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

Bittencourt, Abílio C.S.P.; Martin, Luois; Dominguez, José M.L.; Silva, Iracema R.; Sousa, Daiana L.
A significant longshore transport divergence zone at the Northeastern Brazilian coast: implications on coastal Quaternary evolution
Anais da Academia Brasileira de Ciências, vol. 74, núm. 3, september, 2002, pp. 505-518
Academia Brasileira de Ciências
Rio de Janeiro, Brasil

Anais da Academia Brasileira de Ciências (2002) 74(3): 505-518
(Annals of the Brazilian Academy of Sciences)
ISSN 0001-3765
www.scielo.br/aabc

A significant longshore transport divergence zone at the Northeastern Brazilian coast: implications on coastal Quaternary evolution

ABÍLIO C.S.P. BITTENCOURT[1], LOUIS MARTIN[2], JOSÉ M.L. DOMINGUEZ[1], IRACEMA R. SILVA[3] and DAIANA L. SOUSA[4]

[1]Laboratório de Estudos Costeiros, CPGG, Instituto de Geociências/UFBA, 40210-340 Salvador, BA, Brasil
[2]CNPq/IRD (ORSTOM), International Convention, Project AIMPACT, 40210-340 Salvador, BA, Brasil
[3]Curso de Pós-Graduação em Geologia/Instituto de Geociências/UFBA, 40210-340 Salvador, BA, Brasil
[4]Curso de Graduação em Geologia/ Instituto de Geociências/UFBA, 40210-340 Salvador, BA, Brasil

Manuscript received on May 29, 2001; accepted for publication on February 26, 2002;
contributed by LOUIS MARTIN*

ABSTRACT

By using the mean directions of the wave-fronts approaching the Brazilian northeastern coastal stretch comprised between the localities of Real river (Sergipe State) and Galinhos (Rio Grande do Norte State) – coincident with those of the main winds occurring in the area – and their periods, we have defined a wave climate model based on the construction of refraction diagrams. The resulting model of sediment transport, as obtained by numerical modelling from the refraction diagrams, taking into consideration the angle of approach and waves heights along the 10-m isobath, was capable of reproducing the patterns of sediment dispersion provided by geomorphic indicators of the longshore drift. All this coastal region, approximately 900 km in length, is characterized by a significant divergence zone in the direction of net longshore drift of sediments, the potential intensity of which increases considerably in value, in almost its entire length, continuously toward downdrift, which might explain the greater or lesser long term susceptibility to erosion, during the Quaternary, along the coastal stretch studied.

Key words: littoral drift, wave refraction, numerical modelling, coastal Quaternary evolution, Northeastern Brazilian coast.

INTRODUCTION

The Brazilian coastal stretch located between Real river and Galinhos, extends approximately 900 km (Fig. 1), and may be divided into three sectors with very distinct physiographic features (Dominguez 1995, Dominguez and Bittencourt 1996, Martin et al. 1998):

Sector I – From Real river to Coruripe point – Characterized by the existence of wide terraces with well-developed beach-ridges, from Holocene to Pleistocene ages, reaching some kilometers in width.

Sector II – From Coruripe point to Guaju – Characterized by weakly developed beach-ridge terraces. In this sector, the Holocene terraces have width averaging hundreds of meters, rarely reaching more than 1 km. The Pleistocene terraces are preserved only in the reentrances of the shoreline.

Sector III – From Guaju to Galinhos – In this sector

Correspondence to: Abilio C.S.P. Bittencourt
E-mail: abilio@cpgg.ufba.br
*Foreign Member of Academia Brasileira de Ciências

beach-ridge terraces are virtually absent. Extensive dune fields of Pleistocene (fixed by vegetation) and Holocene (still active) characterize this sector.

The entire coastal stretch is almost continuously bordered by tablelands 10 to 40 km in width and 10 to 100 m in height. Fossil sea cliffs in these tablelands mark the contact between the hinterland and the Quaternary plains. These tablelands are made up of poorly consolidated continental sediments of Miocene-Pliocene age (Barreiras Group – Mabesoone et al. 1972, Bigarella 1975). At several stretches within Sector II and, mainly in Sector III, the coastline exhibits active sea cliffs carved in these tablelands.

Dominguez (1995), Dominguez and Bittencourt (1996) and Martin et al. (1998), based on the knowledge of the Quaternary coastal evolution of the region, have qualitatively evaluated the susceptibility to erosion of this coastal stretch. They have shown that the present coastal erosion phenomenon is not related to a possible sea level rise in response to an overall increase in the earth's temperature. Instead, it is intrinsically related to the sediment budget in the coastal zone. As regards to the sediment budget, these authors have shown that these coastal sectors exhibit, since the Pleistocene, the following long term trends:

Sector I – tendency of progradation of the coastline, characterized by a positive sediment budget.

Sector II – tendency of equilibrium or incipient progradation, characterized by a null or slightly positive sediment budget.

Sector III – tendency of equilibrium or erosional retreat, characterized by a null or slightly negative sediment budget.

As the studied coastal stretch is entirely located within the trade winds belt, the waves generated by these winds, of extremely constant velocity and direction, exerts a strong influence on the coastal processes (Dominguez et al. 1992). Martin et al. (1998), based on a detailed analysis of the atmospheric circulation system, presented a conceptual model for the wave regime affecting the study area. From this model they concluded that (Fig. 1): a) from the boundary between Alagoas and Pernambuco states to the south limit of the area there is a net north to south longshore drift; b) from the boundary between Alagoas and Pernambuco states to Touros there is a net south to north longshore drift; c) from Touros to the extreme west of the area there is a net east to west longshore drift. There should be mentioned that such directions had already been previously conjectured by Silvester (1968) based on his study of the net longshore drift directions of sediment along the world's coastal regions. Martin et al. (1998) call attention to the fact that the divergence in the direction of the net longshore drift of sediments should make this coastal stretch very susceptible to erosion.

The continental shelf of the coastal stretch (Fig. 1) is relatively flat, presenting small irregularities, mainly in Sector I. In general, it has a greater width in front of Sector II, and is narrow in Sectors I and III, except at the northern portion of Sector III, where it becomes wider. The average height of the tides in this region increases gradually, from 1.8 m at Aracaju to 3.0 m at Macau, a village located at 53 km west of Galinhos (Fig. 1) (DHN 1999). The tides are semidiurnal.

The aim of the present work is to evaluate the role of the longshore drift of sediments on the coastal quaternary evolution, based on the construction of a Wave Climate Model for the study area.

WAVE CLIMATE MODEL

The direct wave measurements existing for the studied coastal stretch correspond to the short and non-coincident, and very scattered time series, thus making difficult to have a consistent view of the wave regime for the whole region (Bandeira and Salim 1995). Using classical techniques (CERC 1984), we have constructed wave refraction diagrams, which allowed us to produce a very generic wave climate model for the study area (Figs. 2 to 5). The bathymetric data used in the construction of these diagrams were extracted from nautical charts published

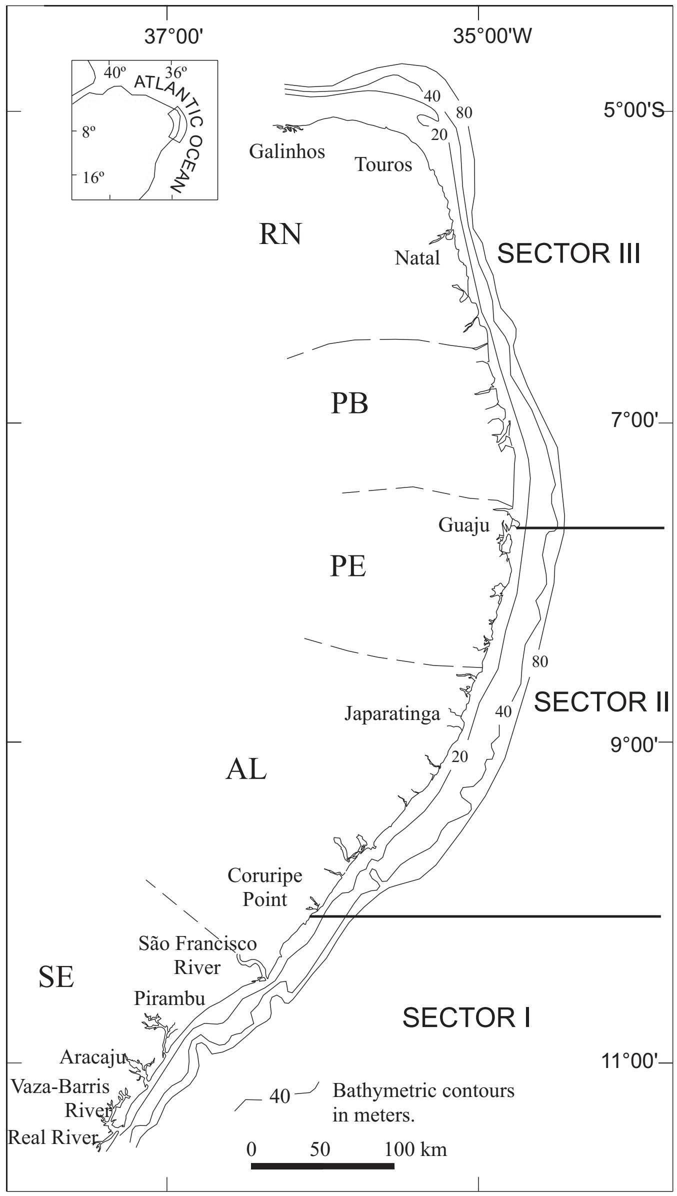

Fig. 1 – Physiographic features of the continental shelf of the Brazilian northeast region between Galinhos and Real river. Also shown the location of the different sectors discussed in the text. The following states are depicted in the figure: SE – Sergipe, AL – Alagoas, PE – Pernambuco, PB – Paraíba and RN – Rio Grande do Norte.

by the Brazilian Navy, at an approximate scale of 1:300,000. The waves were not propagated in waters depths less than 10 m, that is the limit for nautical charts. The following wave-front directions were considered for the refraction diagrams: NE (N45°), E (N90°), SE (N135°) and S (N180°). Such

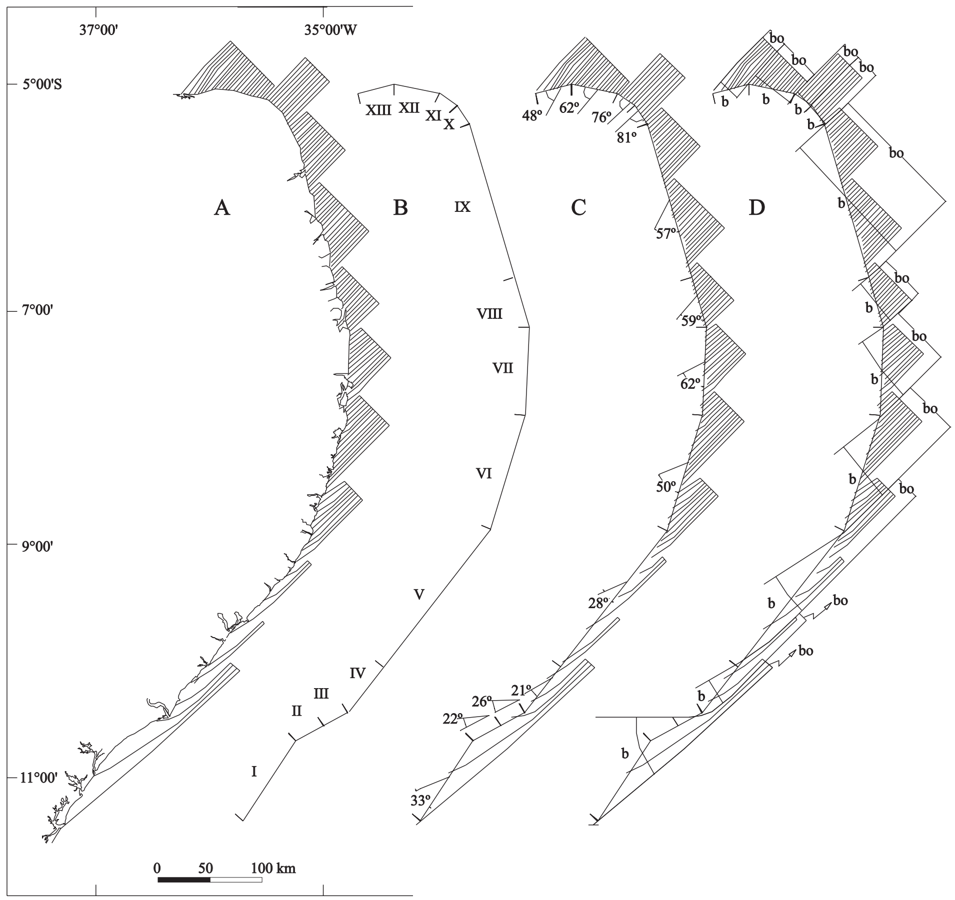

Fig. 2 – A – Refraction diagram for waves with a 5 sec period, arising from the NE (N45°). B – Different segments in which the coastline has been rectilinearized. C – Incidence angles formed by waves from NE in relation to the rectilinearized coastal segments. D – Measurements of b and b_o for estimating the height of waves along the rectilinearized coastal segments.

directions correspond to the main wind directions occurring along the studied coastal region (DHN 1993). We also considered the most significant periods and wave heights associated to these directions (US Navy 1978): period of 5 sec, and height of 1.0 m for the NE and E directions, and period of 6.5 sec and height of 1.5 m for the SE and S directions.

In general, it is observed that the NE (Fig. 2), E (Fig. 3) and SE (Fig. 4) wave-fronts practically reach the entire studied coastal stretch. The exception is a small part in the north area, at west of Calcanhar Cape, in relation to the SE (Fig. 4) waves. On the other hand, the S wave-front are not incident on the coastline from João Pessoa toward north (Fig. 5). The E waves practically do not refract, except in the region surrounding the mouth of the São Francisco river and to the west of the Calcanhar Cape (Fig. 3), where there are divergences of the wave-rays. The NE (Fig. 2), SE (Fig. 4) and S (Fig. 5) wave-fronts refract, with the observance that this process increases from south to north in relation to the SE (Fig. 4) and S (Fig. 5) directions and, inversely, from north to south, in relation to the NE (Fig. 2) direction.

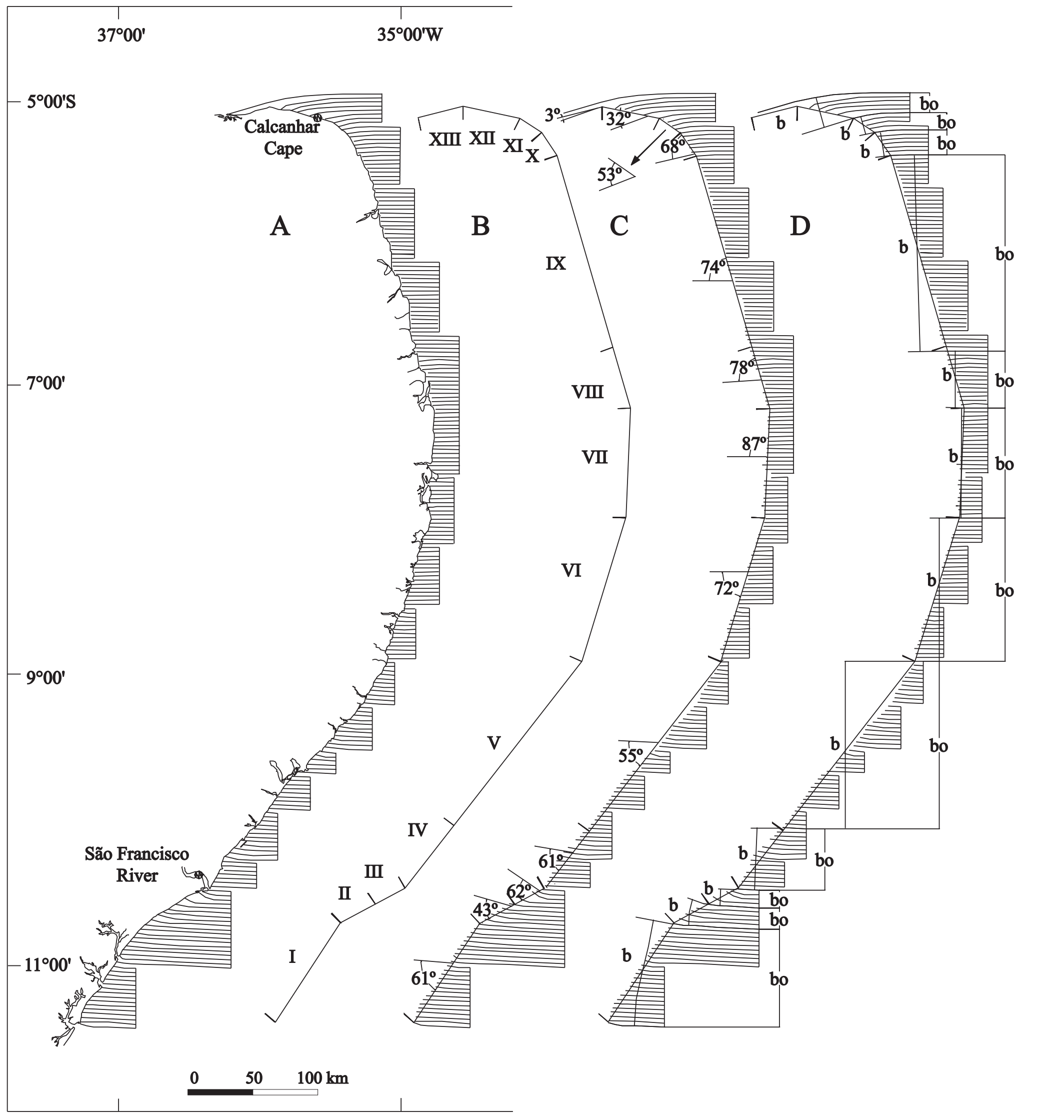

Fig. 3 – A – Refraction diagram for waves with a 5 sec period, arising from the E (N90°). B – Different segments in which the coastline has been rectilinearized. C – Incidence angles formed by waves from E in relation to the rectilinearized coastal segments. D – Measurements of b and b_o for estimating the height of waves along the rectilinearized coastal segments.

POTENTIAL INTENSITY AND DIRECTION OF THE NET LONGSHORE DRIFT

The potential intensity of the longshore drift of sediments was determined taking into account that: a) the wave energy is directly proportional to the square of its height (Davies 1972) and b) the intensity of the longshore drift is proportional to the angle with which the wave-front strikes the coastline (Zenkovitch 1967, Komar 1976, Kokot 1997), according to the function $y = \text{sen}\,a \cdot \cos a$ (Komar 1976). Thus, the potential intensity of the longshore drift of sediments, calculated per unit area and expressed in non-dimensional units, was given by the function $x = y \cdot H^2$, where H, in the present case, is the wave

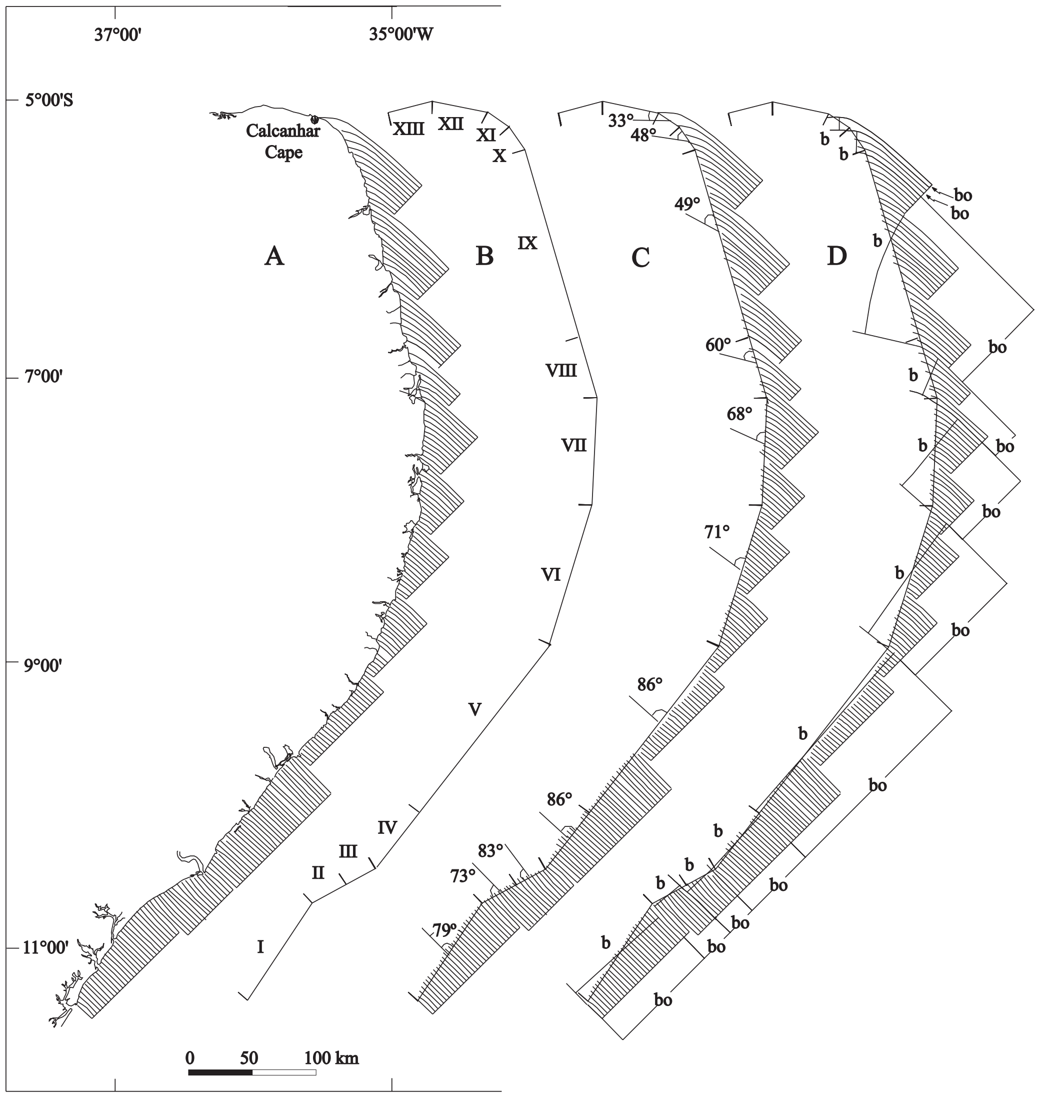

Fig. 4 – A – Refraction diagram for waves with a 6.5 sec period, arising from the SE (N135°). B – Different segments in which the coastline has been rectilinearized. C – Incidence angles formed by waves from SE in relation to the rectilinearized coastal segments. D – Measurements of b and b_o for estimating the height of waves along the rectilinearized coastal segments.

height along the 10 m isobath. The wave height was estimated using the equation $H=H_0(b/bo)^{1/2}$ (Bascom 1954), where the subscript zero designates deep water conditions, and b is the distance between two orthogonals to the wave-fronts. The studied coastline has been divided into 13 segments. Each of these segments has been approximated by a straight line according to the coastline orientation (Fig. 2). In some cases, as for example in the segments II and III, a same rectilinear stretch has been divided into two segments, due to the fact that it displayed two distinct patterns of distance between wave-rays along the coast (Figs. 3 and 5). The distances b and b_0 were measured between the orthogonal lim-

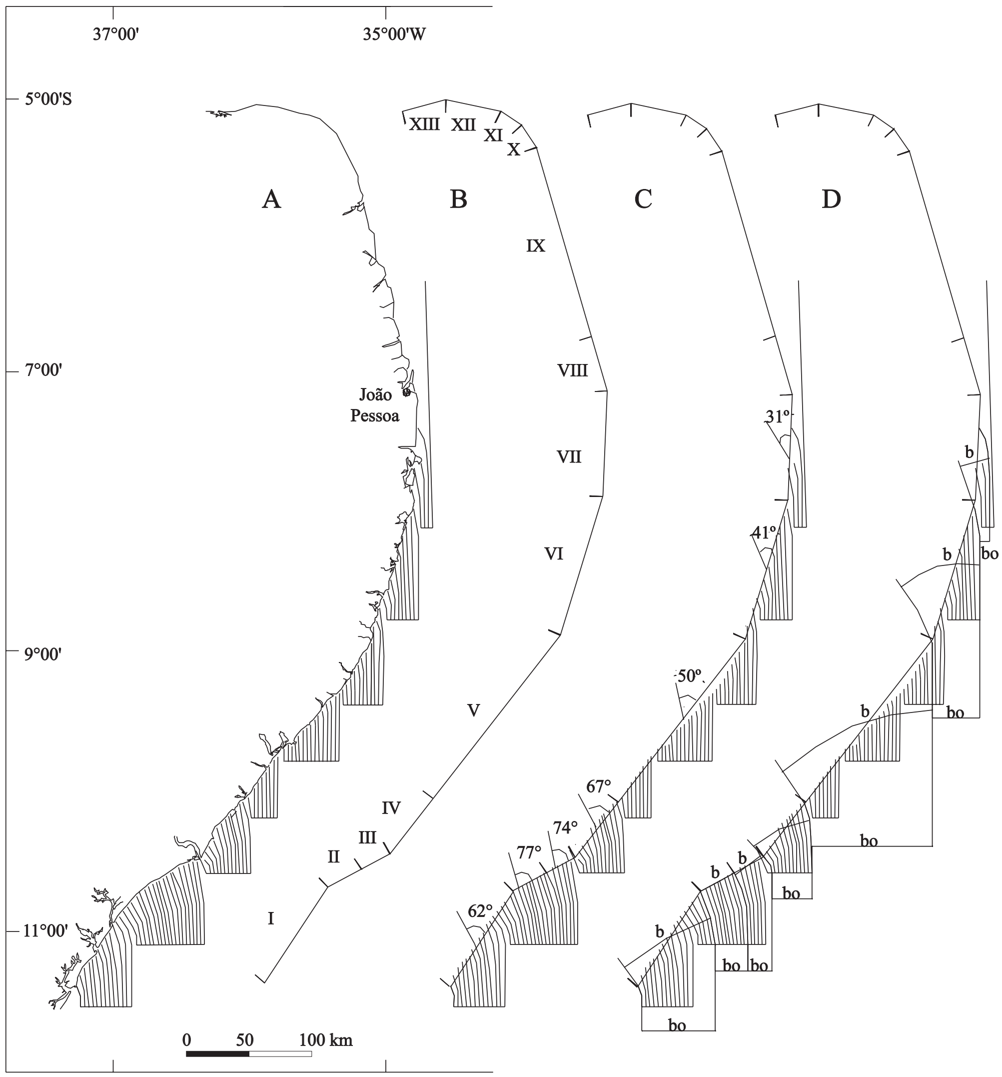

Fig. 5 – A – Refraction diagram for waves with a 6.5 sec period, arising from the S (N180°). B – Different segments in which the coastline has been rectilinearized. C – Incidence angles formed by waves from S in relation to the rectilinearized coastal segments. D – Measurements of b and b_o for estimating the height of waves along the rectilinearized coastal segments.

its of the beam of orthogonals incidental upon each segment, or, rarely, when this was not possible, encompassing contiguous segments (for example, segments I, II and III, Fig. 2). Thus, an average value of the wave height was obtained for the considered coastal stretch. The angle α between each segment and a given wave-front was that prevailing between the wave-rays incidental upon the segment, as measured directly in the refraction diagram (Figs. 2 to 5). Subsequently, the value obtained for the intensity of the drift was multiplied by the percentage of the annual frequency of the wind direction (DHN 1993) to which the considered wave-front is associated.

The values of potential intensity and direction obtained for the sediment longshore drift along the studied coastal stretch are shown on Table I, together with the direction and potential intensity of the net longshore drift. In the coastal stretches presenting seasonally opposite drift directions, the net longshore drift direction has been defined taking into account the predominant direction, given by the difference of intensities between opposite longshore drifts. For example, in segment I, the sum of the intensities of the north to south drifts was 1912, while the value obtained for the sum of the drift intensities in the opposite direction was 1605 (Table I). Thus, the net longshore drift direction obtained was north to south with a potential intensity in the value of 307 (Table I).

Figure 6 shows that the studied coastal region is characterized by presenting a significant divergence in the direction of the net sediments longshore drift, the nodal point of which is located in the neighborhood of Japaratinga, quite near the location foreseen by Martin et al. (1998). The geomorphic indicators along the coastline, as observed on various published maps and aerial photographs (e.g., direction of migration of sand spits) (Bittencourt et al. 1983, Barbosa et al. 1986a,b, Dominguez et al. 1990, MMA/UFRJ/FUJB/LAGET 1996) indicate a general pattern of sediment dispersion that are essentially similar to those computed in the present work. As for the potential intensity of the net longshore drift, one observes that it, from the nodal point, presents the following behavior. To the north, during almost the entirety of the coastal stretch, it increases continuously, from a value of 2052 (Segment VI) up to 4360 (Segment X), passing next to decrease, also continuously, up to a value of 794 (Segment XIII) (Fig. 6). To the south, the potential of the net longshore drift also increases continuously, from a value of 724 (Segment V) up to 3556 (Segment II), and next abruptly decrease to 307 (Segment I) (Fig. 6).

DISCUSSION AND CONCLUSIONS

The patterns of sediment dispersion defined in the present work confirms the conceptual model of Martin et al. (1998), identifying a remarkable divergence in the direction of the net longshore drift, with the nodal point near the locality of Japaratinga (Fig. 6). Such pattern is confirmed by the geomorphical indicators of the longshore drift. Most significant in it is the fact that the potential intensity of the net sediments longshore drift increases considerably in a continuous manner both northwards and southwards, from Japaratinga. This fact implies an increasing sediment deficit in the downdrift direction, a situation that can explain, as will be discussed below, the characterization made by Dominguez and Bittencourt (1996) and Martin et al. (1998) in relation to the susceptibility to erosion of the studied coastal stretch.

The characteristics pointed out by Dominguez (1995), Dominguez and Bittencourt (1996) and Martin et al. (1998) for sectors I, II and III, that, on a long term, they present, respectively, a tendency a) to progradation, b) to equilibrium or an incipient progradation, and c) to equilibrium or an erosional retreat, is related to the data of the present work as follows. Sector I presents a progradation trend not only because there discharges one of the largest rivers of the Brazilian coastline, the São Francisco river (Figs. 1 and 6), but also due to the fact that there is an abrupt variation in the potential intensity of the net longshore drift. In effect, near the locality of Pirambu (Fig. 6), it changes abruptly from a value of 3556 to 307 (Fig. 6), thus creating favourable conditions for deposition of the sediment load in transit. From the north limit of Sector I to Pirambu the intensity of the net longshore drift increases continuously in value, passing from 724 to 3556 (Fig. 6). This fact could imply a situation of increasing deficit of sediments to downdrift. The presence of the São Francisco river, however, prevent such deficit. To the southwest of its mouth, the river sediment discharge is responsible by this fact. From its mouth to northeast, there is a significant zone of progradation due to the groin effect produced by the river, blocking the sediment transit (Bittencourt et al. 1982). The fact that the beach-ridge terraces have very small expression in Sector II and are practically non-existent in Sector III might

TABLE I

Potential intensity of the net longshore drift for each rectilinearized coastal segment (see Figure 6)

Segment	Origin of the wave front	Wave height along the coastline (H)*	Angle of incidence (α)	Main longshore drift component
I	N45°	0.4	33°	N–S
	N90°	1.0	61°	N–S
	N135°	1.5	79°	S–N
	N180°	1.3	62°	S–N
II	N45°	0.4	22°	N–S
	N90°	0.9	43°	N–S
	N135°	1.5	73°	N–S
	N180°	1.4	77°	S–N
III	N45°	0.4	26°	N–S
	N90°	1.0	62°	N–S
	N135°	1.5	83°	N–S
	N180°	1.3	74°	S–N
IV	N45°	0.6	21°	N–S
	N90°	1.0	61°	N–S
	N135°	1.5	86°	S–N
	N180°	1.2	67°	S–N
V	N45°	0.8	28°	N–S
	N90°	1.0	55°	N–S
	N135°	1.5	86°	S–N
	N180°	1.3	50°	S–N
VI	N45°	1.0	50°	N–S
	N90°	1.0	72°	N–S
	N135°	1.5	71°	S–N
	N180°	1.2	41°	S–N
VII	N45°	1.0	62°	N–S
	N90°	1.0	87°	N–S
	N135°	1.4	68°	S–N
	N180°	0.9	34°	S–N
VIII	N45°	1.0	59°	N–S
	N90°	1.0	78°	S–N
	N135°	1.3	60°	S–N
	N180°	NI	–	–
IX	N45°	1.0	57°	N–S
	N90°	1.0	74°	S–N
	N135°	1.2	49°	S–N
	N180°	NI	–	–
X	N45°	1.0	81°	N–S
	N90°	1.0	68°	S–N
	N135°	1.2	48°	S–N
	N180°	NI	–	–
XI	N45°	1.0	76°	S–N
	N90°	1.0	53°	S–N
	N135°	0.8	33°	S–N
	N180°	NI	–	–
XII	N45°	1.0	62°	E–W
	N90°	0.8	32°	E–W
XIII	N45°	0.9	48°	E–W
	N90°	0.8	3°	E–W

TABLE I (continuation)

Segment	Intensity of the longshore drift per unit of area $X = \text{sen}\,\alpha \cdot \cos\alpha \cdot H^2 \times (100)$	Percentage of the 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 longshore drift)
I	7 38 42 69	18 47 30 5	126 1786 1260 345	N → S 307
II	5 38 63 42	18 47 30 5	90 1786 1890 210	N → S 3556
III	6 41 26 45	18 47 30 5	108 1927 780 225	N → S 2590
IV	13 42 15 53	18 47 30 5	234 1974 450 265	N → S 1493
V	23 46 15 81	5 42 45 8	115 1932 675 648	N → S 724
VI	44 29 66 65	5 42 45 8	220 1218 2970 520	S → N 2052
VII	37 5 72 34	5 42 45 8	185 210 3240 272	S → N 3117
VIII	42 20 68 –	5 42 45 8	210 840 3060 –	S → N 3690
IX	45 26 75 –	5 42 45 –	225 1092 3375 –	S → N 4242
X	16 35 66 –	5 42 45 –	80 1470 2970 –	S → N 4360
XI	23 47 29 –	5 42 45 –	115 1974 1305 –	S → N 3394
XII	41 27	13 87	533 2349	E → W 2882
XIII	41 3	13 87	533 261	E → W 794

NI – Non-incidence of waves. *H = Ho(bo/b)$^{1/2}$ · Ho = normalized height of the wave in deep water per unit length: N45° and N90° (1.0m), and N135° and N180° (1.5m). For the meaning of b and bo, see figure 2.

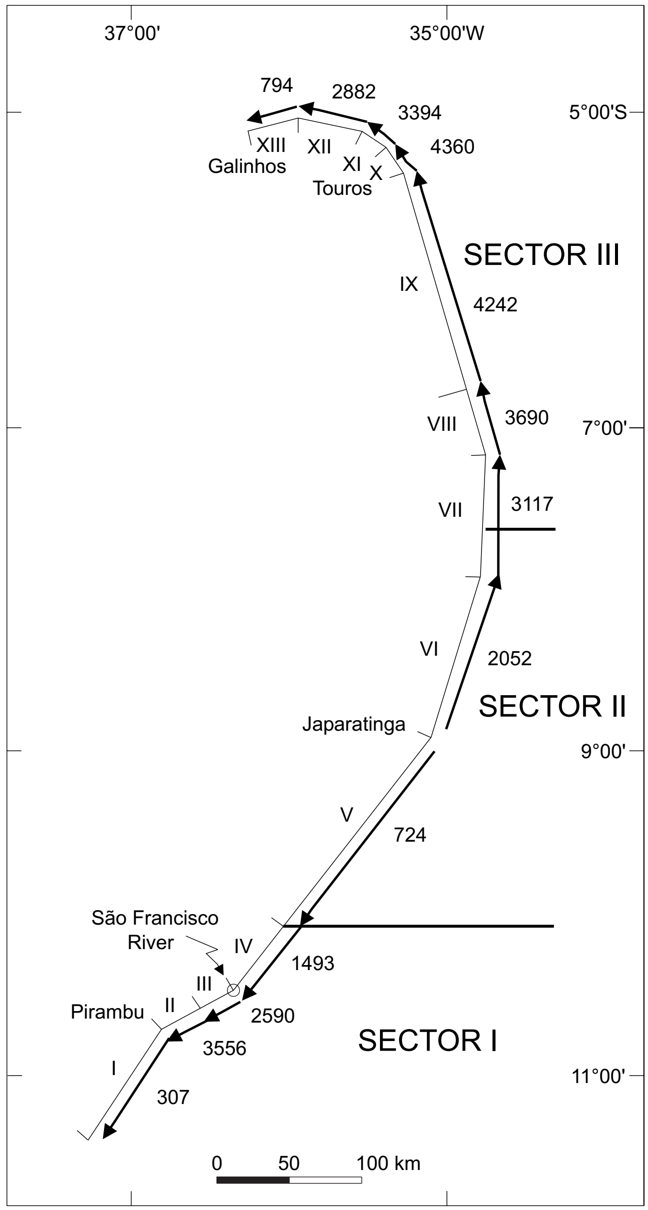

Fig. 6 – Directions of the net longshore drift computed in the present work for each rectilinearized segment. The numbers at the arrow side are the potential intensity of the net longshore drift (See Table I).

be related to the circumstance that both are coastal stretches from where the sediments are being continuously removed by the action of the longshore drift, without a significant contributions of the rivers to replace them (Dominguez and Bittencourt 1996). Such a removal is much more effective in Sector III than Sector in II for the following reasons. In Sector III, the intensity of the net longshore drift grows po-

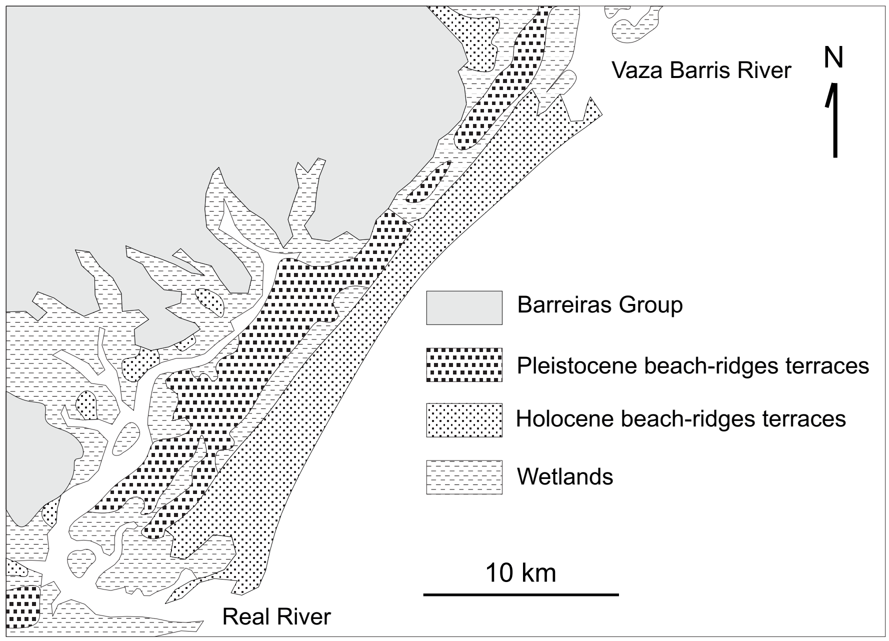

Fig. 7 – Simplified geological map of the coastal plain between Real and Vaza-Barris rivers illustrating the persistence of the sediment dispersion and accumulation patterns during the Quaternary Period (After Dominguez et al. 1992).

tentially in the downdrift direction in almost all its extension and always with values much higher than in Sector II (Fig. 6). Such behavior is observed from its south limit as far as the locality of Touros, where the intensity of the net longshore drift starts to decrease towards as far as Galinhos (Fig. 6). In Sector II, the intensity of the net longshore drift increases near their north and south extremes (Fig. 6). These facts can explain the existence of many more coastal stretches presenting active sea-cliffs in the Barreiras Group in Sector III than in Sector II. Another factor contributing to the fact that beach-ridge terraces are virtually absent in Sector III, is the development of large fields of dunes along this coastal stretch (Dominguez and Bittencourt 1996, Martin et al. 1998), fed by the beach face sediments. As for the long term tendency to erosional retreat or equilibrium in the coastal stretch between Touros and Galinhos, despite the intensity of the net longshore drift be decreasing considerably (Fig. 6), one should take into account the action of tides existing there. Actually, this coastal stretch, as already mentioned, presents the highest average tide heights of the region, with values comprised between 2.6 m in Natal, and 3.0 m near Galinhos (DHN 1999) (Fig. 1). Considering the different heights and percentages with which the waves strikes this coastal stretch (Segments XI, XII and XIII, Table I), one arrives at an average height of 0.84 cm for it. With such characteristics, the coastal stretch between Touros and Galinhos corresponds to a type Dominated by Tides, according to the classification of Davis and Hayes (1984). Actually, as shown by Testa and Bosence (1999), the intertidal region before Touros is strongly influenced by tidal currents, its bedforms being strongly controlled by unidirectional current from SE to NW, parallel to the coastline. Testa and Bosence (1999) also considered the bedforms to be controlled by currents induced by the SE to NW wind. Thus, it is likely that these unidirectional currents, parallel to the coastline and generated by the action of the tides and winds, have prevented the accumulation of sediments during the Quaternary between Touros and Galinhos.

Because of the remarkable stability observed in the high pressure cell of the South Atlantic, trade winds generated in this cell are expected to show a remarkable persistence during the Quaternary (Dominguez et al. 1992). Consequently, these authors conclude to be logical to expect that the patterns of sediment dispersion along the coastal stretch analyzed herein have maintained themselves also persistent during the Quaternary. In this sense, using the paleogeographic reconstructions obtained in different coastal plains along the Brazilian East-Northeast coast, Dominguez et al. (1992) have shown that, in general, such patterns remained the same since the Pleistocene. In relation to the studied coastal stretch a significant example may be observed in the coastal plain of beach-ridges terraces between the Real and Vaza-Barris rivers, in Sector I (Figs. 1 and 7). In this region, there may be clearly seen that the geometry of the Pleistocene beach-ridge terraces display a remarkable correspondence with those of Holocene beach-ridges terraces and with the present coastline. As considered by Dominguez et al. (1992), although other regions of the world present evidences of this persistence in the dispersion patterns (e.g. Cape Kennedy, NE of Florida, delta of the Apalachicola river, NW of Florida), this phenomenon is accentuated along Brazil's East-Northeast coastline because of its location in relation to the trade winds belt.

Finally, it should be emphasized that there are other coastal regions in the world characterized by large zones of divergence in the direction of the net longshore drift of sediments, such as the south coastline of Africa, east of the United States and west of Australia, for example (Silvester 1968). However, as far as we know, the tendency to a potential intensity of the net longshore drift of sediments, in a zone of divergence with such a dimension (900 km), increasing in almost its entire extension continuously in value toward downdrift, seems to us to be an unique case documented in the literature.

ACKNOWLEDGMENTS

A.C.S.P. Bittencourt, J.M.L. Dominguez and D.L. Sousa thank CNPq (Brazilian National Research Council), the first two for their Research Productivity Fellowship, and the third for his Scientific Initiation Scholarship. This research was financed by CNPq (Process no 521185-95-5) and by the International Convention CNPq/IRD (Orstom), Project AIMPACT.

RESUMO

Utilizando-se as direções médias das principais frentes-de-onda que se aproximam do trecho costeiro do nordeste brasileiro compreendido entre as localidades de Rio Real (Sergipe) e Galinhos (Rio Grande do Norte) – coincidentes com aquelas dos principais ventos que ocorrem na área – e de seus períodos, nós definimos um modelo de clima de ondas baseado na construção de diagramas de refração. O modelo resultante de transporte de sedimentos, obtido por modelagem numérica feita a partir dos diagramas de refração, considerando o ângulo de aproximação e a altura das ondas ao longo da isóbata de 10m, foi capaz de reproduzir os padrões de dispersão de sedimentos fornecidos pelos indicadores geomórficos de deriva litorânea. Toda essa região costeira, com cerca de 900km de extensão, caracteriza-se por se constituir em uma grande zona de divergência no sentido da deriva litorânea efetiva dos sedimentos, cuja intensidade potencial aumenta consideravelmente de valor, por quase toda a sua extensão, de uma maneira contínua, no sentido de sotamar. Este fato implica em um défict crescente de sedimentos no sentido de sotamar, o que pode explicar a maior ou menor suscetibilidade, de longa duração, para a erosão ao longo do trecho costeiro aqui estudado, durante o Quaternário.

Palavras-chave: deriva litorânea, refração de onda, modelagem numérica, evolução do Quaternário costeiro, costa do Nordeste brasileiro.

REFERENCES

Bandeira JV and Salim LH. 1995. Relato Sucinto sobre o Conhecimento das ondas na Costa Brasileira: uma contribuição ao 1° Seminário sobre as ondas e marés. Arraial do Cabo – RJ. 1° Seminário sobre ondas e marés. Instituto de Estudos do Mar Almirante Paulo Moreira – Ministério da Marinha, p. 31-33.

Barbosa LM, Bittencourt ACSP, Dominguez JML and Martin L. 1986a. The Quaternary coastal deposits of the State of Alagoas: influence of the relative sea-level changes. In: J. Rabassa (Ed.), Quaternary of South America and Antarctica Peninsula, Vol. 4. Balkema, Rotterdam, p. 269-290.

Barbosa LM, Bittencourt ACSP, Dominguez JML and Martin L. 1986b. Mapa Geológico do Quaternário Costeiro do Estado de Alagoas (jointly published with the Mapa Geológico do Estado de Alagoas, 1:250.000). DNPM. Série Mapas e Cartas de Síntese, 2, Seção Geológica N^{o} 2, Recife, Brazil.

Bascom WJ. 1954. The control of stream outlets by wave refraction. J Geol 62: 600-605.

Bigarella JJ. 1975. The Barreiras Group in northeastern Brazil. An Acad Bras Cienc 47: 365-393.

Bittencourt ACSP, Dominguez JML, Martin L and Ferreira YA. 1982. Dados preliminares sobre a evolução do delta do Rio São Francisco (SE/AL) durante o Quaternário: influência das variações do nível do mar. In: IV Simpósio do Quaternário. Rio de Janeiro, Brazil, p. 49-68.

Bittencourt ACSP, Martin L, Dominguez JML and Ferreira YA. 1983. Mapa Geológico do Quaternário Costeiro do Estado de Sergipe (jointly published with the Mapa Geológico do Estado de Sergipe, 1:250.000). DNPM, Brazil.

CERC (Coastal Engineering Research Center). 1984. Shore Protection Manual. U.S. Army Corps of Engineers. Washington, D.C. V. I, 597p.; V. II, 603p.

Davies JL. 1972. Geographical variation in coastal development. Longman Inc New York, 204p.

Davis RA and Hayes MO. 1984. What is a wave dominated coast? Mar Geol 60: 313-329.

DHN (Diretoria de Hidrogafia e Navegação). 1993. Atlas de Cartas-Piloto. Oceano Atlântico, de Trindade ao Rio da Prata, 13p.

DHN (Diretoria de Hidrogafia e Navegação). 1999. Tábuas das Marés, 194p.

Dominguez JML. 1995. Shoreline erosion in NE Brazil: a coastal evolution approach to assess short and long term causes. In: 1st SEPM Congress on Sedimentary Geology. Florida, Congress Program and Abstracts: 47.

Dominguez JML and Bittencourt ACSP. 1996. Regional Assessment of Long-term Trends of Coastal Erosion in Northeastern Brazil. An Acad Bras Cienc 68: 355-371.

Dominguez JML, Bittencourt ACSP, Leão ZMAN and Azevedo AEG. 1990. Geologia do Quaternário Costeiro do Estado de Pernambuco. Rev Bras Geocienc 20: 208-215.

Dominguez JML, Bittencourt ACSP and Martin L. 1992. Controls on Quaternary coastal evolution of the east-northeastern coast of Brazill: roles of sea-levels history, trade winds and climate. Sed Geol 80: 213-232.

Kokot RR. 1997. Littoral drift, evolution and management in Punta Médanos, Argentina. J Coastal Res 13: 192-197.

Komar PD. 1976. Beach processes and sedimentation. Prentice Hall, New Jersey, 429p.

Mabesoone JM, Campos e Silva A and Beurlen K. 1972. Estratigrafia e origem do Grupo Barreiras em Pernambuco, Paraíba e Rio Grande do Norte. Rev Bras Geocienc 2: 173-188.

Martin L, Dominguez JML and Bittencourt ACSP. 1998. Climatic control of coastal erosion during a sea-level fall episode. An Acad Bras Cienc 70: 249-266.

MMA/UFRJ/FUJB/LAGET. 1996. Macrodiagnóstico da Zona Costeira do Brasil na Escala da União. Brasília: Programa Nacional do Meio Ambiente, 280p.

Silvester R. 1968. Sediment transport long-term net movement. In: The Encyclopedia of Geomorphology, (Ed.) R. W. Fairbridge. Reinhold Book Corp. p. 958-989.

Testa V and Bosence DWJ. 1999. Physical and biological controls on the formation of carbonate and siliciclastic bedforms on the north-east Brazilian shelf. Sed 46: 279-301.

US Navy. 1978. Marine Climatic Atlas of the World, V. IV, South Atlantic Ocean. Washington DC 325p.

Zenkovitch VP. 1967. Processes of Coastal development. Oliver & Boyd, London, 738p.