Anais da Academia Brasileira de Ciências
ISSN: 0001-3765
aabc@abc.org.br
Academia Brasileira de Ciências
Brasil

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Anais da Academia Brasileira de Ciências, vol. 72, núm. 2, jun;, 2000, pp. 271-287
Academia Brasileira de Ciências
Rio de Janeiro, Brasil

Patterns of Sediment Dispersion Coastwise the State of Bahia – Brazil

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Manuscript received on September 10, 1999; accepted for publication on March 13, 2000;
presented by Kenitiro Suguio

ABSTRACT

Using the average directions of the main wave-fronts which approach the coast of Bahia State – coinciding with that of the main wind occurring in the area – and of their periods, we define a wave climate model based on the construction of refraction diagrams. The resulting model of sediment transport was able to reproduce, in a general way, the sediment dispersion patterns furnished by geomorphic indicators of the littoral drift. These dispersion patterns control the generation of different types of sediment accumulations and of coastal stretches under erosion. We demonstrate that the presence of the Abrolhos and Corumbaú Point coral reefs is an important factor controlling the sediment dispersion patterns, since them act as a large protection against the waves action.

key words: Littoral drift, wave refraction, numerical modelling, State of Bahia, Brazil.

INTRODUCTION

The coast of the State of Bahia – Brazil (Fig.1) is entirely situated within the trade wind belt of the South Atlantic (NE - E - SE), which is related to the high-pressure cell occurring in this region. In fact, this system represents the major atmospheric circulation center along this extension of the South Atlantic ocean (Bigarella 1972, Martin *et al.* 1998). Another important element of the atmospheric circulation in this region is the periodic advance of the Atlantic Polar Front which takes place during the autumn and winter, and generates strong winds coming from SSE (Bigarella 1972, Martin *et al.* 1998). It is noteworthy the fact that, in an interannual scale, the high-pressure cell normally shows a tendency to remain relatively stationary. Seasonably, however, this cell tends to expand and contract. During the winter, the high-pressure zone covers a vast area of Brazil, while during the summer it returns to the ocean. On the coastal zone, this seasonal moviment of the high-pressure zone controls the position of the Divergence Zone (DZ), between the trade winds sensu stricto (SE) and the return trade winds (NE). During the winter, the DZ is located at approximately 20°S while, during the summer time, the position changes to approximately 13°S (Bigarella 1972, Martin *et al.* 1998). This circulation pattern allows the coast of the State of Bahia to be reached by winds arising from the NE and E during the spring-summer period, and winds coming from the SE and E during the autumn-winter period. Moreover, during the autumn-winter period the winds arising from the SSE, associated with the periodical advance of

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the Atlantic Polar Front, reinforce the trade winds from the SE. This general atmospheric circulation system is susceptible to disturbances, particularly on the occasion of severe events of the so-called phenomenon El Niño, which can disturb the advance of the Atlantic Polar Front.

The atmospheric circulation system briefly described above is responsible for the general pattern of wave-fronts reaching the coastline of the State of Bahia (Dominguez *et al.* 1992; Martin *et al.* 1998). Moreover, as it is discussed later, this circulation system is the major control of the sediment dispersion pattern observed alongside the coast of Bahia.

The aim of the present study is to define, according to a general model of wave climate acting upon the coast, the major patterns of sediment dispersion alongside the littoral of the State of Bahia.

GEOLOGIC SETTING

The sediments occurring in the continental margin contiguous to the State of Bahia can be subdivided into large sequences, with ages ranging from the Late Jurassic to the Present Time (Chang *et al.* 1988, 1992). They are: (i) the continental sin-rift; (ii) evaporitic transitional; (iii) shallow carbonated platform; and (iv) the transgressive-regressive sequences. During the Cenozoic Period, sedimentation in the continental margin was characterized by deltaic-fluvial sediments that graded offshore towards the shallow carbonated platform, and basin shales, organized in a typical progradational architecture.

At the end of the Pliocene, sandy-clayey sediments of alluvial origin, the so-called Barreiras Formation accumulated alongside the coastal zone. Such deposition extended far away offshore in relation to the present day coastline. Remnants of this formation are still found in the continental shelf nowadays. It is suggested that the deposition of the Barreiras Formation occurred contemporaneously with a tilting of the continental margin (Ghignone 1979, Bittencourt *et al.* 1999). Nowadays, the Barreiras Formation forms tablelands bordering the coast of the State of Bahia (Figs. 2 and 8D).

During the Quaternary Period, the coastal zone was affected by several transgressive-regressive episodes. During the last two episodes, the present sea level was exceeded at approximately 120,000 years B.P. (8±2m), and 5,100 years B.P. (5±1m) (Martin et al. 1979 1980 1982). Testimonies of these two episodes are found alongside the eastern Brazilian coast. This sea level history strongly controlled the evolution of the coastal zone, which is nowadays characterized by two groups of marine terraces covered by beach-ridges. These terraces are usually separated from each other by low lying zones corresponding to the old lagoons (Dominguez *et al.* 1987 1992, Martin & Dominguez 1994).

PHYSIOGRAPHIC ASPECTS OF THE CONTINENTAL SHELF AND COAST OF THE STATE OF BAHIA

In the State of Bahia, the continental shelf can be subdivided into two well-defined stretches. In the first one north of Ilhéus, the continental shelf is quite narrow presenting a strong bathymetric gradient with the isobaths arranged approximately parallel to each other, and also with relation to the coastline. On the other hand, in the second stretch south of Ilhéus, the continental shelf widens, reaching an expressive width in front of Belmonte and Caravelas (Fig. 1). There, it presents a low bathymetric gradient, and the isobaths exhibit quite irregular contours. As remarkable physiographic features in this region, it stands out the Royal Charlotte and Abrolhos banks, besides the coral reefs (Fig. 1).

From a physiographic viewpoint, the coastline of the State of Bahia can be divided into five sectors. They are described below starting from the north towards the south (Fig. 2).

Sector I – This sector is almost straight, extending from the northern limit of the study area up to the district of Itapoã. A vast portion of this littoral stretch is characterized by the presence of deposits of the Barreiras Formation near the coast. The Quaternary coastal plain is quite narrow, presenting a maximum width of a few hundreds meters, such as

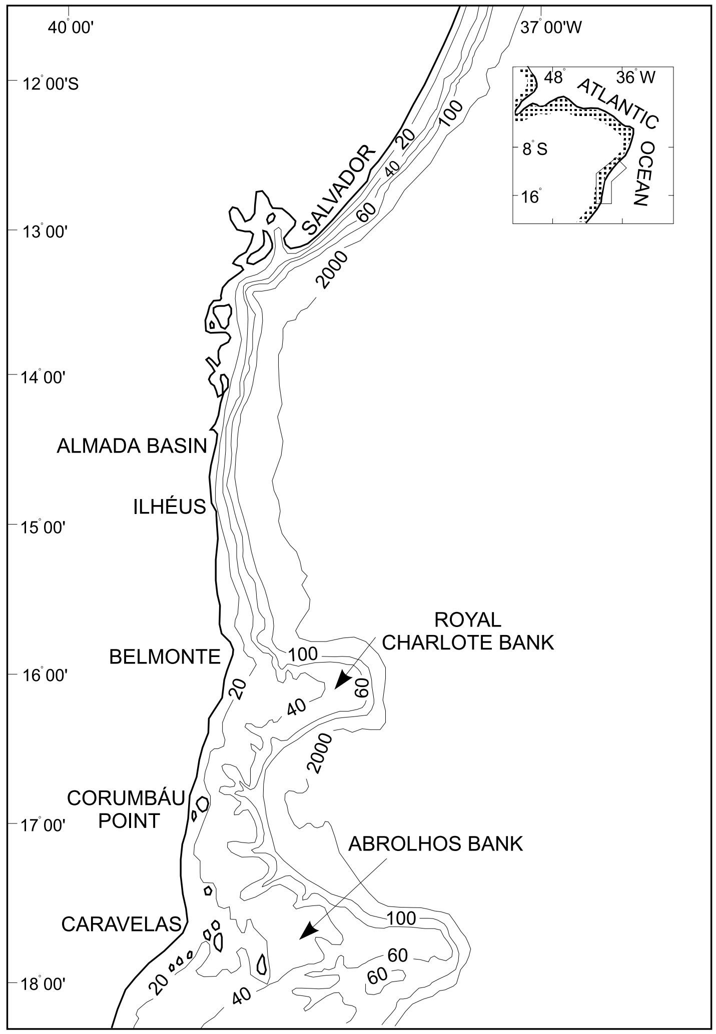

Fig. 1 – Physiographic aspects of the continental shelf of the State of Bahia. Bathymetric contours in meters.

the case between the localities of Conde and Arembepe. There, the Quaternary sediments are better preserved in the valleys and reentrances excavated in the Barreiras Formation.

Sector II – This sector extends from the district of Itapoã up to the entrance of Todos os Santos Bay. It differs from the previous one because the Pre-cambrian basement outcrops on the coastline. Quaternary deposits are discontinuous, and poorly developed.

Sector III – This sector comprises the coastal zone within the Todos os Santos Bay, small bays, and inlets extending towards the south up to Itacaré. This sector includes the Recôncavo Basin showing a typical morphology of submersion, irregular coastline, and several islands. The Quaternary deposits in the Todos os Santos Bay are either absent or poorly developed. At the south of the Bay, however, they become expressive.

Sector IV – This sector is limited by the localities of Itacaré and Ilhéus. Similarly to the sector II, it is characterized by the presence of the Pre-cambrian basement either reaching the sea or quite close to it. Moreover, the Quaternary deposits are poorly developed, except for the proximities of Ilhéus.

Sector V – This sector extends from Ilhéus up to the southern limit of the study area. It is characterized by the presence of the Barreiras Formation which, in some places, reaches the coastline forming active sea cliffs such as those occurring between Prado and the Corumbaú Point. The Quaternary coastal plain shows significant widths such as 25 km in the mouth of the Jequitinhonha River, and 17 km in the coastal plain of Caravelas. Also, this coastal stretch is characterized by the coral reefs of Abrolhos.

WAVE CLIMATE MODEL FOR THE COAST OF THE STATE OF BAHIA

Significant direct measurements of the wave regime alongside the coastline of the State of Bahia are not available. Nevertheless, using classical techniques (CERC 1984), standard wave refraction diagrams can be constructed resulting in a generic model of the wave climate for the study area (Figs. 3 and 4). The bathymetric data used in the construction of these diagrams were extracted from the nautical charts published by the Brazilian Navy, in a scale approximately 1:300,000. Waves were not propagated in water depths shallower than 10m. The following wave-fronts directions were considered during construction of the refraction diagrams: NE(N45°), E(N90°), SE(N135°), and SSE (N157.5°) (Martin *et al.* 1998). Also, it was taken into account the following most significant periods and heights associated to them: the 5.0sec period and 1.0m height for the NE(N45°) and E(N90°) directions, and the 6.5sec period and 1.5m height for the SE(N135°) and SSE(N157.5°) directions (U.S. Navy 1978). The directions chosen represent the major wind directions occurring coastwise the State of Bahia, as previously mentioned. It has been estimated that for the periods considered, the wave-fronts from the NE and E start interfering with the sea-bottom at a depth of approximately 20m, while for those coming from the SE and SSE, this interaction begins approximately at 35m. For most of Sector III, wave refraction diagrams were not constructed because of the following reasons: a) our scale of observation does not allow an appropriate representation of this stretch of coastline which is very segmented and b) the nautical charts do not depict important submarine features, such as river mouth bars and ebb tidal delta complexes which strongly influence wave refraction.

The wave-refraction diagrams show that the wave-fronts arising from the SE and SSE (Figs. 3A and B), refract more intensively than those coming from the NE and E (Figs. 4A and B). This can be verified by the larger number of coastal stretches showing divergence and convergence of wave-rays associated with SE-SSE waves. Thus, for example, it is remarkable the divergence of wave-rays in the coastal stretch between the Catoeiro Point and Itaquena, in relation to the SE waves (Fig. 3A), and between the Baleia Point and the St. Antonio Point, in relation to the SSE waves (Fig. 3B). Excepting the region located south of the Baleia Point, the coastal stretches showing divergence of wave-rays, in relation to the waves from the NE are not too expressive (Fig. 4A). The same is observed in relation to the waves from E (Fig. 4B). Regarding the coastal stretches showing significant convergence of wave-rays, these occur with the waves from the SSE and SE only. This is particularly remarkable between Itaquena and St. Antonio Point, with the SSE waves (Fig. 3B), and between Prado and the Corumbaú Point, with relation to the SE waves (Fig. 3A).

SEASONAL ORIENTATION OF THE LITTORAL DRIFT ALONGSIDE THE COAST OF THE STATE OF BAHIA

Longshore drift directions associated with each wave systems have been deduced from the refraction diagrams and the general orientation of the coastline

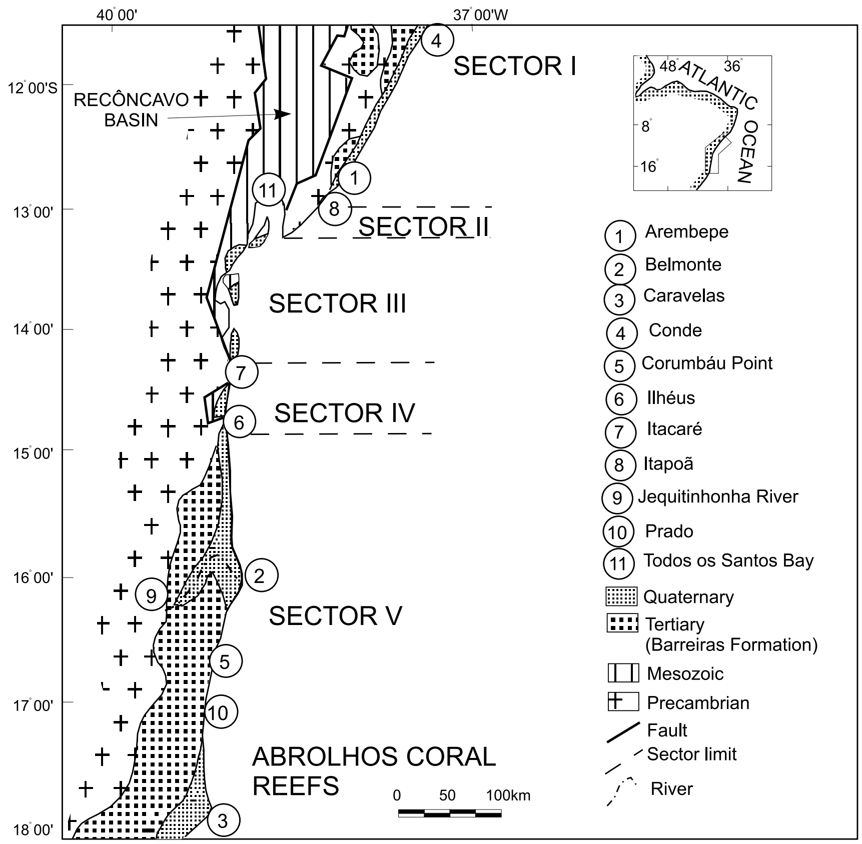

Fig. 2 – Simplified geological map of the study area showing the location of the different physiographic sectors discussed in the text.

(Figs.3 and 4).

Longshore drift directions could not be deduced for a few sectors between the following localities: a) Catoeiro Point and Itaquena (waves from the SSE – Fig.3B); b) Catoeiro Point and Prado (waves from the SE – Fig. 3A); c) Mucuri River and the Baleia Point (waves from the E – Fig. 4B); and, d) Catoeiro Point and the extreme south of the study area (waves from the NE – Fig. 4A). These regions are normally characterized by low wave energy levels in comparison with the other coastal stretches analyzed in the present work. As a matter of fact, in general, these coastal stretches are regions of wave-shadows and significant wave-ray divergence, therefore, becoming places of enormous dispersion of wave energy (King 1972, Komar 1976). Therefore, these regions show low levels of wave energy (Bascom 1954, Goldsmith 1976). Thus, taking into account the regional approach of our analysis, the littoral drift occurring in these regions can be considered negligible. Similarly, alongside the coastal stretch between the mouth of the Pojuca River and Salvador, it has not been possible to determine any longshore drift orientation with relation to the NE waves, because the refracted wave rays do not reach the shoreline (Fig. 4A).

DISCUSSION AND CONCLUSIONS

The potential intensity of the net littoral drift was determined taking into account that the energy of the

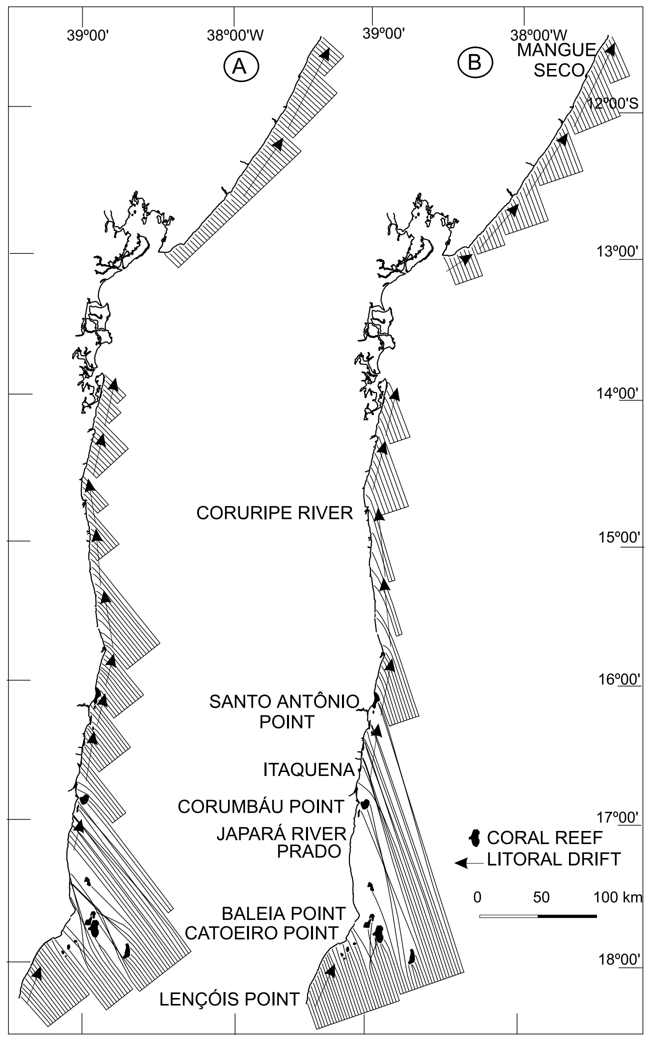

Fig. 3 – Refraction diagram for waves with a 6.5 sec period, arising from the SE (N135°) (A) and SSE (N157.5°) (B), referred to the coastal stretch of the State of Bahia.

waves is directly proportional to the square of their heights (Davies 1972). Since the intensity of the littoral drift is proportional to the angle with which the wave-front strikes the shoreline (Zenkovitch 1967, Komar 1976, Kokot 1997), such factor was also considered according to the function y = sen $\alpha \times$ cos α (Komar 1976). Thus, the potential intensity of the littoral drift of sediments, calculated per unit area, and expressed by a non-dimensional value, was given by the function $x = y \times H^2$, where H, is the deep water wave height. Afterwards, the value obtained for the drift intensity was multiplied by the annual frequency percentage of the wind direction that is related to a particular wave-front. Alongside the whole coast of the State of Bahia, however, adequate sources providing data on wind directions are limited to Salvador and Caravelas (DHN 1993). Therefore, Ilhéus was chosen as an equidistant point

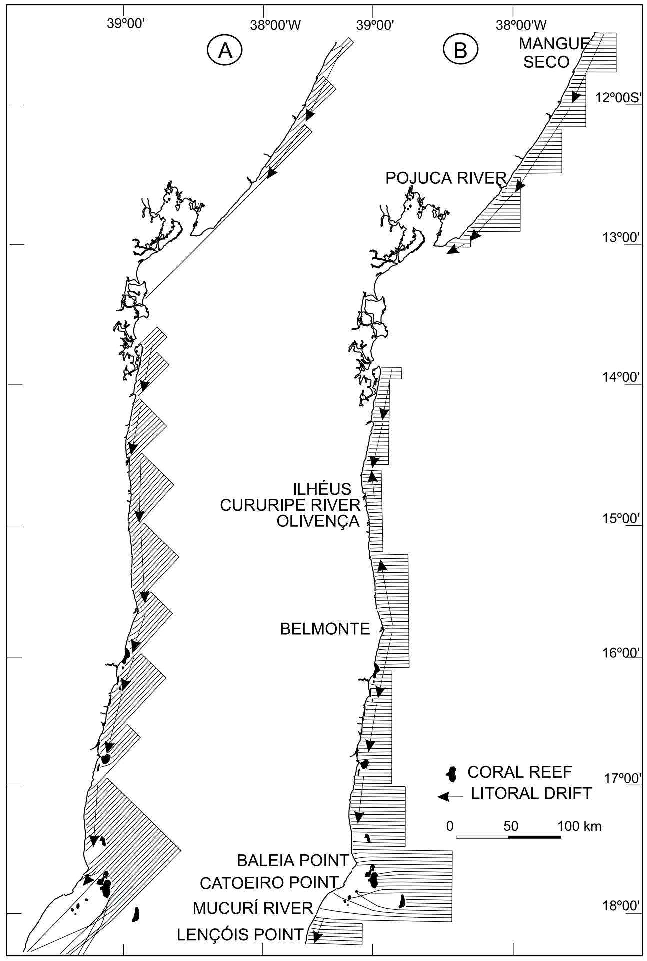

Fig. 4 – Refraction diagram for waves with 5 sec period, arising from NE (N45°) (A) and E (N90°) (B), referred to the coastal stretch of the State of Bahia.

from both sources of data (Fig. 1), and the coastal stretches located above and below Ilhéus assumed to share the same wind regime occurring in Salvador and Caravelas, respectively. The coast of the State of Bahia was divided into 14 segments. Each of these segments was approximated to a straight line according to the orientation of its coastline. Then, the angles that the direction of the different deep water wave-fronts form with each of the segments were directly measured on the charts (Fig. 5).

A few limitations in the accuracy of the values obtained for the potential intensity of the littoral drift were inevitable. Besides the diffraction and reflection processes occurring in the existing islands alongside the coast of Bahia being ignored, it was also used the deep water wave heights in the calculations for determining the littoral-drift intensity. In fact, the wave height can be modified by several factors before reaching the shoreline (Komar 1976, Goldsmith 1976). Although there are means to estimate the height of the refracted waves using the refraction diagrams (Bascom 1954), this proce-

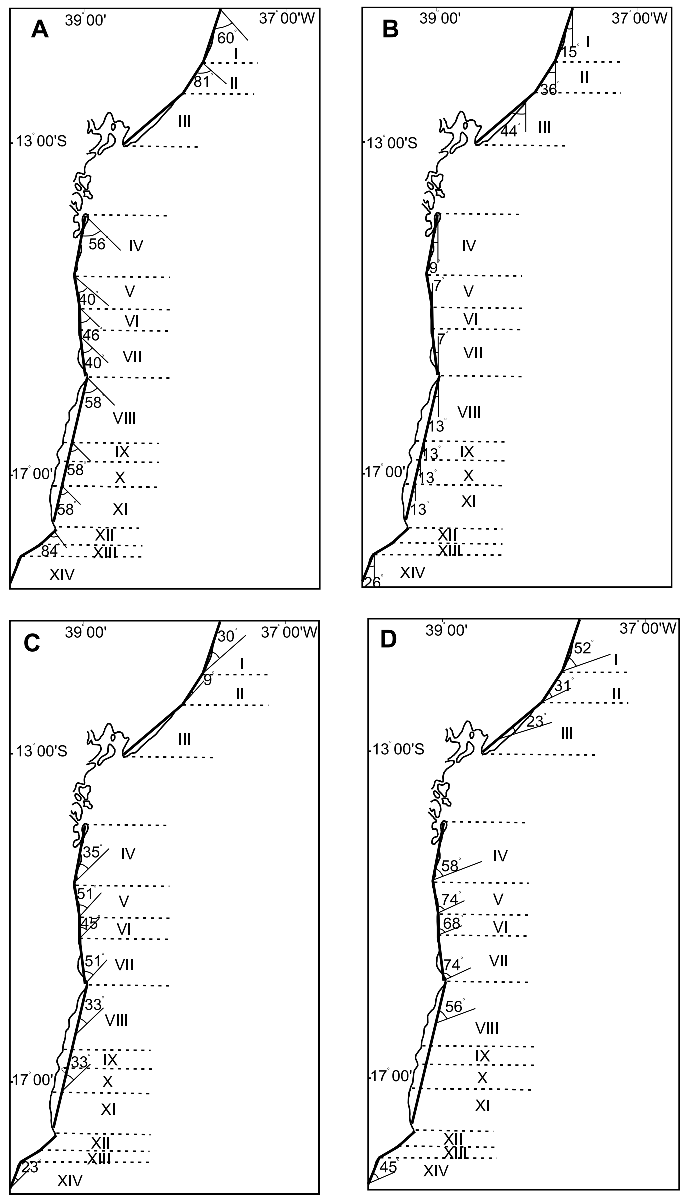

Fig. 5 – Angles of incidence formed by wave-fronts arising from the NE (N45°) (A), E (N90°) (B), SE (N135°) (C) and SSE (N157.5°) (D), in relation to the different directions shown by the coastline of the State of Bahia, represented here by several segments. There was no incidence of waves from the NE (A) in Segments III, X, XIII and XIV (See Fig. 4A), from the E (B), in Segments XII and XIII (See Fig. 4B), from the SE (C), in Segments IX, XI and XII (See Fig 3A), and from the SSE (D), in Segments IX, XI and XV (See Fig. 3B). The angle of incidence is almost zero in the Segments VI (B), III and XIII (C) and XII and XIII (D).

dure is not applicable to regions showing complex wave patterns, where the processes of refraction and diffraction are mixed together. A typical example of this kind is found at the Abrolhos region. Furthermore, the angle of incidence used herein was determined using the direction of propagation of waves in deep water, which affects the precision of the measurements. This becomes clear in some places where the wave-fronts after being refracted, reach the coastline showing different directions than those originally presented offshore. This is mainly observed in the region south of Coruripe River (Figs. 3 and 4), and remarkably with relation to the waves arising from the SE and SSE (Figs. 3A and B). In fact, the use of such procedure was carried out under the circumstances imposed by the scale of observation used in this work. This imposition required the littoral to be divided into large straight extensions masking the majority of the littoral's sinuosity, therefore, considerably modifying the angles of incidence of the wave-fronts with the coastline. On the other hand, the use of the directions of the wave-fronts in deep water is justified as they represent approximate mean direction values.

In some of the different segments in which the coastline of Bahia was divided it was not noticed the incidence of any wave-front, either because these regions were located in wave-shadows or because the wave heights were considered negligible. These were the cases of the segment III, with relation to the waves from the NE (Fig. 5A, also see Fig. 4A), and the segments IX, X, and XI, with relation to the waves from the SSE (Fig. 5D, also see Fig. 3B). Moreover, it was not recorded any indication of drift in the segment III, with relation to the waves from the SE (Fig. 5C). However, this case was attributed to the fact that the angle of incidence of the waves in this region was equal to zero (See Fig. 3A).

The potential intensity values and directions obtained for the littoral drift alongside the coast of Bahia are shown on Tables I and II, along with the net littoral drift direction. This net littoral drift direction was estimated with and without the influence of the wave-fronts arising from the SSE. This procedure is justified because the advance of the Atlantic Polar Front, which is responsible for the wave-fronts arising from the SSE, can be obstructed in those years in which the atmospheric phenomenon El Niño occurs. Consequently, the action of these waves alongside the coast of Bahia can be quasi-periodically stopped (Farias et al., 1985; Martin *et al.* 1993, Bittencourt *et al.* 1997). In the coastal stretches showing seasonal opposite drift orientations, the net littoral drift was defined by assuming the predominant direction as given by the difference of the intensities of the opposite drifts. For instance, in the segment I, the summation of the drift intensities from the south to the north was 3455, while the value obtained for the summation of the intensities of the opposite drift direction, that is, from the north to the south was 1949 (Table I). Thus, the net drift direction resulting was from the south to the north, and with an intensity value of 1506, considering the SSE waves, and a value of 961 without the influence of these waves (Table I).

Alongside the coast of the State of Bahia, the net littoral drift normally shows a prevailing direction from the south to the north. Significant local reversals of this drift direction, however, occur alongside the coast creating important drift divergence zones. Examples of these divergence zones are seen in those coastal stretches between the following localities: a) Baleia Point and Corumbaú Point; b) Corumbaú Point and Belmonte; and c) Salvador and Mangue Seco (Fig. 6). The existing geomorphic indicators alongside the coast of the State of Bahia (spits, recurved spits, tombolos, asymmetric coastal accumulations, etc.), provided drift directions which were essentially similar to the net drift directions estimated in the present work. The sole exception is for the coastal stretch between the Baleia and the Catoeiro points (Fig. 6). This can be explained by the fact that we used average wave-fronts directions. For example, a more southerly approach of the wave fronts would generate a south to north littoral drift (Fig. 3B), which could conceivably dominate over

TABLE I

Potential intensity of the net littoral drift for the coastal Segments I through IX, calculated per unit area, with and without the influence of the SSE waves (See Figs. 5 and 6)

Segments	Origin of the Wave-Front	Angle of Incidence (α)	Component of the Drift towards the North or South	Intensity of the Littoral Drift per Unit Area sen α . cos α .H^{2*}($\times$100)	Percentage of the Annual Annual Incidence of the Waves	Drift Intensity Multiplied by the Percentage of the Annual Incidence	Intensity of the Dominant Drift Minus the Secondary Drift (Net Littoral Drift) With the Influence of the Waves from the SSE	Intensity of the Dominant Drift Minus the Secondary Drift (Net Littoral Drift) Without the Influence of the Waves from the SSE
	NE (N 45°)	60°	N→S	43	18	774		
I	E (N 90°)	15°	N→S	25	47	1175	(1506)	(961)
	SE (N 135°)	30°	S→N	97	30	2910	S→N	S→N
	SSE (N 157,5°)	52°	S→N	109	5	545		
	NE (N 45°)	81°	N→S	15	18	270		
II	E (N 90°)	36°	N→S	47	47	2209	(934)	(1429)
	SE (N 135°)	9°	S→N	35	30	1050	N→S	N→S
	SSE (N 157,5°)	31°	S→N	99	5	495		
	NE (N 45°)	NI	–	–	–	–		
III	E (N 90°)	44°	N→S	50	47	2350	(1945)	(2350)
	SE (N 135°)	0°	–	–	–	–	N→S	N→S
	SSE (N 157,5°)	23°	S→N	81	5	405		
	NE (N 45°)	56°	N→S	46	18	828		
IV	E (N 90°)	9°	N→S	15	47	705	(2152)	(1647)
	SE (N 135°)	35°	S→N	106	30	3180	S→N	S→N
	SSE (N 157,5°)	58°	S→N	101	5	505		
	NE (N 45°)	40°	N→S	49	31	1519		
V	E (N 90°)	7°	S→N	12	35	420	(1978)	(1211)
	SE (N 135°)	51°	S→N	110	21	2310	S→N	S→N
	SSE (N 157,5°)	74°	S→N	59	13	767		
	NE (N 45°)	46°	N→S	50	31	1550		
VI	E (N 90°)	0°	–	–	35	–	(1816)	(802)
	SE (N 135°)	45°	S→N	112	21	2352	S→N	S→N
	SSE (N 157,5°)	68°	S→N	78	13	1014		
	NE (N 45°)	40°	N→S	49	31	1519		
VII	E (N 90°)	7°	S→N	12	35	420	(1978)	(1211)
	SE (N 135°)	51°	S→N	110	21	2310	S→N	S→N
	SSE (N 157,5°)	74°	S→N	59	13	767		
	NE (N 45°)	58°	N→S	45	31	1395		
VIII	E (N 90°)	13°	N→S	22	35	770	(1350)	(2)
	SE (N 135°)	33°	S→N	103	21	2163	S→N	N→S
	SSE (N 157,5°)	56°	S→N	104	13	1352		
	NE (N 45°)	58°	N→S	45	31	1395		
IX	E (N 90°)	13°	N→S	22	35	770	(2165)	(2165)
	SE (N 135°)	NI	–	–	–	–	N→S	N→S
	SSE (N 157,5°)	NI	–	–	–	–		
	NE (N 45°)	NI	–	–	–	–		
X	E (N 90°)	13°	N→S	22	35	770	(1393)	(1393)
	SE (N 135°)	33°	S→N	103	21	2163	S→N	S→N
	SSE (N 157,5°)	NI	–	–	–	–		

*Normalized height of the wave in deep water per unit length; NE and E (1,0m), and SE and SSE (1,5m).

NI – No incidence of waves, or waves of negligible height (See Figures 3 and 4 for the wave-fronts arising from the SE/SSE and E/NE, respectively).

TABLE II

Potential intensity of the net littoral drift for the coastal Segments X through XIV, calculated per unit area, with and without the influence of the SSE waves (See Figs. 5 and 6).

Segments	Origin of the Wave-Front	Angle of Incidence (α)	Component of the Drift towards the North or South	Intensity of the Littoral Drift per Unit Area sen $\alpha . \cos\alpha . H^{2*}$ ($\times$100)	Percentage of the Annual Annual Incidence of the Waves	Drift Intensity Multiplied by the Percentage of the Annual Incidence	Intensity of the Dominant Drift Minus the Secondary Drift (Net Littoral Drift) With the Influence of the Waves from the SSE	Intensity of the Dominant Drift Minus the Secondary Drift (Net Littoral Drift) Without the Influence of the Waves from the SSE
	NE (N 45°)	58°	N→S	45	31	1395		
XI	E (N 90°)	13°	N→S	22	35	770	(2165)	(2165)
	SE (N 135°)	NI	–	–	–	–	N→S	N→S
	SSE (N 157,5°)	NI	–	–	–	–		
	NE (N 45°)	84°	N→S	10	31	310		
XII	E (N 90°)	NI	–	–	–	–	(310)	(310)
	SE (N 135°)	NI	–	–	–	–	N→S	N→S
	SSE (N 157,5°)	0°	–	–	–	–		
	NE (N 45°)	NI	–	–	–	–		
XIII	E (N 90°)	NI	–	–	–	–	–	–
	SE (N 135°)	0°	–	–	–	–		
	SSE (N 157,5°)	0°	–	–	–	–		
	NE (N 45°)	NI	–		–	–		
XIV	E (N 90°)	28°	N→S	41	35	1435	(1731)	(236)
	SE (N 135°)	23°	S→N	81	21	1701	S→N	S→N
	SSE (N 157,5°)	45°	S→N	112	13	1456		

*Normalized height of the wave in deep water per unit length; NE and E (1,0m), and SE and SSE (1,5m).

NI – No incidence of waves, or waves of negligible height (See Figures 3 and 4 for the wave-fronts arising from the SE/SSE and E/NE, respectively).

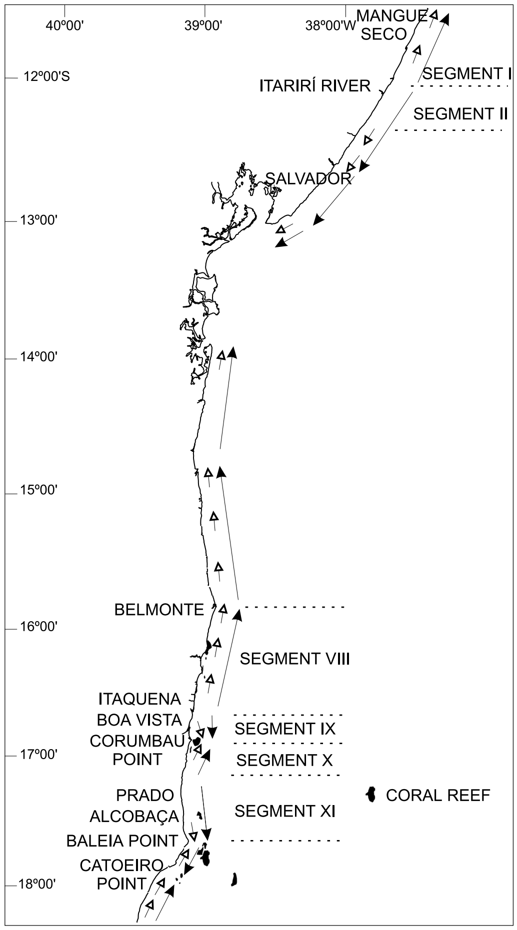

Fig. 6 – Comparison of net littoral drift directions computed in this work for the State of Bahia (large arrows) with these provided by the available geomorphic indicators (small errors). Also shown are some of coastal segments discussed in the text.

the littoral drift induced by the NE waves.

According to the definition used herein for the net littoral drift direction, it can be ascertained that the segment VIII represents the only coastal stretch of Bahia to be susceptible to a decrease of wavefronts from the SSE during the episodes involving the meteorological phenomenon El Niño (Table I, Fig. 5D). Despite the limitations previously mentioned, the resultant model of sediment transport for the studied stretches of the coast of Bahia is capable to confirm those general patterns of sediment dispersion provided by the geomorphic indicators.

Besides the control by the atmospheric circulation system, the patterns of sediment dispersion alongside the coast of Bahia are also regulated by the general orientation of the coastline. In fact, the configuration assumed by the coastline of Bahia can be considered a legacy from the Mesozoic, when the South America and Africa split apart forming two separated continents (Bittencourt *et al.* 1999). As a result, alongside the coastal stretch from Salvador up to Mangue Seco, it is observed a remarkable parallelism between the coastline and an existing fault line in the continental margin (Fig. 7). Similarly, from Belmonte towards the south, it is quite evident the southwestward deflection of the littoral, following the overall orientation shown by two faults systems occurring in this region (Fig. 7). In the proximity of the mouth of the ItariríRiver, a little change in the coastline direction follows the northward deflection of a fault line in the continental margin (Fig. 7). This fact is responsible for the divergence of the littoral drift direction occurring in this area (Fig. 6). Since in the coastal stretch southwest of the ItariríRiver's mouth the waves from the SE arrive almost parallel to the shore (segment II, Fig. 5C), they generate a weak littoral drift in this area. As a result, the littoral drift produced by the waves coming from the E and NE, even though being shorter than those from the SE, provide a remarkable influence on this region (segment II, Table I). On the other hand, in the coastal stretch located northeast of the ItariríRiver's mouth, the littoral presents a very little deflection towards the north. This small deviation of the coastline, however, allows the waves arising from the southeast to form an expressive angle with the shore (segment I, Fig. 5C). Consequently, these waves perform a pivotal role in the delineation of the net littoral drift direction in this area (segment I, Table I).

Another important factor involved in the control of the patterns of sediment dispersion alongside the coast of the State of Bahia is related to the pres-

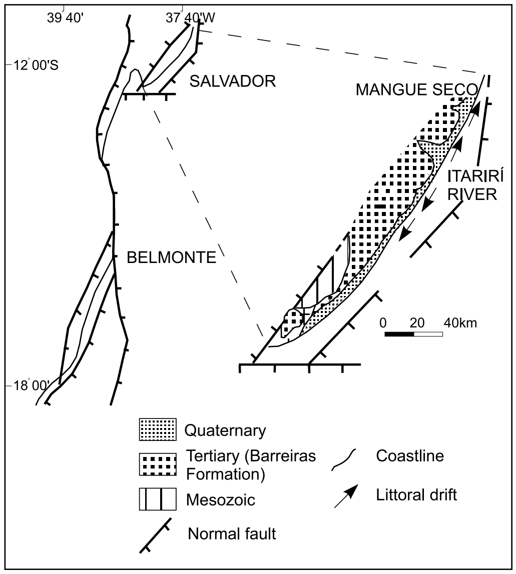

Fig. 7 - Simplified tectonic framework of the marginal basins of the State of Bahia (modified from Campos *et al.* 1974). The figure also shows a map based upon Campos *et al.* (1974), and Martin *et al.* (1980).

ence of the coral reefs of the Abrolhos and the Corumbaú Point (Fig. 1). Clearly, these coral reefs provide an important protection against the waves acting upon the coastal stretches facing to them (Figs. 3 and 4) (Dominguez 1987). In fact, the presence of these coral reefs explains the dominance of a littoral drift induced by weak waves from the E and NE, in nearly the whole coastal extension between Itaquena and the Baleia Point. These drift reversals originate the two divergence zones of littoral drift occurring in this region (Fig. 6), and are a direct consequence of the protection provided by the reefs inhibiting the strong waves from the SE and SSE from reaching the shore (Figs. 3 and 6).

The patterns of sediment dispersion discussed above favored the formation of the different kinds of accumulation forms occurring alongside the coast of Bahia. Also, these patterns are responsible for the existence of large extensions of the shoreline under erosion. Amongst the several kinds of accumulation forms, it stands out the cuspate accumulation form occurring at Caravelas (Figs. 2 and 8A) and Belmonte (Figs. 2 and 8B). In the case of Caravelas, the cuspate form is related to the convergent pattern of the littoral drift occurring in this area (Fig. 6). In the case of Belmonte, however, the accumulation process results from the groin effect induced by the Jequitinhonha River, which obstructs the sediment flux coming from the south (Dominguez 1987, Dominguez *et al.* 1987) (Fig. 6). Another significant accumulation form is represented by the Mangue Seco spit, showing an extension of approximately 15 km long (Figs. 6 and 8C). This accumulation form is located downdrift of an abrupt change in shoreline orientation, which inflects landward. This landward inflection of the shoreline causes a decrease in longshore transport rates, favoring sediment deposition and, therefore, allowing the formation of a spit, according to the mechanism discussed in Zenkovitch (1967).

Coastal stretches showing severe erosion are found between the Corumbaú Point and Prado, and just above Boa Vista, with extensions of approximately 40 km and 10 km long, respectively. In both sectors, active sea cliffs are present in the Barreiras Formation (Figs. 6 and 8D). The existence of these cliffs is correlated to the longshore drift divergences occurring in these regions, that are in fact, places where the sediment budget is negative (Fig. 6). In the proximity of the mouth of the ItariríRiver, another important longshore drift divergence is present. As a consequence, during the last 5.000 years the shoreline has prograded just a few tens of meters.

Because of the overall stability observed in the South Atlantic high-pressure cell, the trade winds generated in this cell are expected to show a remarkable persistence during the Quaternary (Dominguez *et al.* 1992). Consequently, these authors concluded to be legitimate to expect that the patterns of sediment dispersion alongside the east-northeastern coast of Brazil, to be also highly persistent. Furthermore, using paleogeographic reconstructions carried out in different Quaternary coastal plains

Fig. 8 – (A) Cuspate accumulation form in the region of Caravelas (Also see figure 2). (B) Cuspate accumulation form in the region of Belmonte (Also see figure 2). (C) Mangue Seco spit (Also see figure 6). (D) Active sea cliffs in sediments of Barreiras Formation located on the north of Corumbáu Point (Also see figure 2).

alongside the Brazilian east-northeastern coast, Dominguez *et al.* (1992) showed that in general, such patterns remained the same since the Pleistocene. Regarding the coast of the State of Bahia, significant examples are provided by the coastal plain regions of Caravelas (Fig. 9A), the Apaga-Fogo and Pedra points (Fig. 9B), and the Guaibim beach-ridge plain (Fig. 9C). In these regions, it can be clearly seen that the geometry of the pleistocene beach-ridge deposits exhibit a remarkable correspondence with the holocene beach-ridges, and the present-day coastline. Nevertheless, in a scale of tens to hundreds of years, relevant disruptions in the longshore sediment dispersal patterns may take place. For instance, important truncations in the beach-ridge alignments at the Caravelas and Jequitinhonha River coastal plains (Fig. 2), testify the existence of erosion periods intercalated in a gen-

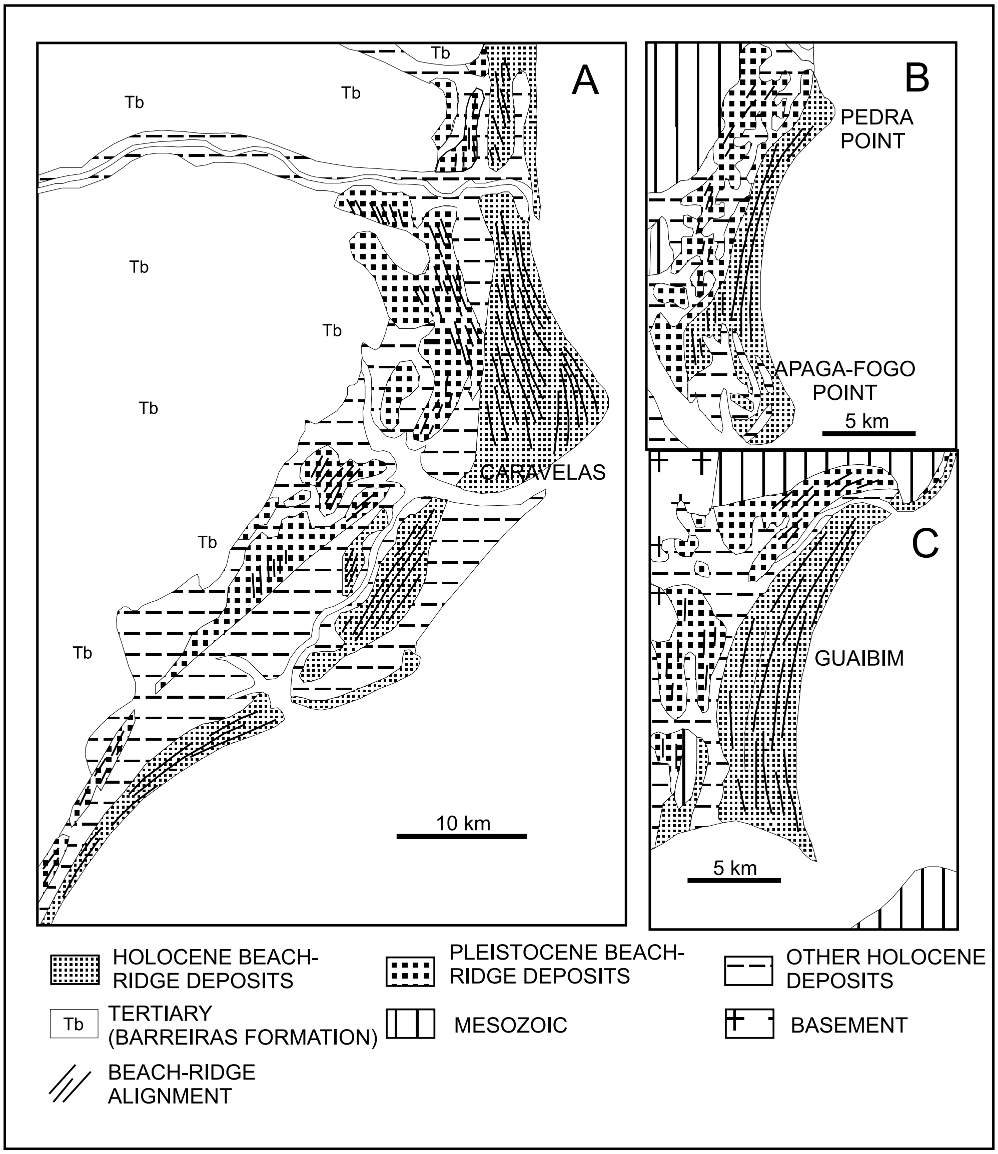

Fig. 9 – Simplified geological maps of some coastal plains alongside the coast of the State of Bahia illustrating the persistence of the sediment dispersion and accumulation patterns during the Quaternary Period (modified from Martin *et al.* 1980).

eral process of progradation. In the coastal plain of the Doce River (approximately 100 km south of the Caravelas coastal plain), the presence of similar beach-ridge truncations was correlated to periods of erosion resulting from the inversion of longshore transport direction (Martin & Suguio, 1992). These inversions have been suggested by some authors to be a result of changes in atmospheric circulation induced by El-Niño- like phenomena (Martin *et al.* 1993).

ACKNOWLEDGEMENTS

A.C.S.P. Bittencourt and J.M.L. Dominguez thank CNPq (Brazilian National Council of Research) for their fellowship. This research work was sponsored by the CNPq (Process no. 522948/96-0), and by the CNPq/IRD (Orstom), international convention, Project AIMPACT.

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