and 7,000 years B.P., the relative sea--level remained below the present level, in fact by about 110 m in the vicinity of 17,000 years B.P. Throughout this low sea-level period, a hydrographic network was established on the emerged part of the continental shelf, and in particular on the sandy terraces. Consequently, some rather wide and deep valleys were formed. Nevertheless, the original surface was often preserved in inter-fluvial zones, where littoral belt alignments are still more or less visible. These old belt alignments exhibit characteristics very different from those of more recent belts, which makes it possible to distinguish between them very easily on aerial photographs (MARTIN et al., 1981).

Stage 6: Maximum of the last transgression

In about 7,000 years B.P. the relative sea-level reached the present level, and then passed through a maximum of 4 to 5 m above the present level in about 5,100 years B.P. Hence the coast was submerged right up to that date. The most common manifestation of this submersion was the formation of barrier island/lagoon systems (Fig. 13 F). Depending on the region, this barrier island/lagoon stage was of varying significance or even absent. When a waterway opened up into one of these lagoons, an intra-lagoon delta was formed, with dimensions varying as a function of the lagoon and waterway sizes (Fig. 13 G).

Stage 7: Construction of Holocene marine terraces

After 5,100 years B.P., the relative sea-level gradually fell to its present position, although two rapid oscillations did occur, between 4,000 and 3,600 years B.P., and between 3,000 and 2,500 years B.P. During the emersion stages, littoral belts clung to the outer part of barrier islands, the lagoons tended to dry up, and the waterways opening into them flowed directly into the ocean (Fig. 13 H). It has been possible in some cases to distinguish among three generations of Holocene terraces, in relation to the three emersion stages occurring after 5,100 years B.P.

4.2. MODEL VALID FOR THE SOUTH OF SAO-PAULO STATE AND FOR THE STATES OF PARANA AND SANTA-CATARINA

This part of the Brasilian coast also contains vast Quaternary sedimentary plains, and the main points of the above outline remain valid. The continental deposits corresponding to the Barreiras Formation are not very extensively disseminated, but there are several local continental deposits (Pariquera-Açu, Alexandra, Canhanduva and other

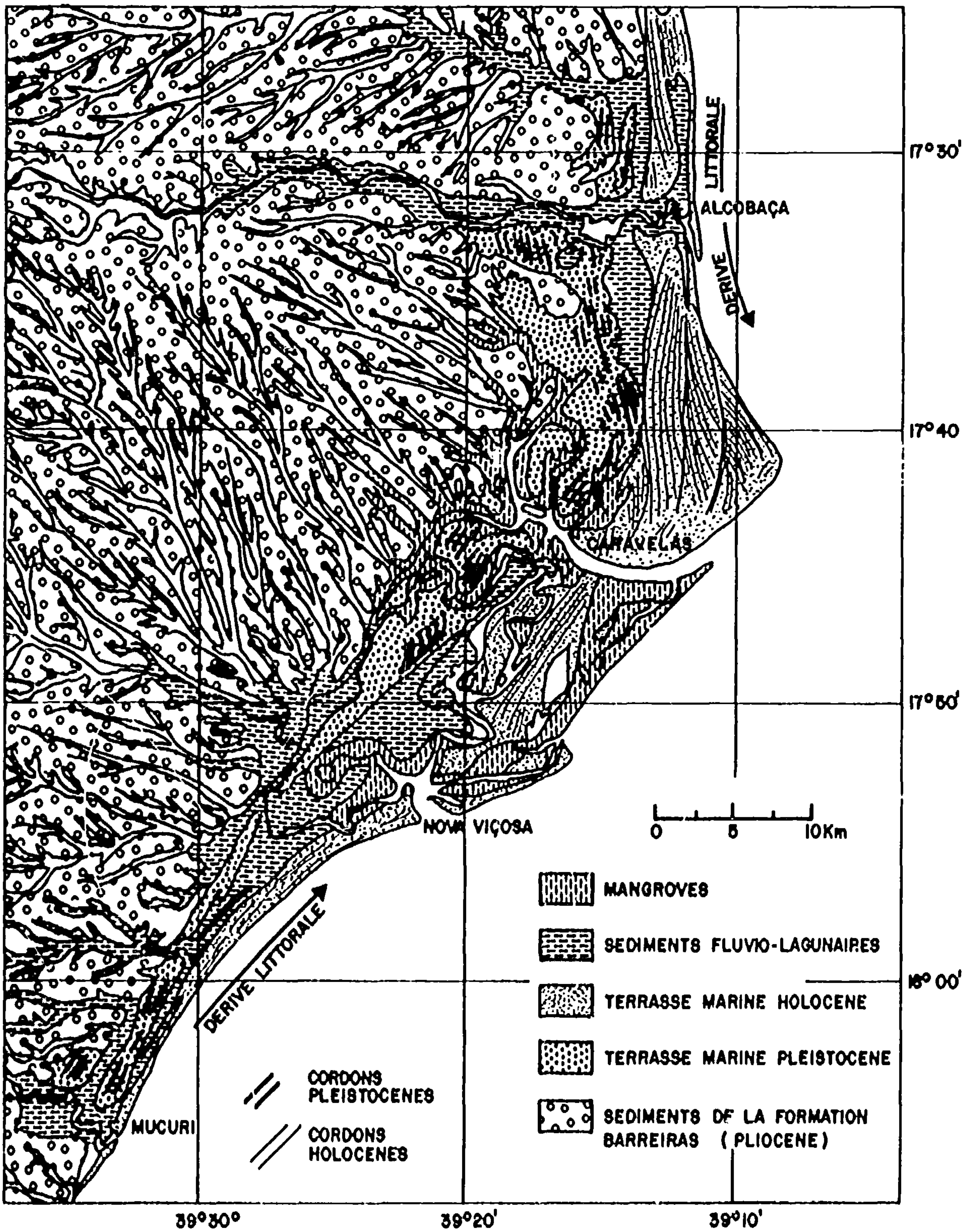


Fig. 14 - Geological map of the Caravelas coastal plain

Formations), that can be correlated with the Barreiras Formation. No records are known in this part of the Brasilian coast of the Old Transgression (Stage 2) or of the Post-Barreiras Continental Formation (Stage 3). The records of Stages 4 and 5, corresponding to the second--last transgression and the subsequent regression, are well developed. The same is true of Stages 6 and 7, corresponding to the maximum of the Holocene transgression and to the following regression. However, as the major part of drainage in this region is oriented towards the interior of the continent (Rio Parana), no substantial intra-lagoon deltas were formed, with the exception of that of Rio Tubarão, which is active to this day. Moreover, as the relative sea-level at the time of the 5,100 years B.P. maximum was lower than the level reached in the Macaé Recife sector, naturally the level then dropped less, so that markedly less sand was deposited from the nearby lower shelf, and hence Holocene terraces are considerably less extensive.

4.3. SPECIAL CASE OF SEDIMENTARY PLAINS LOCATED AT THE MOUTH OF A LARGE WATERWAY (RIOS PARAIBA DO SUL, DOCE, JEQUITINHONHA AND SAO--FRANCISCO)

In association with the mouths of the main waterways flowing into the Atlantic Ocean along the central part of the Brasilian coast, there are coastal plains that BACCOCOLI (1971), taking the definition of SCOTT and FISHER (1969) as a basis, considered to be "highly destructive deltas dominated by waves". BACCOCOLI assigned all these deltas to the Holocene age, and proposed an evolutionary scheme for the development of these deltaic plains since the maximum of the Flandrian transgression (last transgression), passing in some cases through an intermediate estuarine stage, finally to constitute typical deltas manifested by a continental advance into the sea.

However, we have seen that numerous "prograded" coastal plains, with no connection to a present or past waterway, exist all along the Brasilian coast. The most typical of these zones is that of Caravelas (Bahia), where, with the exception of fluvial deposits, one finds all the other types of sedimentary deposits existing in the "Quaternary Brasilian deltas" described by BACCOCOLI. To the point that this writer has suggested that this sedimentary accumulation could represent an old delta of the Rio Mucuri, an unexpressed waterway, located in the southern part of the coastal plain. This would then amount to a "delta dominated by waves" constructed without the presence of a waterway (Fig. 14).

The fact that "progradation" zones could be formed without the presence of a waterway immediately drew our attention. Obviously, in such a case it is necessary to look elsewhere for the source of the bulky sediments serving as raw material for the plain. Now we have seen that a relative sea-level drop of several metres can well, on a sandy coast, supply considerable quantities of sand. A study of the classical models of coastal sedimentation shows that wave energy, tide amplitude, solid fluvial discharge and others have been considered to be crucial factors for this type of sedimentation (FISHER, 1969;

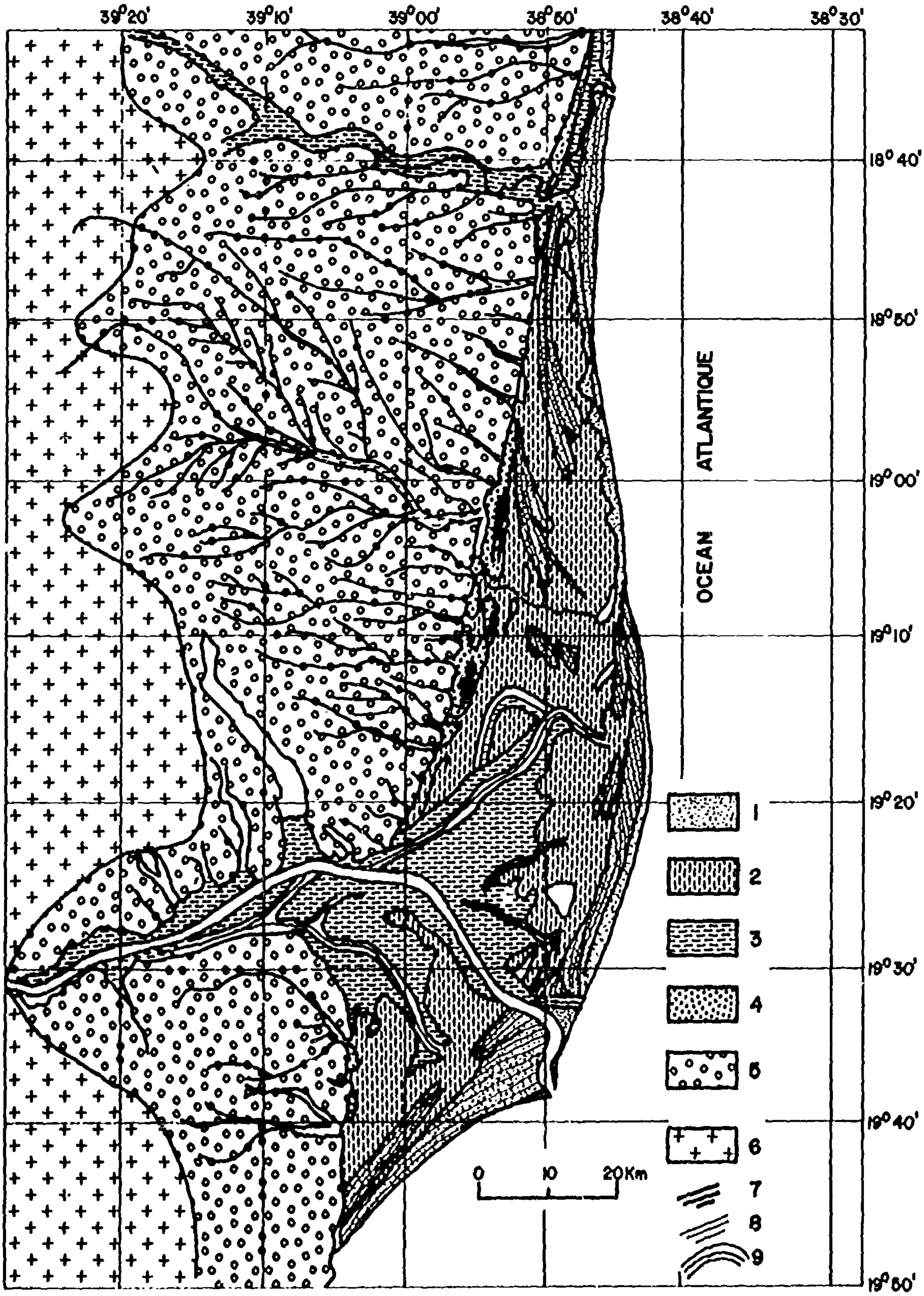


Fig. 15 - Geological map of the Rio Doce coastal plain. 1) Holocene marine terrace; 2) Lagoon sediments; 3) Fluvial sediments (intra-lagoon delta); 4) Pleistocene marine terrace; 5) Continental sediments (Barreiras Formation); 6) Precambrian formations; 7) Alignments of Pleistocene littoral belts; 8) Alignments of Holocene littoral belts; 9) Rio Doce palaeo-channels

CALLOWAY, 1975; HAYES, 1975), but strangely enough, no authors take possible relative sea-level oscillations into account. In their classical work on the subject, COLEMAN and WRIGHT (1975) analysed close to 400 parameters having an effect on the construction of sandy deltaic deposits, but they quite simply forgot to pay any attention to the most important: a possible lowering of the relative sea-level during the Holocene.
We have seen that at a river mouth, in the event that a dominant littoral drift exists, the sand brought in by the waterway can be deposited only on the side of the mouth lying below the littoral drift current. Only in the exceptional cases when there is no littoral drift (wave fronts parallel to the coast) can the sand brought in by the waterway, and reshaped by waves, be deposited on both sides of the mouth, and only in this case can a true "destructive delta dominated by waves" be formed. Now a detailed study has shown us that, in the sedimentary plains at the mouths of Rios Paraìba do Sul, Doce, Jequitinhonha and Sào-Francisco, the littoral drift has permanently, or at least for long periods of time, followed the same direction (DOMINGUEZ et al., 1983).

Coastal plains with an intra-lagoon delta

This category includes the plains at the mouths of Rios Doce (Espirito-Santo) and Paraìba do Sul (Rio de Janeiro). The Rio Doce coastal plain forms an assymetric crescent in the direction of the sea, with a maximum width of 38 km and a length of 130 km, and covering an area of 2,500 km² (Fig. 16). The Rio Paraìba do Sul coastal plain forms a lobe of 120 by 60 km, covering an area of 3,000 km² (Fig. 16). These two plains consist of Pleistocene and Holocene littoral marine sediments, and Holocene fluvial and lagoon sediments. For the coastal plain of Rio Doce, it has been possible to describe the main stages of the general model (Fig. 17 and 18). However, no record of stages 2 and 3 has been found. On the other hand, the lagoon formed during stage 6 having reached a very large size, the Rio Doce managed to build a vast intra-lagoon delta. It was also possible to find evidence for the existence of a second barrier island/lagoon system, related to the small transgressive stage that occurred between 3,800 and 3,600 years B.P. Similarly, there exists a second generation of Holocene littoral belts. It was not possible to find any evidence for the existence of a third barrier island/lagoon system, related to the third submersion stage, which occurred between 2,700 and 2,500 years B.P. This does not mean that the submersion stage did not take place, but only that it did not result in the formation of a barrier island/lagoon system. With minor differences due to local problems, the Rio Paraìba do Sul coastal plain formation runs along the same lines.

Coastal plains without an intra-lagoon delta

This category includes the plains of Rios Jequitinhonha and Sào-Francisco. For poorly determined reasons, the stage 6 (barrier island/lagoon system) lagoon did not extend in the E-W direction, and therefore remained fairly narrow; this explains why the waterways could not build, for lack of space, intra-lagoon deltas.

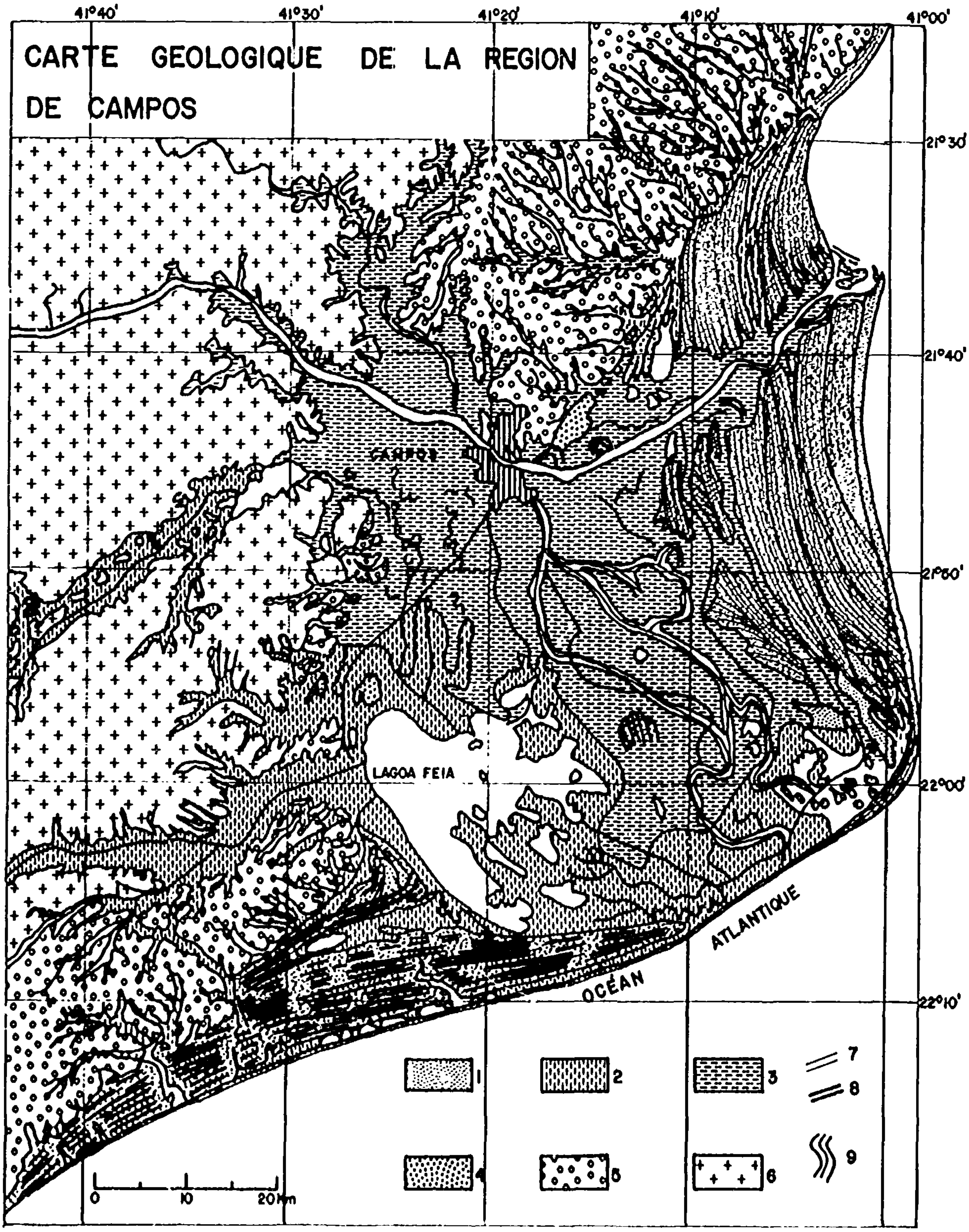


Fig. 16 - Geological map of the Rio Paraiba do Sul coastal plain. 1) Holocene marine terrace; 2) Lagoon sediments; 3) Fluvial sediments (intra-lagoon delta); 4) Pleistocene marine terrace; 5) Pliocene continental sediments (Barreiras Formation); 6) Precambrian formations; 7) Alignments of Holocene belts; 8) Alignments of Pleistocene belts; 9) Palaeo-channels of the Rio Paraiba do Sul

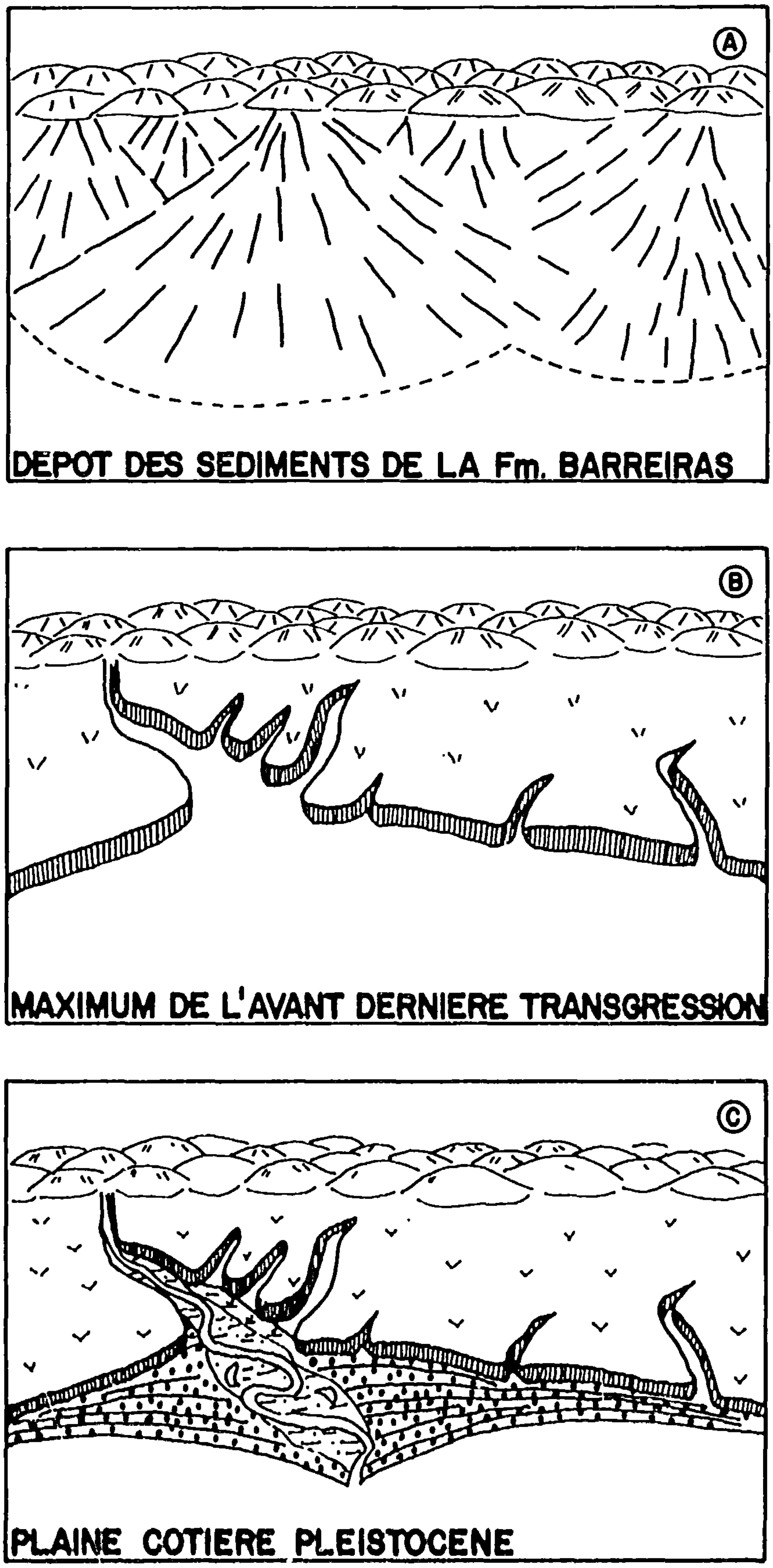


Fig. 17 - Schematised evolution of the Rio Doce coastal plain in the Pleistocene

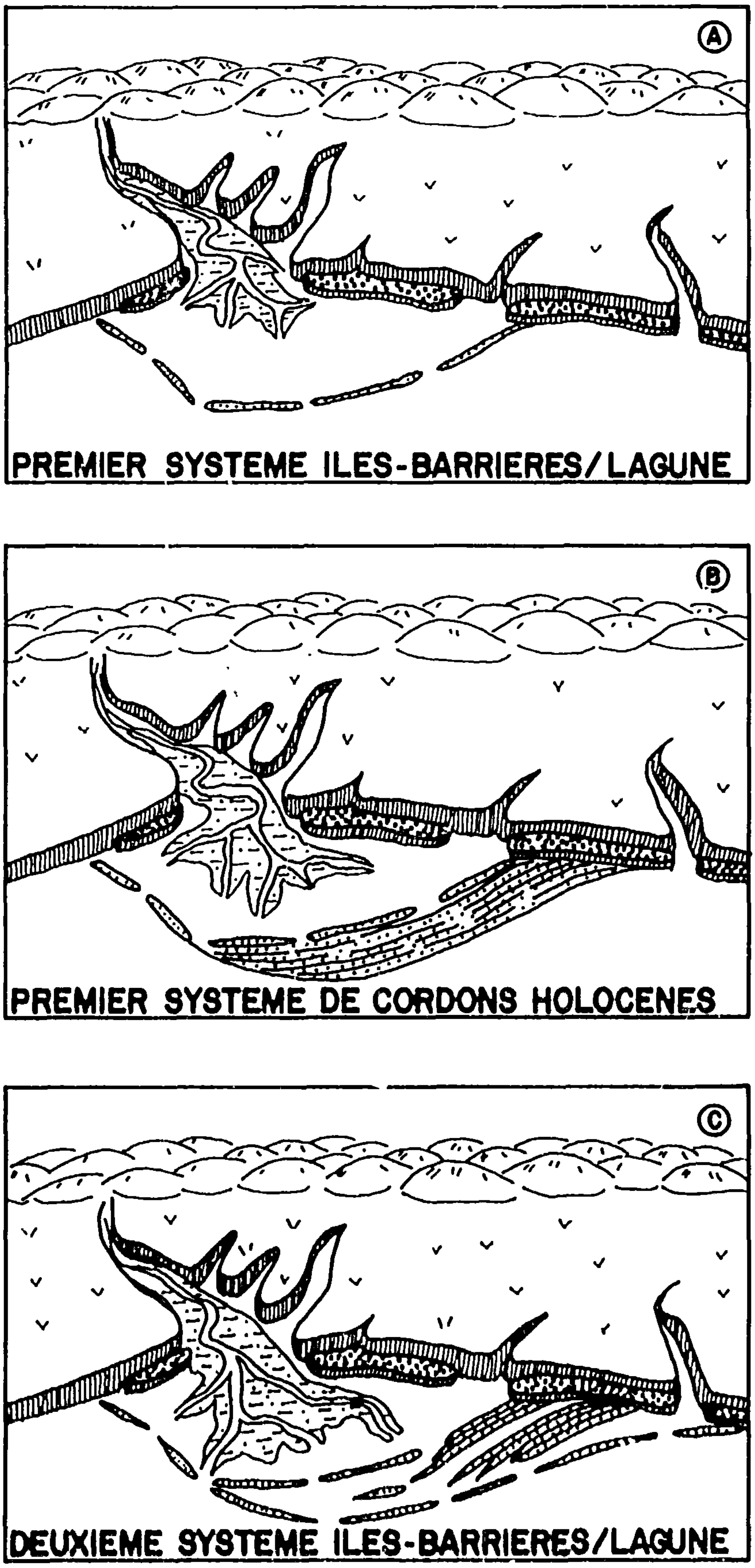


Fig. 18 - Schematised evolution of the Rio Doce coastal plain in the Holocene

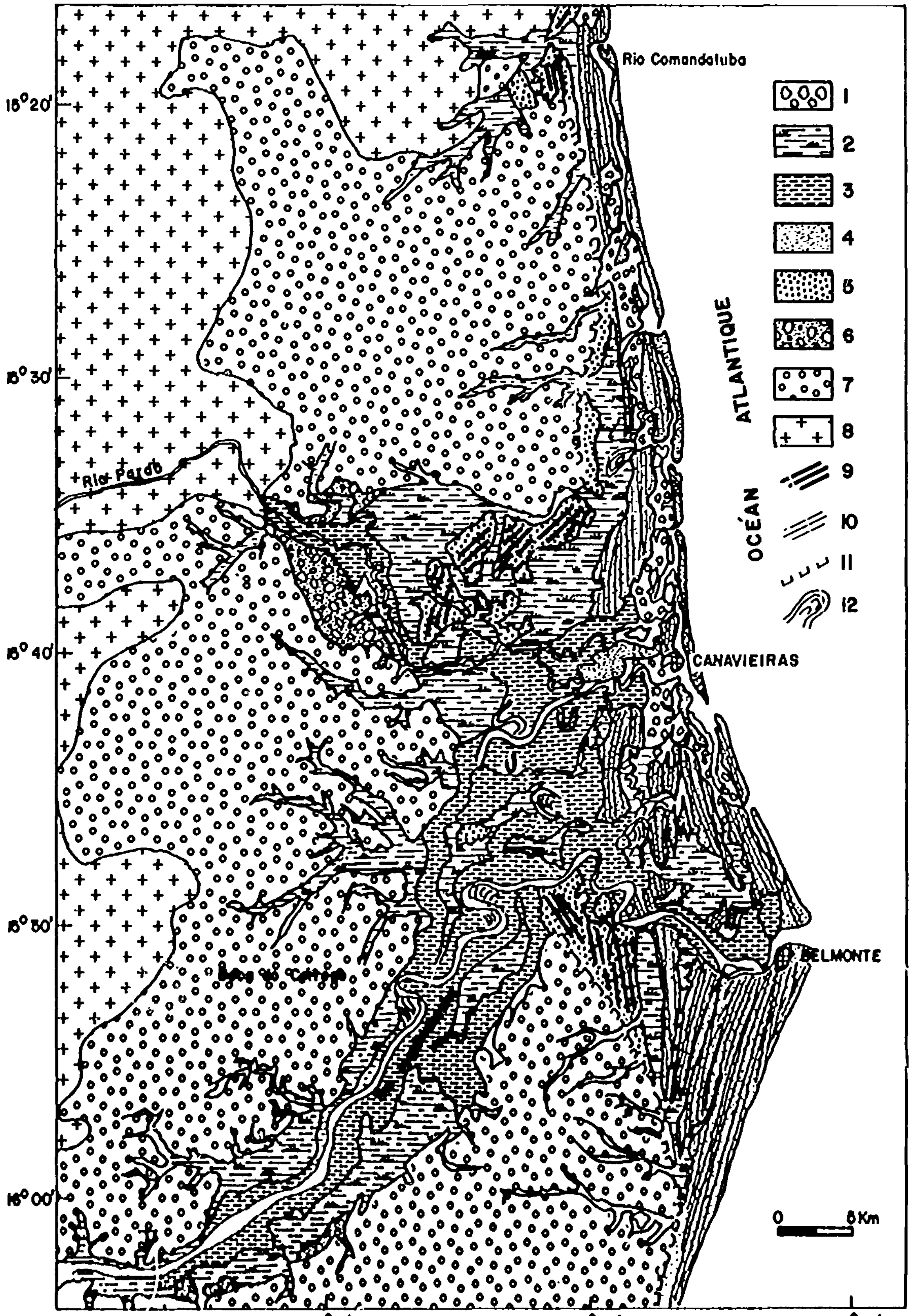


Fig. 19 - Geological map of the Rio Jequitinhonha coastal plain. 1) Mangrove; 2) Lagoon sediments; 3) Fluvial sediments; 4) Holocene marine terrace; 5) Pleistocene marine terrace; 6) Pout-Barreiras continental sediments; 7) Pliocene continental sediments (Barreiras Formation); 8) Precambrian formations; 9) Alignments of Pleistocene belts; 10) Alignments of Holocene belts; 11) Dead cliffs; 12) Palaeo-channels of the Rio Jequitinhonha

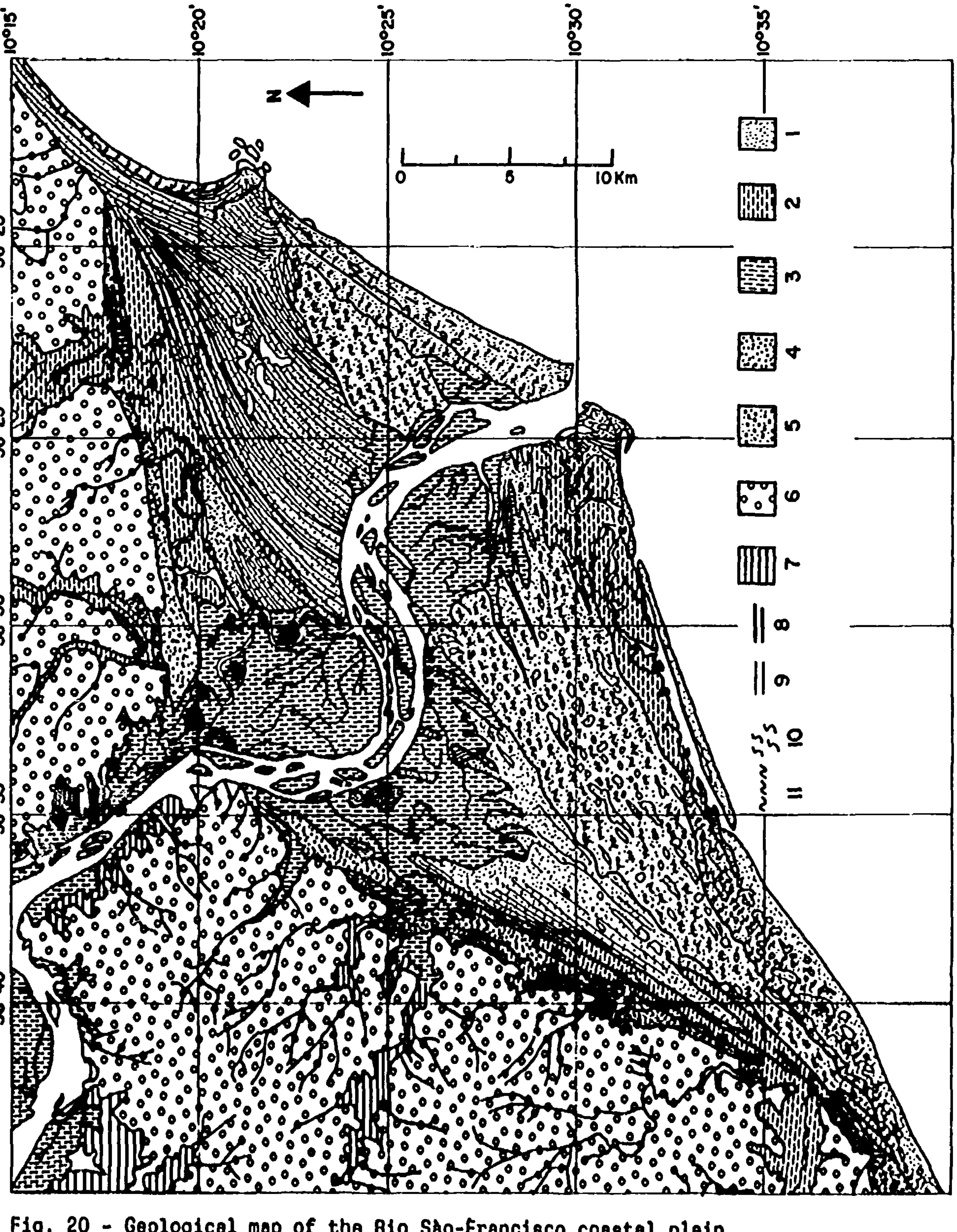


Fig. 20 - Geological map of the Rio Sào-Francisco coastal plain.
1) Holocene marine terrace; 2) Lagoon sediments; 3) Fluvial sediments; 4) Pleistocene marine terrace; 5) Post-Barreiras continental sediments; 6) Pliocene continental sediments (Barreiras Formation); 7) Mesozoic and Palaeozoic formations; 8) Alignments of Pleistocene belts; 9) Holocene alignments; 10) Fixed dunes; 11) Active dunes

The most thoroughly studied coastal plain is that of Rio Jequitinhonha (DOMINGUEZ, 1982; DOMINGUEZ et al., 1982). Installed in a zone hollowed out from Barreiras Formation sediments, it occupies a sector of almost 100 km of coast, covering an area of 800 km² (Fig. 19). As for the Rio Sào-Francisco coastal plain, it forms a triangle of 50 by 25 km, covering an area of 750 km² (Fig. 20). The Rio Sào-Francisco has its outlet in a hollowed zone of the Barreiras Formation, which is indisputably tectonic in origin (PONTE, 1969). In the coastal plain of Rio Jequitinhonha, all the stages described in the general model have been demonstrated with very great precision (Fig. 21, 22 and 23). Stage 7 has even been sub-divided into three sub-stages, corresponding to the three emersion periods occurring in the ranges 5,100-3,900, 3,600-2,900 and 2,500-0 years B.P. Moreover, two sudden displacements of the mouth have been correlated with the two short transgressive periods of 3,80063,600 and 2,700-2,500 years B.P. The coastal plain of Rio Sào-Francisco was formed according to the same model. However, it was not possible to find evidence for several generations of Holocene sandy terraces, in connection with the different emersion stages occurring after 5,100 years B.P. This may be due to the fact that, for tectonic reasons, the lower reaches of the Rio Sào-Francisco could not shift as easily as those of the Rio Jequitinhonha, at the time of the sudden relative sea-level rises occurring after 5,100 years B.P.

5. CONCLUSIONS

The existence of large Quaternary coastal plains is one of the characteristics of the central part of the Brasilian coast. These plains are either situated at the mouth of a large waterway, or have no connection with a present or previous waterway. A second characteristic of this coast is that it was, as opposed to other regions of the world, submerged until about 5,100 years B.P., and on the average above water since then. A third characteristic of this region is that it is a high--energy coast, where the littoral drift current plays an essential role in the transport of coarse sediments. The submersion period occurring before 5,100 years B.P. often resulted in the formation of barrier islands, which isolated lagoons of varying size from the open sea. When these lagoons were sufficiently large, the waterways opening into them would build up intra-lagoon deltas. The emersion period occurring after 5,100 years B.P. was reflected in a tendency for the lagoons to dry up. It was only from that time on that the waterways opening into the lagoons could flow directly into the sea. Coastal plains situated at the mouths of large waterways, such as the Rios Paraìba do Sul, Doce, Jequitinhonha and Sào-Francisco, were classified until now in the category of "highly destructive deltas dominated by waves". It is clear that application of the term delta to these plains is an exaggeration, to say the least. In fact, we have seen that coastal plains with very similar characteristics bore no relationship at all to present or previous waterways. Moreover, we have managed to demonstrate that those situated at the mouth of a large waterway were built up for a large part from coarse sediments supplied by lowering of the relative sea-level. This is corroborated by the fact that, throughout the entire lagoon stage, sediments transported by the waterway were trapped in the lagoon, and hence could not have contributed to the edification

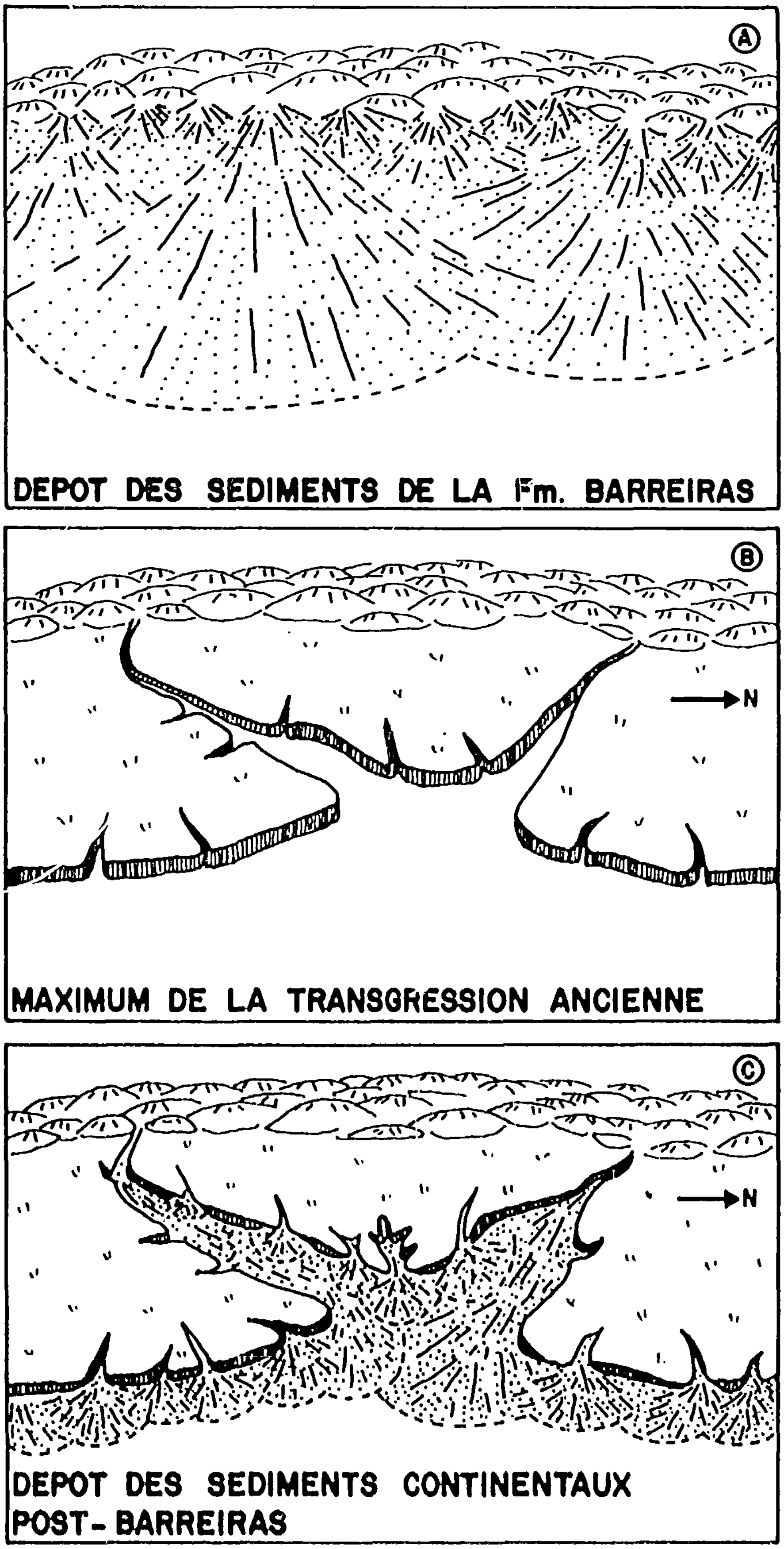


Fig. 21 - Schematised evolution of the Rio Jequitinhonha coastal plain in the Pleistocene

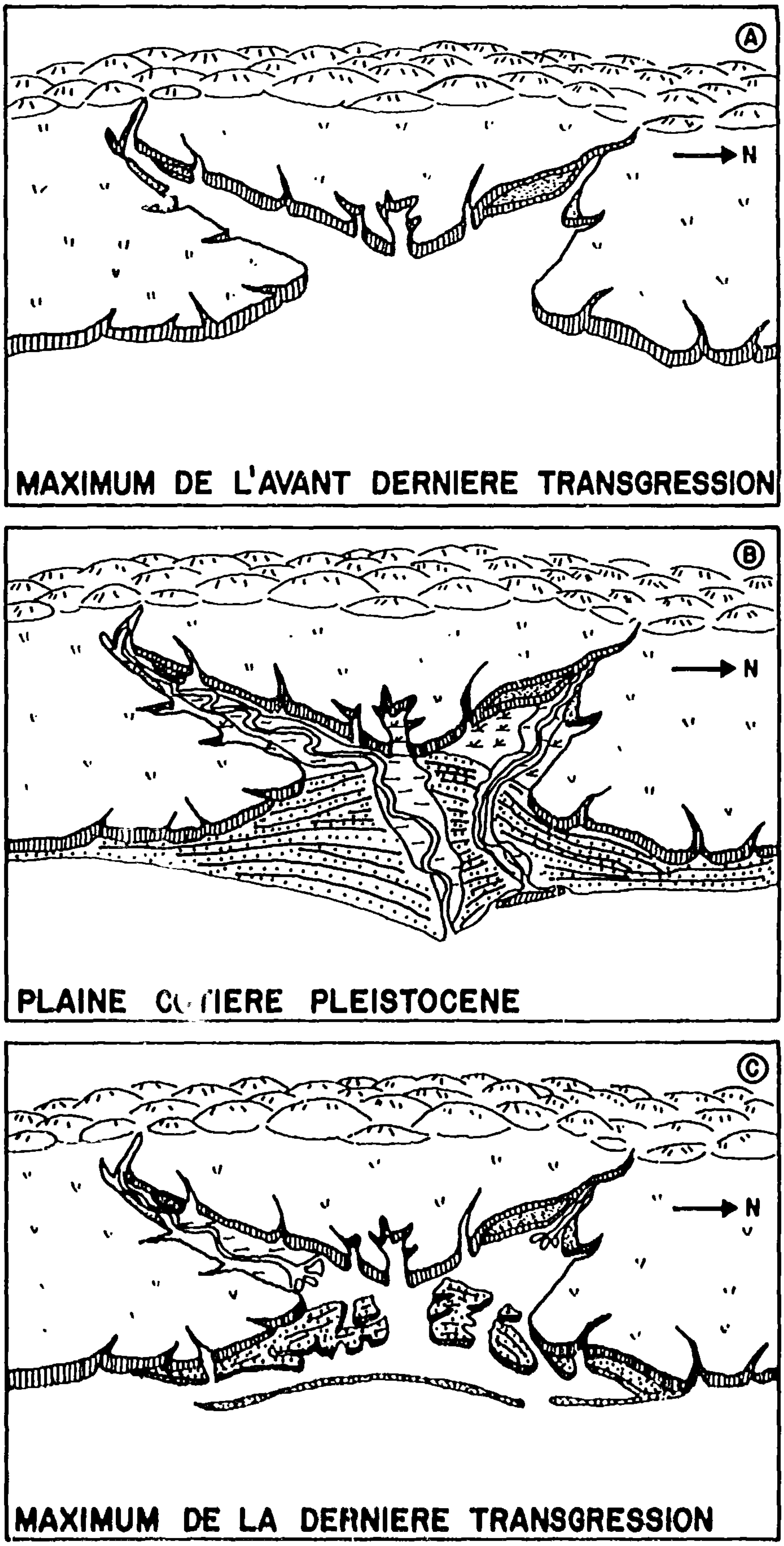


Fig. 22 - Schematised evolution of the Rio Jequitinhonha coastal plain:
A) before 120,000 years B.P. B) after 120,000 years B.P.
C) before 5,100 years B.P.

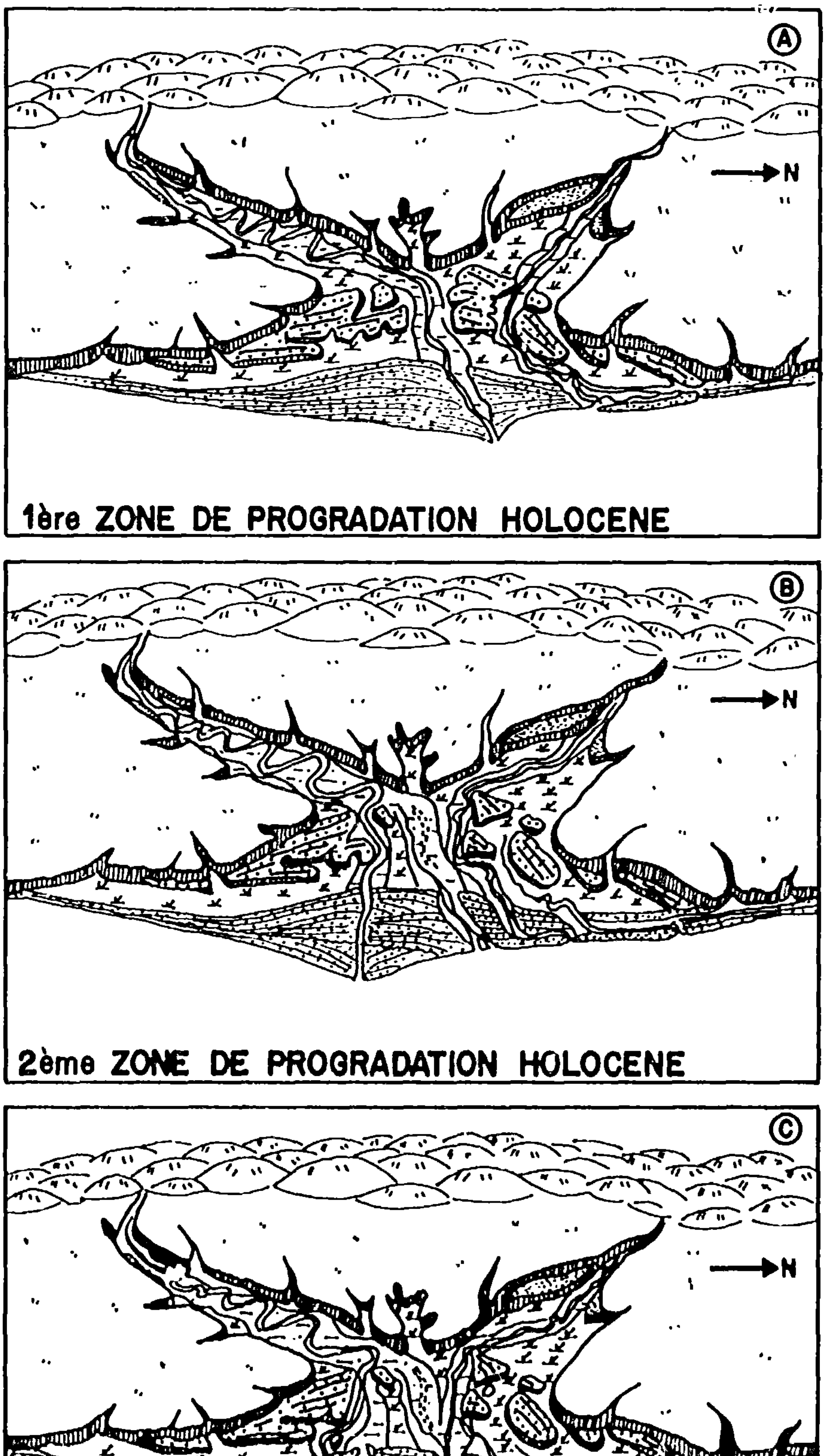


Fig. 23 - Schematised evolution of the Rio Jequitinhonha coastal plain after 5,100 years B.P.

of the sandy terraces that were formed on the outside of the barrier islands. It was only once the waterway flowed directly into the sea that it started to play an important role in the construction of the coastal plain situated at the river mouth. For in this case, the flow of water blocks littoral transport and causes an accumulation of sand in the part of the plain lying in the drift current. On the other hand, sand transported by the river is deposited only on the side of the plain located below the littoral drift current.

BIBLIOGRAPHY

Bacoccoli, G. 1971. Os deltas marinhos holocenicos brasileiros. Uma tentativa de classificacao. Boletim Tecnico Petrobras, 14, p. 5-38, Rio de Janeiro.

Bigarella, J.J.; Andrade, G.O. 1964. Consideracoes sobre a estratigrafia dos sedimentos cenozoicos em Pernambuco (Grupo Barreiras). Universidade Parana, Geologia, vol. 3, 22 pp., Curitiba.

Bittencourt, A.C.S.P.; Dominguez, J.M.L.; Martin, L.; Ferreira, Y. de A. 1982a. Evolucao do "delta" do Rio Sao Francisco (SE/AL) durante o Quaternario. Influencia das variacoes do nivel do mar. Atas do IV Simposio do Quaternario no Brasil, p. 49-68, Rio de Janeiro.

Bittencourt, A.C.S.P.; Martin, L.; Dominguez, J.M.L.; Ferreira, Y. de A. 1982b. O Quaternario Costeiro do Estado de Sergipe. XXXII Congresso Brasileiro de Geologia, Boletim 2 (Breves Comunicacoes), p. 92, Salvador.

Bittencourt, A.C.S.P.; Martin, L.; Vilas-Boas, G.S.; Flexor, J-M. 1979a. Quaternary marine formations of the coast of the State of Bahia, Brazil. Proceedings 1978 International Symposium on coastal evolution in the Quaternary, p. 232-253, Sao-Paulo.

Bittencourt, A.C.S.P.; Vilas-Boas, G.S.; Flexor, J-M.; Flexor, J-M. 1979b. Geologia dos depositos quaternarios do litoral do Estado da Bahia. Textos Basicos, 1, p. 1-21, Salvador.

Branner, J.C. 1904. The stone reefs of Brazil, their geological and geographical relations. Bulletin Museum Comp. Zool., Harvard College, vol. 44, Geol. Ser. 7.

Bruun P. 1962. Sea level rise as a cause of shore erosion. American Association of Civil Engineers Proceedings, Journal of Waterways and Harbors Division, 88, p. 117-130.

Carvalho, K.W.B.; Garrido, J.L.P. 1966. Reconhecimento geologico da Bacia Sedimentar Bahia Sul - Espirito Santo. Petrobras, DEXPRO, Relatorio 2496, 77 pp., Salvador.

Coleman, J.M.; Wright, L.D. 1975. Modern river deltas - Variability of process and sand bodies. In: Broussard, M.L. (ed.), Delta models for exploration, Houston Geol. Soc., p. 99-150.

Davies, J.L. 1972. Geographical variations in coastal development. In: Clayton, K.M. (ed.), Geomorphology Text 4, New York, Longman & Co. Ltd., 204 pp.

Dominguez, J.M.L. 1983. Evolucao quaternaria da planicie costeira associada a foz do Rio Jequitinhonha (BA). Influencia das variacoes do nivel do mar e da deriva litoranea de sedimentos. Dissertacao de Mestrado, Universidade Federal da Bahia, 73 pp., Salvador.

Dominguez, J.M.L.; Bittencourt, A.C.S.P.; Martin,L. 1981. Esquema evolutivo da sedimentacao quaternaria nas feicoes deltaicas dos rios Sao Francisco (SE/AL), Jequitinhonha (BA), Doce (ES) e Paraiba do Sul (RJ). Revista Brasileira de Geociencias, vol. 11, p. 227-237, Sao Paulo.

Dominguez, J.M.L.; Bittencourt, A.C.S.P.; Martin, L. 1983. O papel da deriva litoranea de sedimentos arenosos na construcao das planicies costeiras associadas a desembocaduras dos rios Sao Francisco (SE/AL), Jequitinhonha (BA), Doce (ES) e Paraiba do Sul (RJ). Revista Brasileira de Geociencias, vol. 13, p. 93-105, Sao Paulo.

Dominguez, J.M.L.; Martin, L.; Bittencourt, A.C.S.P. 1981b. Evolucao paleogeografica do delta do Rio Jequitinhonha durante o Quaternario. Influencia das variacoes do nivel do mar. IV Simposio do Quaternario no Brasil, Atas, p. 69-83, Rio de Janeiro.

Dominguez, J.M.L.; Martin, L.; Bittencourt, A.C.S.P.; Ferreira, Y. de A.; Flexor, J-M. 1982. Sobre a validade da utilizacao do termo delta para designar as planicies costeiras associadas as desembocaduras dos grandes rios brasileiros. XXXII Congresso Brasileiro de Geologia, 2 (Breves Comunicacoes), 92, Salvador.

Dubois, R.N. 1976. Nearshore evidence in support of the Bruun rule on shore erosion. Journal of Geolcgy, vol. 84, p. 485-491.

Dubois, R.N. 1977. Predicting beach-erosion as a function of rising water level. Journal of Geology, vol. 85, p. 470-476.

Fairbridge, R.W. 1961. Eustatic changes in sea level. Physics and Chemistry of the Earth, vol. 4, p. 99-185.

Fisher, W.L. 1969. Facies characterization of Gulf Coast Basin delta system with Holocene analogues. Transactions Gulf Coast Assoc. Geol. Soc., 19, p. 239-260.

Flexor, J-M.; Martin, L. 1979. Sur l'utilisation des grès coquilliers de la région de Salvador (Brésil) dans la reconstruction des lignes de rivage holocènes. Proceedings 1978 International Symposium on Coastal Evolution in the Quaternary, p. 343-355, Sao Paulo.

Freitas, R.O. 1951. Ensaio sobre a tectonica moderna do Brasil. Faculdade Filosofia, Ciencias e Letras, USP, Boletim 130, Geologia 6, 120 pp., Sao Paulo.

Galloway, W.E. 1975. Process framework for describing the morphologic and stratigraphic evolution of deltaic depositional systems. In: Broussard, M.L. (ed.), Delta models for exploration, Houston Geol. Soc., p. 87-89.

Ghignone, J.L. 1979. Geologia dos sedimentos anerozoicos do Estado da Bahia. In: Inda,H. (ed.), Geologia e recursos minerais do Estado da Bahia, SME, CPM, 1, p. 24-117, Salvador.

Hartt, C.F. 1870. Geology and physical geography of Brazil. Fords, Osgood & Co., Boston, 620 pp.

Hayes, M.O. 1979. Barrier island morphology as a function of tidal and wave regime. In: Leatherman, S.P. (ed.), Barrier island from Gulf of St Lawrence to the Gulf of Mexico, New York Academic Press, p. 1-27.

King, C.A.M. 1972. Beaches and coasts. Edward Arnold, London, 570 pp.

Komar, P.D. 1973. Computer models of delta growth due to sediment input from rivers and longshore transport. Geological Society America Bulletin, 84, p. 2217-2226.

Komar, P.D. 1976. Beach processes and sedimentation. Prentice Hall Inc., New Jersey, 429 pp.

Martin, L.; Bittencourt, A.C.S.P.; Flexor, J-M.; Vilas-Boas, G.S. 1984a. Evidencia de um tectonismo quaternario nas costas do Estado da Bahia. XXXIII Congresso Brasileiro de Geologia, Anais 1, p. 19-35, Rio de Janeiro.

Martin, L.; Bittencourt, A.C.S.P.; Vilas-Boas, G.S. 1981. Différentiation sur photographies aériennes des terrasses sableuses pléistocènes et holocènes du littoral de l'état de Bahia (Brésil). Photo-Interprétation 3, fasc. 4/5, Paris.

Martin, L.; Bittencourt, A.C.S.P.; Vilas-Boas, G.S. 1982. Primeira occorencia de corais pleistocenicos da costa Brasileira. Datacao do maximo da penultima transgressao. Ciencias da Terra 1, p. 16-17, Salvador.

Martin, L.; Bittencourt, A.C.S.P.; Vilas-Boas, G.S.; Flexor, J-M. 1978. Introducao ao estudo do Quaternario do litoral da Bahia, trecho Salvador-Ilheus. Revista Brasileira de Geociencias, 9 (4), p. 309--320, Sao Paulo.

Martin, L.; Bittencourt, A.C.S.P.; Vilas-Boas, G.S.; Flexor, J-M. 1980c. Mapa Geologico do Quaternario Costeiro do Estado da Bahia. Governo do Estado da Bahia, SME, 2 folhas escala 1/250,000, texto em Portugues e Frances, 57 pp., Salvador.

Martin, L.; Flexor, J-M.; Blitzkow, D.; Suguio, K. 1985. Geoid change indications along the Brazilian coast during the last 7,000 years. Proceedings Vth International Coral Reef Congress, Tahiti, vol. 3, p. 85-90.

Martin, L.; Flexor, J-M.; Vilas-Boas, G.S.; Bittencourt, A.C.S.P.; Guimaraes, M.M.M. 1979b. Courbe de variation du niveau relatif de la mer au cours des 7000 dernières années sur un secteur homogène du littoral brésilien (nord de Salvador). Proceedings 1978 International Symposium on Coastal Evolution in the Quaternary, p. 264--274, Sao Paulo.

Martin, L.; Suguio, K. 1975. The State of Sao Paulo coastal marine Quaternary geology. The ancient strandlines. International Symposium on the Quaternary, Proceedings, Acad. Brasileira de Ciencias, vol. 47, p. 249-263, Rio de Janeiro.

Martin, L.; Suguio, K. 1976a. Etude préliminaire du Quaternaire marin. Comparaison du lit de Sao Paulo et Salvador, Brésil. Cahier ORSTOM, Série Géologie, vol. VIII, p. 33-47, Paris.

Martin, L.; Suguio, K. 1976b. Les variations du niveau de la mer au Quaternaire Récent dans le sud de l'Etat de Sao Paulo. Utilisation des "sambaquis" dans la détermination d'anciennes lignes de rivage holocènes. Actes du XLII Congrès International des Américanistes, vol. IX, p. 73-83, Paris.

Martin, L.; Suguio, K. 1978. Excursion route along the coastline between the town of Cananeia (State of Sao Paulo) and Guaratiba outlet (State of Rio de Janeiro). 1978 International Symposium on Coastal Evolution in the Quaternary, Special Publication 2, 97 pp., Sao Paulo.

Martin, L.; Suguio, K.; Flexor, J-M. 1979a. Le Quaternaire marin du littoral brésilien entre Cananeia (SP) et Barra de Guaratiba (RJ). Proceedings 1978 International Symposium on Coastal Evolution in the Quaternary, p. 296-331, Sao Paulo.

Martin, L.; Suguio, K.; Flexor, J-M. 1984. Informacoes fornecidoas pelos sambaquis na reconstrucao de paleolinhas de praia quaternaria. Exemplos da costa Brasileira. Revista Pre-Historia, vol. VI, p. 128-147, Sao Paulo.

Martin, L.; Suguio, K.; Flexor, J-M.; Bittencourt, A.C.S.P.; Vilas--Boas, G.S. 1980. Le Quaternaire marin brésilien (littoral pauliste, sud-fluminense et bahianais). Cahier ORSTOM, Série Géologie IX (1), p. 96-124, Paris.

Martin, L., Suguio, K.; Flexor, J-M.; Dominguez, J.M.L.; Azevedo, A.E.G. 1984b. Evolucao da planicie costeira do Rio Paraiba do Sul (RJ) durante o Quaternario. Influencia das variacoes do nivel do mar. XXXIII Congresso Brasileiro de Geologia, Anais 1, p. 84-97, Rio de Janeiro.

Martin, L.; Vilas-Boas, G.S.; Bittencourt, A.C.S.P.; Flexor, J-M. 1980b. Origine des sables et âges des dunes situées au nord de Salvador (Brésil). Importance paléoclimatique. Cahier ORSTOM, Série Géologie XI (1), p. 125-132.

Morner, N.A. 1980. Eustasy and sea-level changes. Journal of Geology, vol. 84, p. 123-152.

Morner, N.A. 1984. Interaction and complexity of sea-level changes, vertical crustal movements and geoidal deformations. Symposium on Neotectonics and Sea-level Variations in the Gulf of California area, Hermosillo, Anstracts Volume, p. 129.

Schwartz, M.L. 1965. Laboratory study of sea-level rise as a cause of shore erosion. Journal of Geology, vol. 73, p. 528-534.

Schwartz, M.L. 1967. The Bruun theory of sea-level rise as a cause of shore erosion. Journal of Geology, vol. 75, p. 76-92.

Scott, A.J.; Fisher, W.L. 1969. Delta systems and deltaic deposition. Discussion notes, Dept. Geol. Sci., Bureau Economic Geology, The University of Texas at Austin.

Suguio, K. 1977. Annotated bibliography (1960-1977) on quaternary shorelines and sea-level changes in Brazil. Contribuicao do Instituto de Geociencias da Universidade de Sao Paulo ao Projeta 61 do PICG, 35 pp.

Suguio, K.; Martin, L. 1976. Brazilian coastline Quaternary formations. The States of Sao Paulo and Bahia littoral zone evolution schemes. International Symposium on Continental Margins of Atlantic Type. Anais, Acad. Brasileira de Ciencias, vol. 48, p. 325-334, Rio de Janeiro.

Suguio, K.; Martin, L. 1976. Presenca de tubos fosseis de Callianassa nas formacoes quaternarias do litoral paulista e sua utilizacao na reconstrucao paleoambiental. Boletim IG, Instituto de Geociencias, USP, 7, p. 17-26, Sao Paulo.

Suguio, K.; Martin, L. 1978a. Quaternary marine formations of the States of Sao Paulo and southern Rio de Janeiro. 1978 International Symposium on Coastal Evolution in the Quaternary, Special Publication 1, 55 pp., Sao Paulo.

Suguio, K.; Martin, L. 1978b. Mecanismos de genese das planicies sedimentares quaternarias do litoral do Estado de Sao Paulo. XXIX Congresso Brasileiro de Geologia, Anais 1, p. 295-305, Ouro Preto.

Suguio, K.; Martin, L. 1982a. Progress in research on Quaternary sea-level changes and coastal evolution in Brazil. Symposium on Holocene Sea-level Fluctuations, Magnitude ans Causes, Dept. Geol., Univ. South Carolina, Columbia, p. 166-181.

Suguio, K.; Martin, L. 1982. Significance of Quaternary sea-level fluctuations for delta construction along the Brazilian coast. Geo-Marine Letters, 1 (3/4), p. 181-185.

Suguio, K.; Martin, L.; Dominguez, J.M.L. 1982. Evolucao do "delta" do Rio Doce (ES) durante o Quaternario. Influencia das variacoes do nivel do mar. IV Simposio do Quaternario no Brasil. Atas, p. 93-116, Rio de Janeiro.

Suguio, K.; Martin, L.; Dominguez, J.M.L.; Bittencourt, A.C.S.P. 1984a. Quaternary emergent and submergent coasts. Comparison of the Holocene sedimentation in Brazil and southeastern United States. Anais Acad. Brasileira de Ciencias, 56 (2), p. 163-167, Rio de Janeiro.

Suguio, K.; Martin, L.; Flexor, J-M. 1980. Sea-level fluctuations during the past 6,000 years along the coast of the State of Sao Paulo. In: Morner, N.A. (ed.), Earth Rheology, Isostasy and Eustasy, p. 471-486, John Wiley & Sons.

Suguio, K.; Martin, L.; Flexor, J-M.; Tessler, M.G.; Eichler, B.B. 1984. Depositional mechanisms active during the late Quaternary at the Paraiba do Sul river mouth area, State of Rio de Janeiro, Brazil. International Symposium on Late Quaternary Sea-level Changes and Coastal Evolution, Mar del Plata, Argentina.

Swift, D.J.P. 1976. Coastal sedimentation. In: Stanley, D.J.; Swift, D.J.P. (eds.), Marine sediments transport and environmental management, p. 255-310, Wiley Interscience Publ.

Van Andel, T.H.; Laborel, J. 1964. Recent high sea-level stand near Recife, Brazil. Science, vol. 145, p. 580-581.

Vilas-Boas, G.S.; Bittencourt, A.C.S.P.; Martin, L. 1981. Leques aluviais pleistocenicas da regiao costeira do Estado da Bahia. XXXIII Reuniao Anual da Sociedade Brasileira para o Progresso da Ciencia, Salvador.

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