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QUATERNARY MARINE FORMATIONS OF THE COAST OF THE
STATE OF BAHIA (BRAZIL)

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ABSTRACT

On the coast of the State of Bahia there is evidence of deposits left by the last three transgressions which reached levels above today's mean sea level. In the northern part of the coast the Precambrian shield is covered by sediments of the Barreiras Formation. Deposits of the last two transgressive events mentioned above are found there, and they are generally poorly developed. Along Todos os Santos Bay, deposits of the penultimate transgression (120,000 years B.P.) situated above today's sea level are not found, and only the deposits of the last transgression are known. These deposits however are not continuous, which may imply the existence of tectonic movements within the bay. Between Todos os Santos Bay and Itacaré on the south, the sandy terraces formed during the aforementioned transgressions are well developed. Between Itacaré and the south of Ilhéus the Precambrian rocks either border the sea or are separated from it by Quaternary deposits of small extent.

The paleobay of Itaípe, situated in the small sedimentary basin of Almada, is an exception. The southern part of the coast of the State of Bahia is characterized by the reappearance of the sediments of the Barreiras Formation bordering the sea. However, in some regions like Canavieiras, Belmonte, Alcobaça, Caravelas, Nova Viçosa e Mucuri, the deposits of sand left by the two last transgressions are very important. In the region of Caravelas crop out sediments of the antepenultimate transgression.

INTRODUCTION

The part of the coast studied here is included between $11^{\circ}20'$ and $18^{\circ}15'$ parallels of south latitude and, in a direct line, it represents about 700 km of the Brazilian coast (Fig.1). This region is situated on the eastern Brazil uplift, which is an elongated anteklise of the crystalline basement situated between the Atlantic Ocean and the plateaus of the inland sedimentary cover. This cover is made up of metamorphic and sedimentary rocks of various ages, affected by Post-Paleozoic tectonic warping and tilting of large radius of curvature with local faulting. The most characteristic feature of this region is the sinking Recôncavo basin (Fig. 1) encased in the uplift along a NNE-SSW direction. This basin began to be formed in the Upper Jurassic as an appendix of the rift through Africa and South America that gave rise to the South Atlantic Ocean. In the littoral zone this graben is limited on the east by the Salvador fault, the total displacement of which is more than 4,000 m and, on the west, by the Maragogipe fault, with displacement of 300 m (Fig. 1). Starting in the Upper Jurassic, the basin began to be filled with sand and clay sediments which show sudden facies variations. These sediments, predominantly of deltaic origin, reach a thickness of 4,000 m in places.

During the whole Cretaceous, the tectonic activity, characterized by a series of elongated blocks aligned in a NNE-SSW direction, remained very intense. The end of the Cretaceous was marked by a progressive decrease in the tectonic activity. Gradually the basin stopped being separated from the remnant of the uplift, becoming a part of the large-scale flexures which characterize it. However, at the end of the

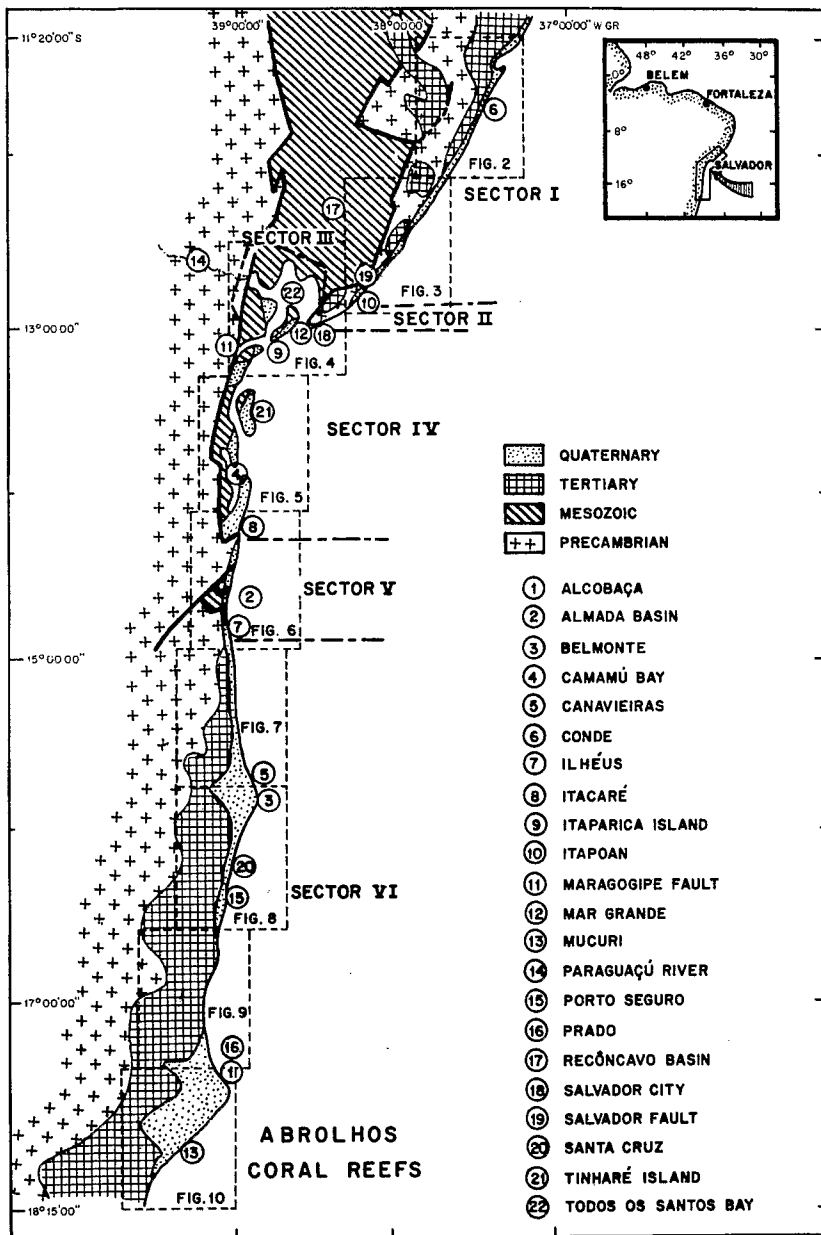


Figure 1 - Geological map of the coast of the State of Bahia showing the boundaries between the sectors and the location of the other figures of this paper.

Tertiary, reactivation of faults affected the Cretaceous formations. Afterwards, the basin became more and more incorporated into the remnant of the uplift, meanwhile, the great fracture lines that characterize the basin tended to close and the vertical movements tended to stop.

The Todos os Santos Bay and the low zones which represent its southern extension are entirely located on the Cretaceous sedimentary formations. The fact that the bay is situated on the sedimentary rocks emplaced in crystalline rocks favours a hypothesis of an origin by differential erosion. However, a study of the hydrographic net of the bay shows that the drainage in the direction of the bay is incipient. In effect, the division line of the waters is situated 1 or 2 km from its margins. This situation is an indication of an insignificant differential erosion. The Paraguaçu river, whose discharge is situated on the western side of the bay, has its course almost totally over Precambrian rocks; hence it could not be responsible for the excavation of the bay by differential erosion. Thus it is necessary to admit that the formation of the bay is relatively recent, since the hydrographic net has not as yet been affected by its presence (TRICART & CARDOSO DA SILVA, 1968). It is possible that the Todos os Santos Bay corresponds to a sunken block or, better, to a series of sinking blocks which might have had different behaviours among themselves.

The Tertiary was marked by a very important detritic sedimentation of braided river deposits in a semi-arid climate. This sedimentation covered the Precambrian formations as well as those of the Cretaceous and extends from the State of Rio de Janeiro to Amazonia (BIGARELLA & AB'SABER, 1964; MABESOONE *et al.*, 1972). These deposits, known as the Barreiras Formation, probably extended over part of the continental shelf (BIGARELLA & ANDRADE, 1964), as is the case in the Prado region (Fig. 1).

The Quaternary was marked world-wide by great transgressions and regressions. Along this part of the Brazilian coast there is evidence of three distinct transgressive episodes. The principal objective of the present work is to characterize and map these formations in this area.

PHYSIOGRAPHIC AND GEOMORPHOLOGIC ASPECTS OF THE
COAST OF THE STATE OF BAHIA

From the point of view of its physiographic and geomorphologic characteristics the coast of the State of Bahia was divided in 6 parts, designated as sectors I, II, III, IV, V and VI (Fig. 1).

SECTOR I - Extends from the region of Conde to the locality of Itapoan. This part of the coast is characterized by the presence of the Barreiras Formation deposits near the coast. The littoral plain situated at the base of the Barreiras coastal cliffs is discontinuous and in many cases is reduced to a strip of some hundreds of meters in width. The Quaternary deposits may be more extensive in the excavated zones of the Barreiras Formation. This sector is also characterized by the presence of a practically continuous line of beach rocks.

SECTOR II - This sector, of small dimensions, lies between the locality called Itapoan and the entrance to Todos os Santos Bay. It is characterized by the presence of the Precambrian basement rocks in contact with the sea. The marine and lagoon Quaternary deposits are poorly developed here. However in this region there can be found numerous local evidences of ancient sea levels above the present mean level.

SECTOR III - Includes the entire coast of the Todos os Santos Bay. Situated in the Reconcavo Basin, the bay presents a morphology typical of a submerged coast with indented aspect, notably the presence of numerous islands concentrated in the northern part. Quaternary deposits are absent or poorly developed in this sector.

SECTOR IV - This part of the coast extends from the Todos os Santos Bay entrance to Itacaré. This region is situated in the Reconcavo Basin and its extension to the south. Southward from Mar Grande, Quaternary sand deposits are well developed. This coastal section is characterized by a series of islands, lagoons and small bays, the most important being Camamu Bay in the south. Dead coral reefs are encountered in some localities, such as in the Itaparica and Tinharé islands.

SECTOR V - Corresponds to the coastal section between Itaquaré and Ilhéus. In a general way, it is characterized by the presence of the Precambrian crystalline basement in contact with the sea. Quaternary deposits are poorly developed, with the exception of the zone of the small sedimentary basin of Almada (Cretaceous) where they are more extensive. During the Quaternary, when sea level was above the present one, a bay existed in this basin, the last evidence of which is the small lagoon of Itaípe.

SECTOR VI - Extends from Ilhéus to the south of the State of Bahia. This littoral section is characterized by the sediments of the Barreiras Formation being once more in contact with the sea. However, in some places the marine Quaternary formations are well developed, such as in the case of the regions of Canavieiras-Belmonte and Alcobaça-Mucuri. During epochs of sea levels lower than the present one, valleys were carved in the Barreiras sediments by the rivers existing in the region; these were subsequently drowned in the epochs of high level. The southern coast of the State of Bahia is marked by the presence of coral reefs, mainly in the Abrolhos region. Extensive occurrences of beach rocks, mainly in Ilhéus, Porto Seguro and Santa Cruz, are equally well known.

QUATERNARY MARINE FORMATIONS

Along the coast of the State of Bahia evidence is found of three great transgressive episodes of the Quaternary. The earliest episode is represented by a sequence 80 to 100 m thick constituted essentially by limestones with some clay intercalations. CARVALHO & GARRIDO (1966) studied these deposits on the basis of data obtained from drilling carried out in the Caravelas region (Fig. 10) and gave them the name of Caravelas Formation. It was possible to date it as Pleistocene on the basis of its abundant bioclasts (pelecypods, gastropods and foraminifera). In the Caravelas region this formation crops out between the sediments of the Barreiras formation and the sand terraces left by the following transgressive episode which reached a level above the present mean sea level, here denominated the penultimate transgression. These sand terraces

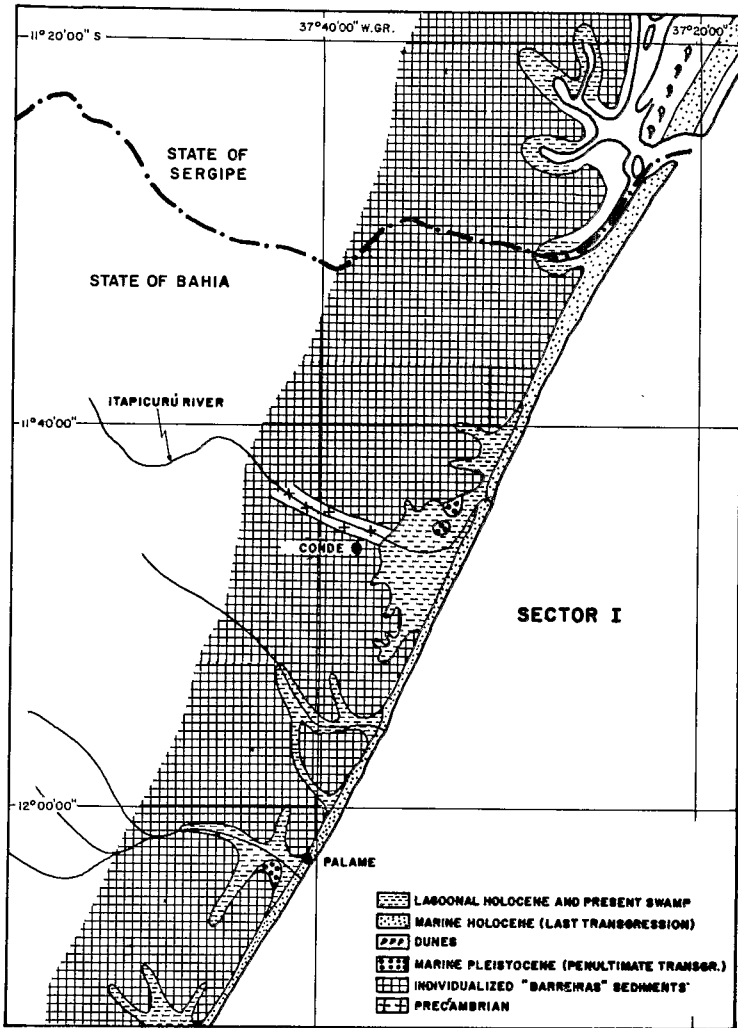


Figure 2 - Geological map of the region between the north boundary of the State of Bahia and Palame.

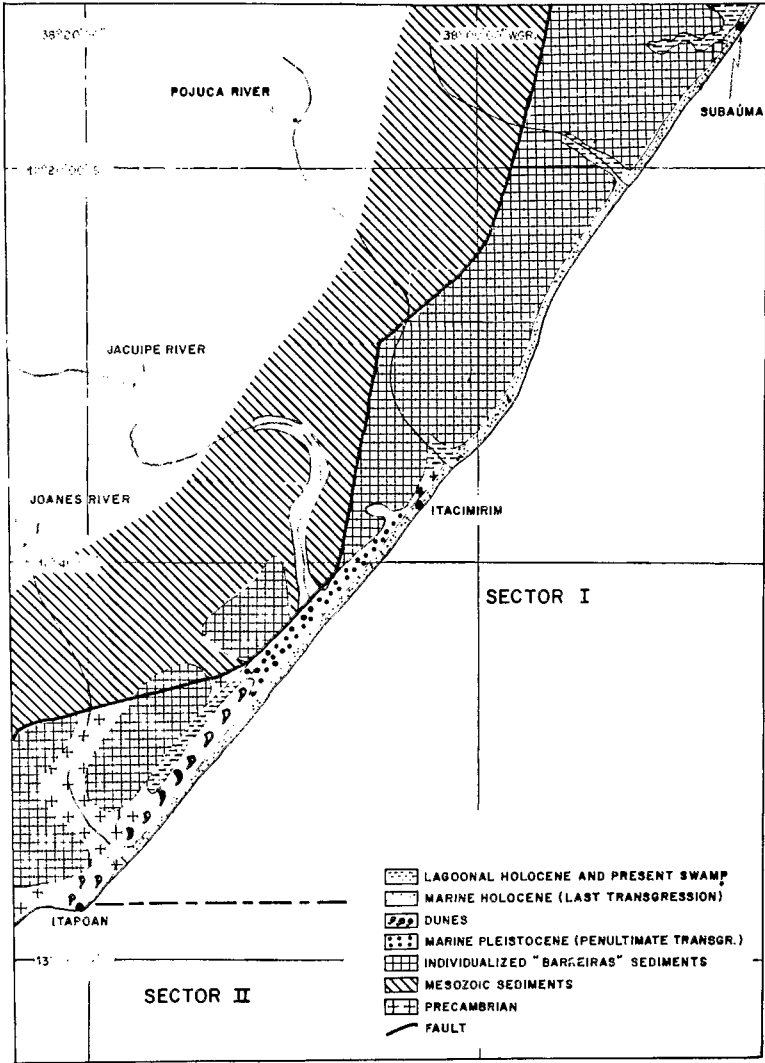


Figure 3 - Geological map of the region between Subaúma and Itapoan.

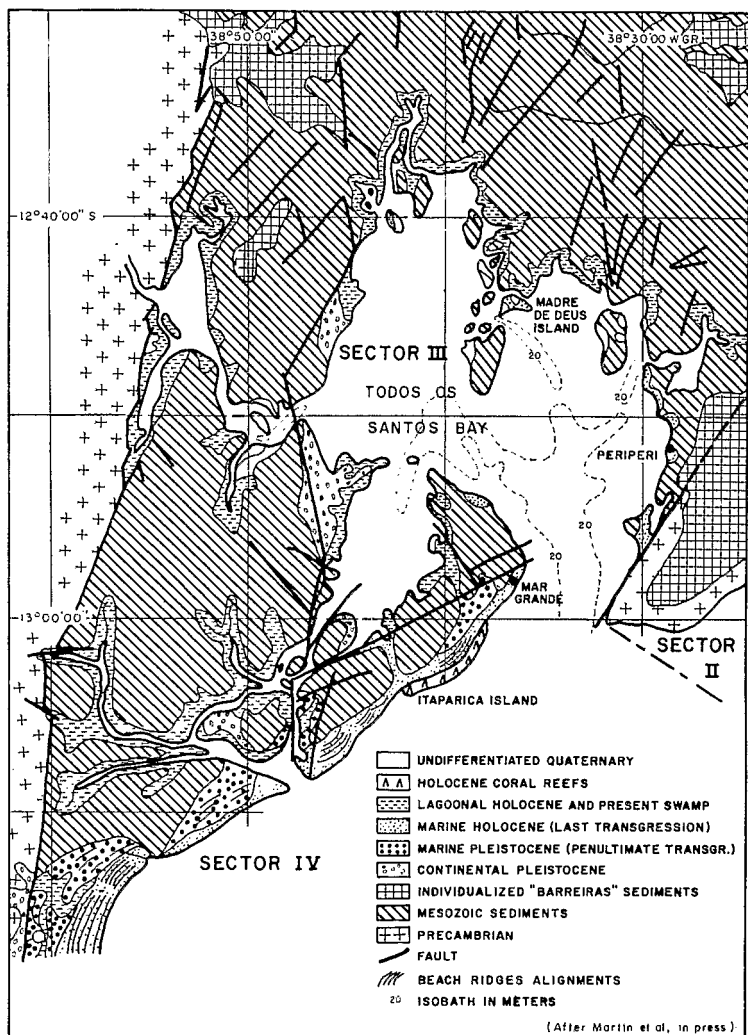


Figure 4 - Geological map of the region of Todos os Santos Bay

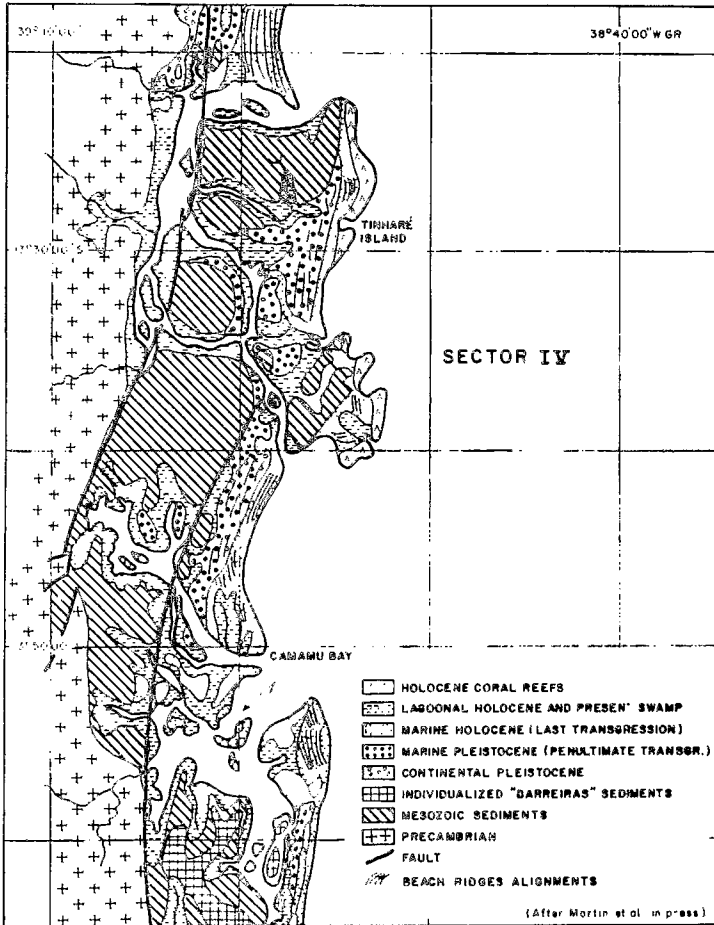


Figure 5 - Geological map of the region between Tinharé Island and Camamu Bay

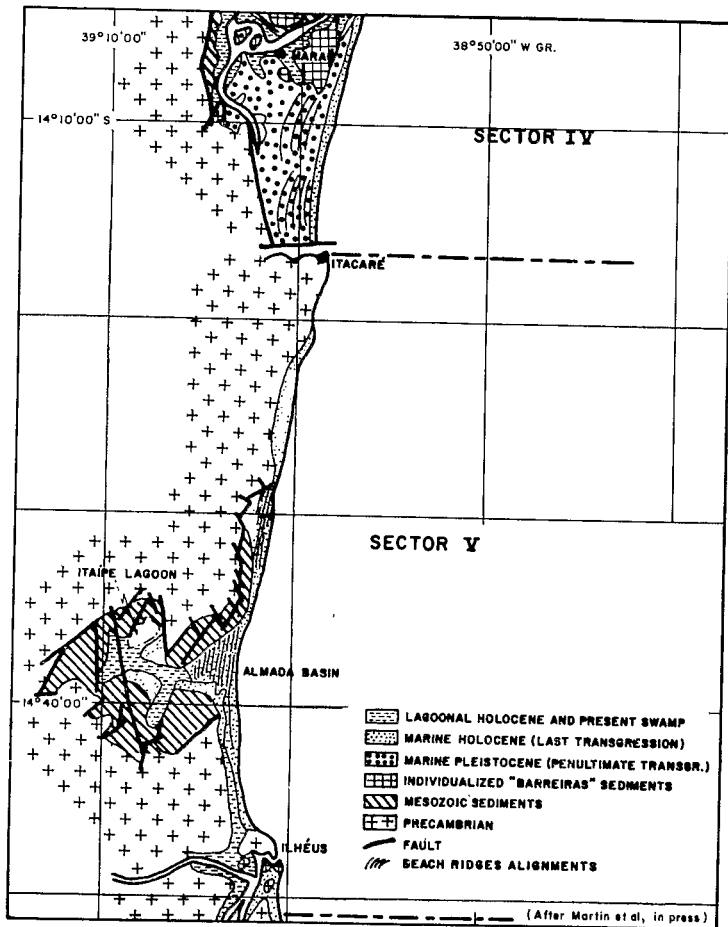


Figure 6 - Geological map of the region between Maraú and Ilhéus

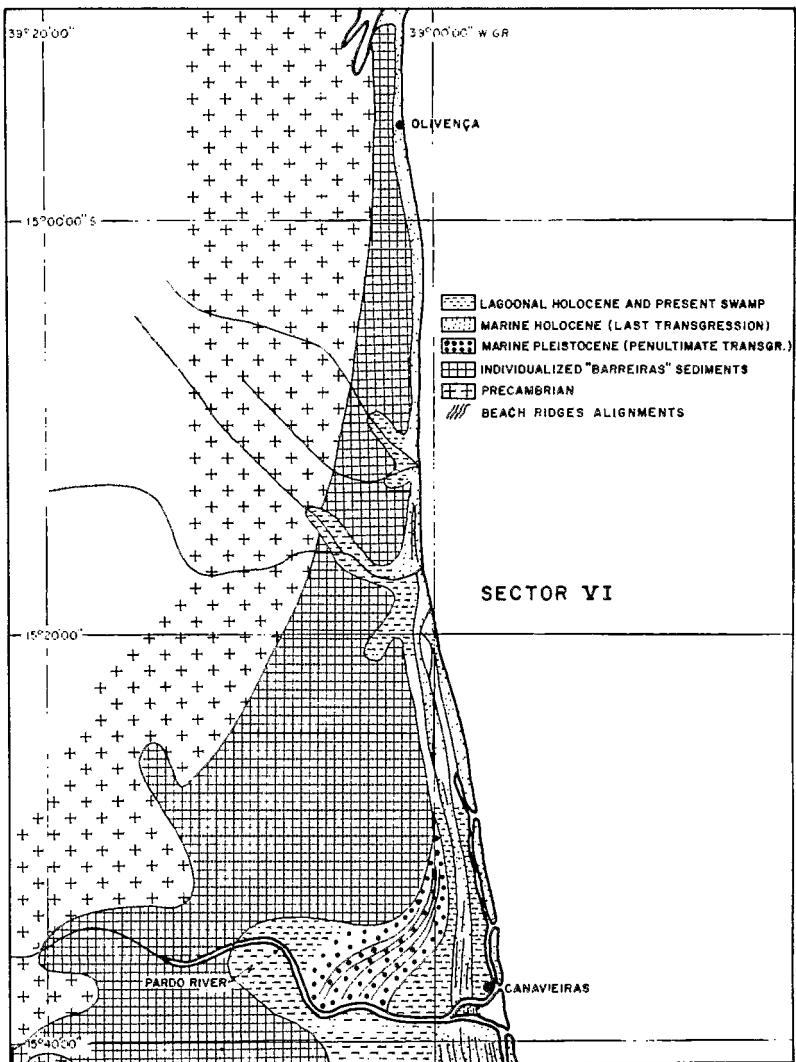


Figure 7 - Geological map of the region between Olivença and Canavieiras

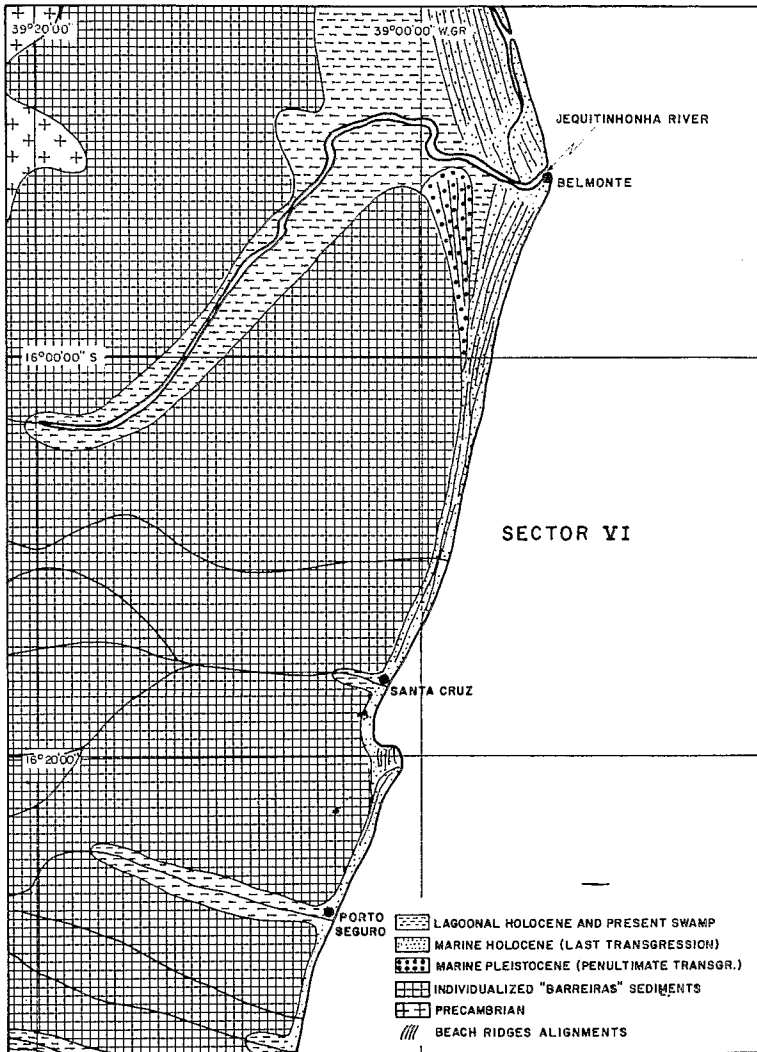


Figure 8 - Geological map of the region between Belmonte and Porto Seguro

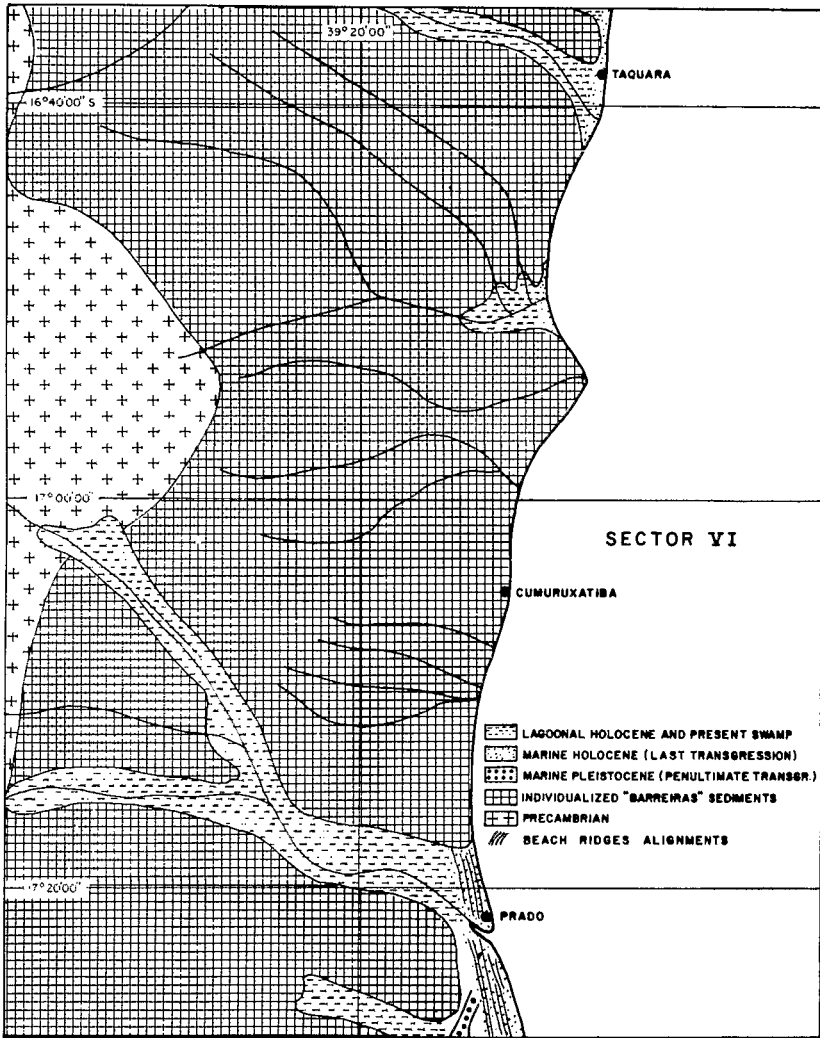


Figure 9 - Geological map of the region between Taquara and Prado

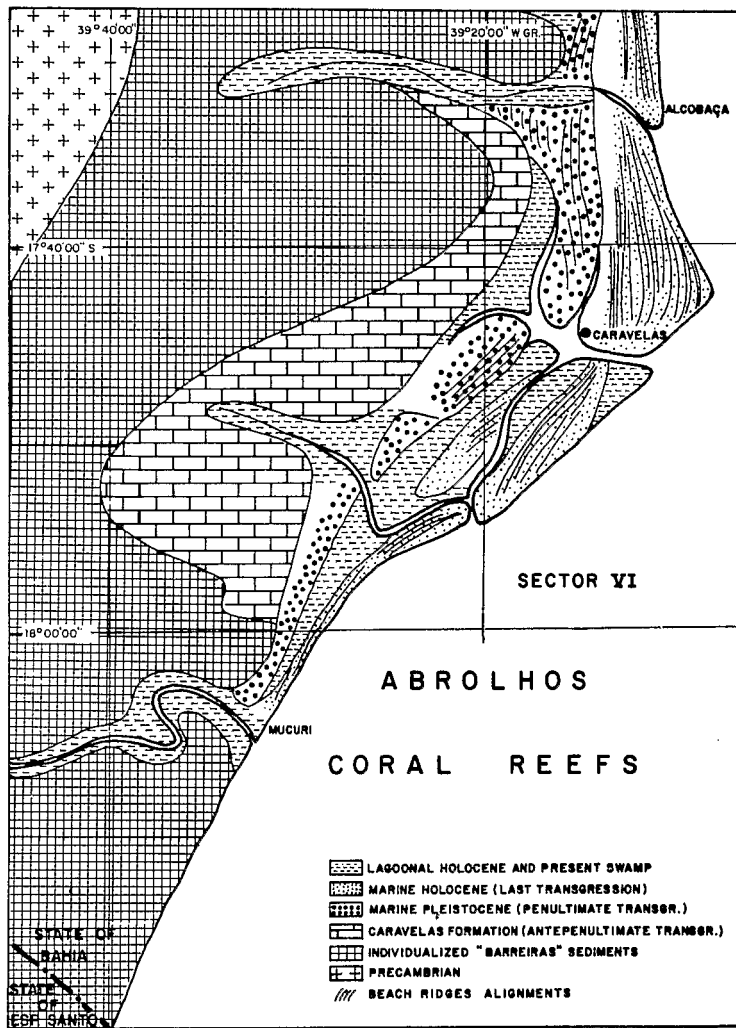


Figure 10 - Geological map of the region between Alcobaca and the south boundary of the State of Bahia

rest discordantly on the calcareous sequence. thus indicating that the Caravelas Formation was deposited during a previous transgression.

The only datings obtained for the deposits left by the penultimate transgression were those obtained by MARTIN *et al.* (in press) for the following materials: a) a piece of wood found in a clay layer which was covered by a marine sand, indicating an age greater than 30,000 B.P. (Bah. 562); b) fragments of wood and vegetal remains found in marine sands rich in secondary organic substances, indicating an age of 27,165 \pm 1,775 years B.P. (Bah. 563). This last sample, being found in a permeable material, should have been highly impregnated by recent humic acids. Thus it is very probable that the measured small activity may correspond to a contamination by a recent carbon which was not totally eliminated by the hot NaOH pretreatment. In effect, a small contamination by recent carbon in a "dead" sample can give rise to a small activity that will result in an inaccurate age measurement, giving an age younger than the real age. Meanwhile, in accordance with the data furnished by the literature, it can be assumed that these marine sands were deposited at the end of the transgressive episode of 120,000 years B.P. and at the beginning of the regression that followed.

Finally, the most recent transgressive deposits are undeniably linked to the final phase of the last transgression in the Holocene (MARTIN *et al.*, this volume).

CHARACTERISTICS OF THE PENULTIMATE AND THE LAST TRANSGRESSIONS

During the course of the final part of the penultimate transgression and in the regression that followed, sand terraces were formed along most of the coast of the State of Bahia. In the section between Salvador and Ilhéus (Figures 4, 5 and 6) these deposits were mapped by MARTIN *et al.* (in press). In general, these are arenaceous sediments, white on the surface and black or brownish in the interior. This dark coloration is secondary, being due to the presence of disseminated organic substances and iron oxide. The littoral origin of these

deposits is evidenced by the presence of *Callianassa* fossil burrows like those in the Cananéia Formation in São Paulo, Brazil (SUGUIO & MARTIN, 1976). These marine arthropods have a very clearly defined zone of life corresponding to the low tide region and are good indicators of the depositional environment. Beach ridges are highly visible in aerial photographs in the upper part of these sand terraces in the region south of Itaparica Island. According to VILAS BOAS *et al.* (this volume), the preservation of these ridges denotes a climatic stability in that region since 120,000 years B.P.

The evidence left by the last transgression above the sea level possesses the following characteristics:

Sand terraces - On the external part of the ancient terraces (penultimate transgression), sand terraces rich in shells are found, the tops of which are situated somewhat more than 4 m above the present high tide. Well marked beach ridges are present on the surface of these deposits.

Vermetidae incrustations - Numerous *Vermetidae* incrustations are found attached to the rocky promontories; they are situated above the present ecological zone of the species. This zone is very well defined and is situated in the upper limit of the inshore zone. It is therefore relatively easy to reconstruct the position of ancient sea levels with a precision on the order of ± 0.5 m, taking as a basis the position of *Vermetidae*. However, it should be taken into account that in the region of wave action this ecological zone can extend upwards 1 m (LABOREL, 1967).

Calcareous algae and corals - *Melobesia* and coral incrustations are also found attached to the rocky outcrops. These organisms have an ecological zone with a very great vertical range, however, they have a very well defined upper limit of life - around + 0.6 m. They indicate thus an upper limit above which the sea could not have reached during their lifetime.

Sea-urchin burrows - Numerous sea-urchin burrows are found on the outcrops of crystalline rocks, mainly in the Salvador region. They are located above the present ecological zone of the species. In spite of the fact that they cannot be dated,

the altimetric information furnished by these burrows, when encountered on vertical walls, can be used, in association with other data, as indicators of ancient sea-level positions.

Beach rocks - Along almost the entire coast of the State of Bahia good exposures of beach rocks are found. The study of the sedimentary structures and the granulometry of these sandstones can indicate the place where the sands composing them were deposited and hence define with a precision of $\pm 0.5\text{m}$ the position of mean sea level at the moment of deposition. It was possible to establish that on this coast there are beach rocks with sands which were deposited in different zones, from the offshore to the backshore. The tidal range in this region being of the order of approximately 2.7 m, it would be dangerous to attribute systematically the same depositional zone to all the sandstones. In the majority of cases these rocks contain shells, thus permitting ^{14}C dating. However, there remains the problem of knowing whether the marine organisms whose shells were dated were contemporaneous with deposition. In any case, it is often possible to choose quite fresh, unaltered shells, which suggests that those two epochs were successive. Isotopic measurements carried out on the beach rock cement of the Salvador region show that the $\delta^{13}\text{C}$ values of the $^{13}\text{C}/^{12}\text{C}$ ratio (with respect to the PDB standard) are between + 3 and + 2 $^{\circ}/\text{oo}$. This indicates that the carbonates of the cement originated in sea water and not from the dissolution of the shell remnants by later fresh water recrystallization. This fact eliminates the possibility of dating negative oscillations of the sea level on basis of the cement of these beach rocks.

GEOGRAPHICAL DISTRIBUTION OF THE REMAINING DEPOSITS OF THE PENULTIMATE AND LAST TRANSGRESSIONS

The distribution of the remaining deposits of the two last transgressive Quaternary episodes which achieved a maximum superior to the present mean sea level will be described according to the different sectors into which the coast of the State of Bahia was divided in this work.

SECTOR I (Figures 2 and 3). In the paleobays of Conde, Palame and Subauma (Fig. 2), the remnants of the penultimate

transgression are indicated by a sand terrace, the top of which is situated 6 m above high tide level. It is probable that originally these remnants might have formed a single deposit which has been dissected by erosion. From Itacimirim to Itapoan (Fig. 3), these deposits are continuous, although they are frequently masked by dunes. The regions eroded in the terraces of the penultimate transgression were afterwards occupied by the sea or lagoons on the occasion of the maximum of the Holocene transgression. The regression that followed deposited a series of beach ridges forming a continuous band with an average width of 0.5 km for all this sector. These ridges closed the ancient bays of Conde, Palame and Subauma. At the moment, datings in this region are not available.

SECTOR II (Figures 3 and 4). During the maximum of the penultimate transgression, the sea penetrated the small valleys carved in the crystalline basement, forming sand terraces situated about 6m above the high tide. These terraces were in part dissected by erosion, however good outcrops are still found. The last transgression now is represented by poorly developed and discontinuous sand deposits; nevertheless, the transgression is indicated by other evidences of ancient marine levels. Thirty-six ^{14}C datings of mollusk shells, *Vermetidae*, calcareous algae and corals were made which permitted the construction of curve of the variations in relative mean sea level for this sector (MARTIN *et al.*, this volume). From this curve, it can be seen that: a) the zero was cut for the first time around 7,000 years B.P.; b) around 5,200 years B.P. the relative mean sea level passed through a maximum situated at 4.7 ± 0.5 m above the present level; c) around 3,800 years B.P. the relative mean sea level passed through a minimum situated slightly under the present level; d) around 3,500 years B.P. the relative mean sea level passed through the second maximum situated at more than 3 m above the present level; e) around 2,700 years B.P. the relative mean sea level passed through a second minimum situated slightly under the present level; f) around 2,400 years B.P. the relative mean sea level passed through the third maximum situated at 2.5 m above the present level; g) starting with this epoch the relative mean sea level returned progressively to the present zero. Around 1,000 years B.P. it was still 1 m above the present

level.

SECTOR III (Figure 4) - Up to the present, no deposits left by the penultimate transgression have been found along the shores of Todos os Santos Bay. As for the last transgression, the existing evidence is rather scattered and localized. At the locality of Pedra Oca (Periperi), *Vermetidae* and a small fossil beach have been found which indicate an ancient mean sea level more than 3 m above the present one, dated respectively 3,030 \pm 120 years B.P. (Bah. 542) and 3,260 \pm 100 years B.P. (Bah. 539). On the Madre de Deus Island, another marine terrace was dated at 3,470 \pm 100 years B.P. (Bah. 269). Its top also indicates an ancient mean sea level superior to 3 m in relation to the present level on the basis of shells collected in its upper part.

SECTOR IV (Figures 4, 5 and 6) - It is in this section of the coast that the sand terraces formed during the penultimate transgression show their major development. They form a more or less continuous band between the Cretaceous formations and the Holocene deposits. In Marau (Fig. 6), they achieve a width of about 15 km. The sand terraces of the last transgression are also well developed there, being in places more than 5 km wide. In Itaparica Island, the highest part of these terraces is situated more than 4 m above high tide. The upper part of the coral reef that borders this island was dated at 3,180 \pm 60 years B.P. (Bah. 515).

SECTOR V (Figure 6) - Up to now, no evidence of the penultimate transgression has been found in this sector. On the other hand, deposits of the last transgression are found along the entire coast, mainly in the Almada region, where they are highly developed. Corals collected on the shores of Itaipé Lagoon were dated at 4,070 \pm 140 years B.P. (Gif. 1064) (LABOREL, 1967).

SECTOR VI (Figures 7, 8, 9 and 10) - Sand deposits of the penultimate transgression are found in the regions of Canavieiras-Belmonte (Figs. 7 and 8) and Prado-Mucuri (Figs. 9 and 10), where they form the internal part of small deltas. In the Canavieiras-Belmonte region the Prado and Jequitinhonha rivers destroyed the central part of the Pleistocene marine deposits.

However, these deposits are well preserved north of the Prado River and south of the Jequitinhonha River. In the Prado-Mucuri region they form a continuous band almost 100 km long. The Holocene deposits, in the form of sand terraces, also constitute a continuous strip interrupted only in the Cumuruxatiba region (Fig. 9), where the Barreiras sediments come directly in contact with the sea. In general, this strip is poorly developed, with the exceptions of the regions of Canavieiras-Belmonte and Prado-Mucuri, where the Holocene ridges are very wide (more than 10 km) and form the external part of the deltas existing there. In the Caravelas delta (Fig. 10), various generations of beach-ridges can be distinguished.

CONCLUSION

Along the entire coast of the State of Bahia evidence of the last transgression is continually being found. In the Todos os Santos Bay area, this evidence is rare and scattered, this discontinuity possibly signifying a reactivation of the southern part of the Reconcavo Basin during the Quaternary.

With the exception of the Todos os Santos Bay, deposits of the penultimate transgression exist all along the coast. These are in the form of sand terraces with heights from 6 to 8 m above the present mean sea level. It is probable that after the maximum of this transgression these deposits might have constituted a continuous formation along the coast which was more or less dissected during the subsequent event.

Finally, in the south of the State, there exists a calcareous formation rich in fossils deposited during a transgression older than the penultimate one.

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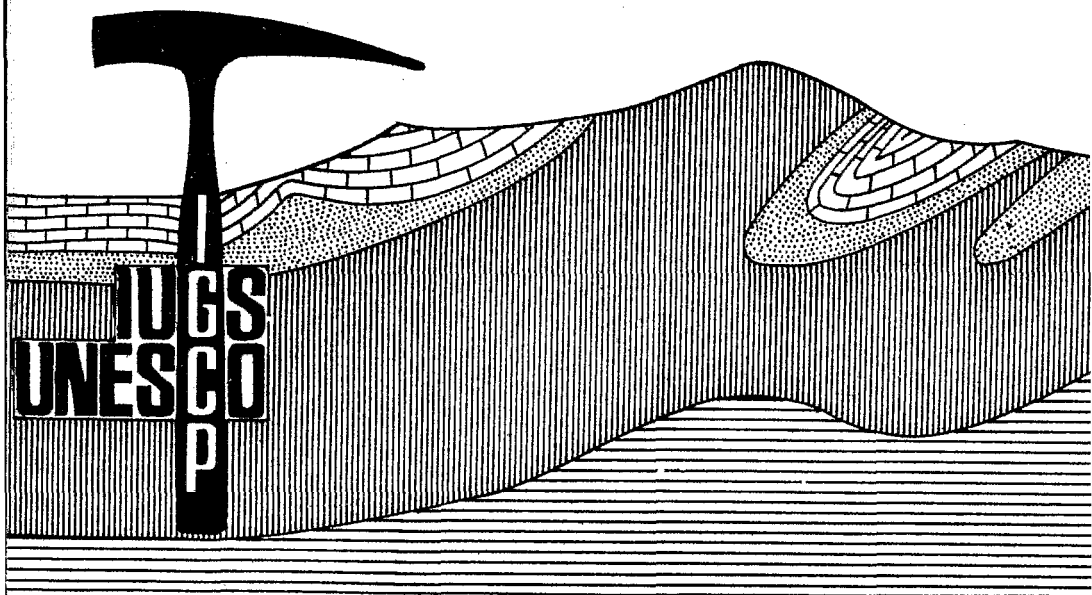
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