Pole 1

LOUIS MARTIN
ORSTOM, France & Observatório Nacional, Rio de Janeiro, Brazil
JOSÉ M.L.DOMINGUEZ
Universidade Federal da Bahia, Salvador, Brazil
KENITIRO SUGUÍO
Universidade de São Paulo, Brazil

7

Consequence of relative sea-level changes during the Quaternary on sandy coastal sedimentation: Examples from Brazil

ABSTRACT

Wave energy, tidal range and river loads, for example, have been considered as the most important factors in the classical models of coastal sedimentation. However, the role played by relative sea-level changes has never been considered. Probably, this is due to the fact that the models have been proposed by authors from Northern Hemisphere countries (United States and Europe), where most commonly the present sea-level is the highest during the Holocene time. This is not the case of Brazil, where the most part of the coast was submerged until 5,100 years BP followed by emergence up today, abstracting two quick oscillations. Obviously, the coastal dynamics could not be the same during relative sea-level rise or sea-level drop. The equilibrium profile of a sandy coast will be destroyed with sea-level change and its restoration will be accompanied by transfer of sands, from backshore and adjacent land areas to foreshore during sea-level rise and from foreshore to backshore during sea-level drop. During submergence periods (relative sea-level rise), barrier-islands/lagoonal systems are dominant and the rivers could reach protected areas, as lagoons and estuaries, to build deltas. On the other hand, during emergence (relative sea-level drop) large amounts of sands will be deposited as beach-ridge plains and lagoons and estuaries will be exsiccated.

Paleogeographic reconstructions supported by numerous radiocarbon datings allowed us to recognize the essential role played by relative sea-level changes, associated with longshore drift of sediments and paleoclimatic fluctuations, in the formation of the coastal plains in Brazil.

RESUMO

Energia das ondas, amplitude das marés e carga fluvial, por

exemplo, têm sido considerados como os fatores mais importantes nos modelos clássicos de sedimentação costeira. Entretanto, o papel das variações do nível relativo do mar nunca têm sido considerado. Provavelmente, este fato ocorre porque os modelos foram propostos por autores de países do Hemisfério Norte (Estados Unidos e Europa), onde mais comumente o atual nível do mar é o mais alto do Holoceno. Este não é o caso do Brasil, onde a maior parte da costa foi submetida à submersão até cerca de 5.100 anos A.P, seguida de emersão até hoje, abstraindo-se duas pequenas oscilações. Obviamente, a dinâmica costeira não poderia ser a mesma durante a subida ou descida do nível relativo do mar. O perfil de equilíbrio é destruido pela variação do nível relativo do mar e a sua restauração será acompanhada pela transferência de areia, de pós-praia e áreas continentais adjacentes para a antepraia durante a subida do nível do mar e da antepraia para a pós-praia durante a descida do nível do mar. Durante períodos de submersão (subida do nível relativo do mar) predominam sistemas de ilhas-barreiras/lagunas e os rios atingiriam áreas protegidas, como lagunas e estuários, para construir deltas. Por outro lado, durante a emersão (descida do nível relativo do mar) grandes quantidades de areias serão depositadas como planícies de cristas praias e as lagunas e estuários serão ressecados.

Reconstruções paleogeográficas suportadas por numerosas datações ao radiocarbono permitiram-nos reconhecer o papel essencial desempenhado pelas mudanças do nível relativo do mar, associadas com a deriva litoranea de sedimentos e flutuações paleoclimáticas, na formação das planícies costeiras brasileiras.

INTRODUCTION

1 ROLE PLAYED BY RELATIVE SEA-LEVEL FLUCTUATION ON COASTAL SANDY SEDIMENTATION

According to Bruun (1962), once established the equilibrium profile in the coastal zone, following sea-level rise will disturb this equilibrium which will be re-established throughout its landward migration. In consequence, beach prism will be eroded and its sediments will be transported and deposited on foreshore. This process will provoke an elevation of the foreshore bottom in equal magnitude to sea-level rise, so water depth will be kept constant (Figure 1a).

Field and laboratory experiments accomplished by several authors (Schwartz, 1965, 1967 and Dubois, 1976, 1977) ratified the Bruun (1962) hypothesis. Although this rule has been developed only for inverse situation, that is, relative sea-level rise, the equilibrium destroyed in coastal sedimentation dynamics during sea-level drop must also be restored (Figure 1b). In fact, relative sea-level drop, decreasing water depth,

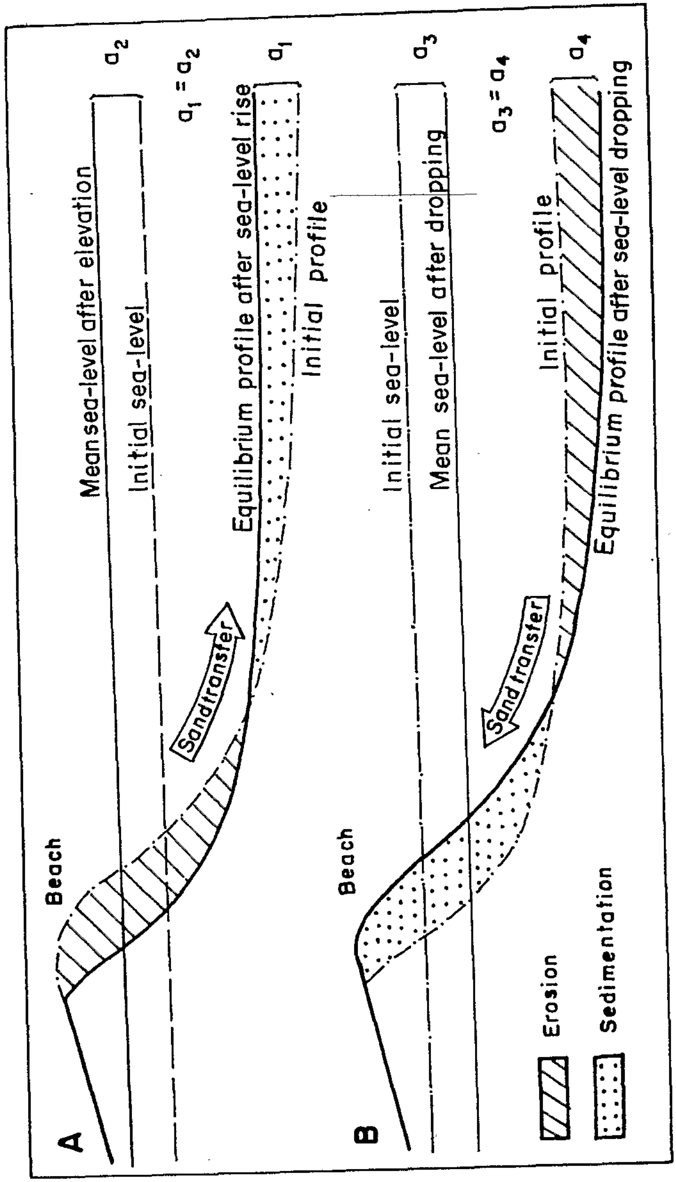

Figure 1. a) Behaviour of littoral zone equilibrium profile as a function of sea-level rise (Modified from Bruun, 1962); b) Behaviour of littoral zone equilibrium profile as a function of sea-level drop (Dominguez, 1982).

will produce desequilibrium in the profile, which will become more aggraded. In consequence, wave will move landward the unconsolidated foreshore sediments, accumulating them in the beach prism and then propitiating coastal progradation. This transference will stop when previously existing water depth is attained. Comparatively, this process is analogous to that when storm beach profile is restored by sediment transfer from foreshore to beach prism in a swell profile, as largely recorded in the literature (Davies, 1972; King, 1972; Komar, 1973, 1976; Swift, 1976). Analogously, this mechanism can be perfectly observed during a monthly tide cycle. During tides, corresponding to a "little transgression", will occur backshore erosion and foreshore deposition and, on the contrary, during quadrature tides, corresponding to "little regression", will occur backshore deposition and foreshore erosion.

Then, it is obvious that in gentle slope sandy coasts, a relative sea-level drop will induce intensive transportation of sand from the inner continental shelf into the beach. If longshore drift is small or null, shoreline progradation will occur through accretion of successive beach-ridges.

2 ROLE PLAYED BY LONGSHORE DRIFT OF SANDS ON COASTAL SANDY SEDIMENTATION

The transportation of sands along a sandy beach is mostly caused by longshore currents generated by the waves. In fact, near to the beaches, the waves do not find sufficient depth to their advancement. This phenomenon is followed by liberation of a large amount of energy which will be partially used to put sands in suspension and, in part, to generate longshore currents. Obviously, this phenomenon will occur only when the wave front reaches obliquely the shorelines.

The velocity of this current is very slow but its influence is very effective where sands were put in suspension by wave-break and, therefore, very important volume of sands will be transported in this way. Several calculations have shown that maximum velocity of longshore currents is attained when waves reach the shoreline with inclinations between 46° and 58° (Larras, 1961). A combination of spreading effect of broken waves and longshore currents will provoke pulsative transportation of sands. Obviously, direction of transportation will depend on the angle of incidence of wave fronts which reach the shoreline.

Certainly, during relative sea-level drop, sands supplied for equilibrium profile re-establishment will be partially moved along the beach as a consequence of this mechanism. This transportation will continue until sands are retained by an obstacle. This explains that great differences can exist within an area subjected to an uniform sea-level drop. Sandy deposits

will be much less developed or even absent where coastal transit is dominant and they become very important where a trap or an obstacle have propitiated their retention. There are many kinds of obstacles, like shoreline embayments, islands, shoals forming areas with low energy, headlands of crystalline rocks, important river mouths, etc.

2.1 Blocking of longshore transportation by a river flow

In favourable conditions, a river flow near its mouth will form an obstacle which can block transportation of sands, in a same way as an artificial groyne in the coast. In general, these structures are founded on the land, extending beyond sea after wave-break and interrupting completely coastal transportation of sediments. As a consequence, the sediments will be retained by the obstacle, in such a way that updrift shoreline will be subjected to a rapid progradation. At the same time, downdrift shoreline will be eroded causing rapid retrogradation (Figure 2).

Komar (1973) simulated the evolution of a delta in a computer model, where the sediments are mostly reworked by wave energy, and called attention to the fact that when the waves form an acute angle, in relation to shoreline, river flow will act as a groyne, trapping the longshore drift of sediments. So, deltaic plain would be subjected to a rapid progradation at updrift side of the river mouth, while at downdrift side the sediments will be removed mostly by erosion.

The active mechanisms at river mouth can be explained as follow (Figure 2):

a) During floods, the river flow acts as a hydraulic jetty, with retention of longshore drift sands in the updrift portion and deposition of fluvial sediments in the downdrift area.

b) On the other hand, the blocking effect of the river flow on longshore sediment transportation will be much less efficient during dry seasons when, partially by erosion of previous deposits, longshore currents will build a sand spit which tends to obstruct the river mouth. If low energy river flow continues, the sand spit will be enlarged to an extent that will only be partially affected during subsequent high energy period. In some cases, only the distal end of the sand spit will be destroyed, and the blocking effect of the river flow will be displaced in the direction of the longshore drift and a new accumulation will occur.

As a consequence of "groyne effect" of the river mouth flow, alternated with low energy conditions, the coastal plain on either side of the river mouth will thus be asymmetric with the updrift portion formed by a series of sandy ridges, and the downdrift portion consisting of alternating sandy ridges and clayey-sandy wetlands. Displacements controlled by the river mouth will be recorded as unconformities in the

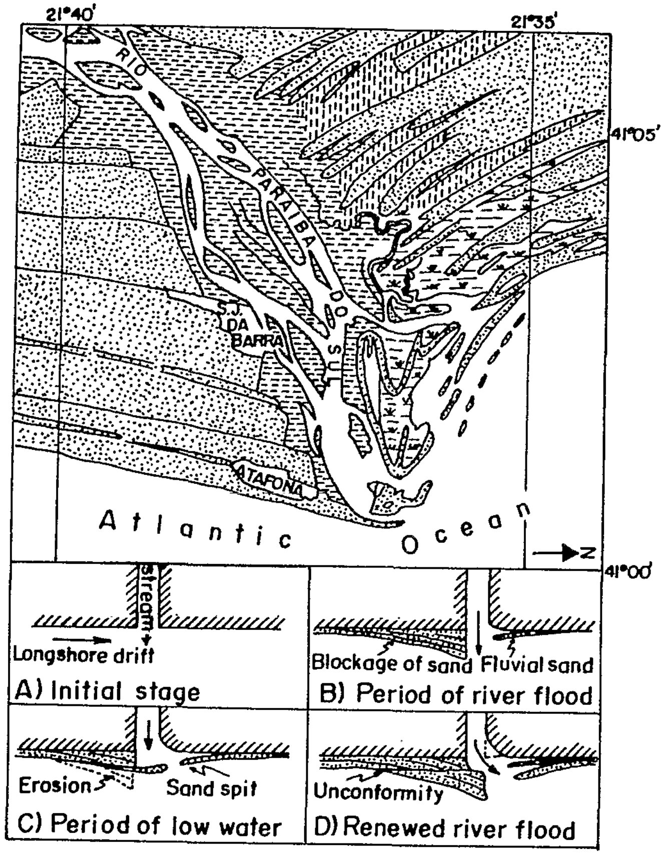

Figure 2. Mechanism of blocking of sands supplied by longshore currents around an important river mouth, exemplified by the Rio Paraíba do Sul (State of Rio de Janeiro).

alignment of sandy ridges.

This mechanism has been recognized in the Rio Paraíba do Sul coastal plain, State of Rio de Janeiro, especially by differences in roundness degrees of beach sands on both sides of the river mouth (Suguio et al., 1984; Martin et al., 1985).

QUATERNARY SEA-LEVEL FLUCTUATIONS ALONG EASTERN AND SOUTH-EASTERN COASTS OF BRAZIL

1 OLDEST QUATERNARY HIGH SEA-LEVEL (> 120,000 YEARS)

The oldest Quaternary high sea-level along eastern and southeastern Brazilian coasts (from States of Alagôas to Santa Catarina) was evidenced only in the coasts of the States of Alagoas, Bahia and Sergipe, where it is known as Ancient Transgression (Bittencourt et al., 1979; Bittencourt et al., 1982b). It is not a well-known event since there are not outcrops which can certainly be attributed to this transgressive episode. The only known evidence is formed of cliffs carved in Pliocene continental deposits of the Barreiras Formation and probably by a not-outcropping coral reef in southern State of Bahia (Carvalho and Garrido, 1966).

2 HIGH SEA-LEVEL OF 120,000 YEARS BP

The above mentioned Ancient Transgression was followed by a new transgressive event, when the relative sea-level was about 8±2 m above the present level about 120,000 years BP. This age has been established by dating coral samples from State of Bahia by Io/U method (Martin et al., 1982). This high sea-level episode is recorded by essentially sandy wave-built terraces.

3 HOLOCENE HIGH SEA-LEVEL

The most recent high sea-level episode was very well established as a function of numerous reconstructions of ancient shorelines in space and time, which have been done using more than 700 radiocarbon ages. Then it was possible to delineate parcial or complete relative sea-level fluctuation curves for several sectors of the Brazilian coast (Suguio and Martin, 1978a, 1978b, 1982a; Suguio et al., 1980; Martin et al., 1979a, 1979b, 1985). In order to have most significant curves, it has only been considered short and homogeneous segments of the coastline (60 to 80 km long) with the same geologic framework and behaviour and sufficiently numerous information. These curves show great resemblance of configuration but they exhibit different vertical amplitudes (Figure 3).

In summary, it is possible to recognize the following sea-level changes along the eastern and southeastern coasts of Brazil: submergence periods (7,000 - 5,100 years BP; 3,800 - 3,600 years BP and 2,700 - 2,500 years BP) associated with emergence episodes (5,100 - 3,800 years BP; 3,600 - 2,700 years BP and 2,500 years BP to the present). The submerged coast is characterized by barrier-island/lagoonal systems, while the emerged coast is characterized by extensive beach-ridge plains.

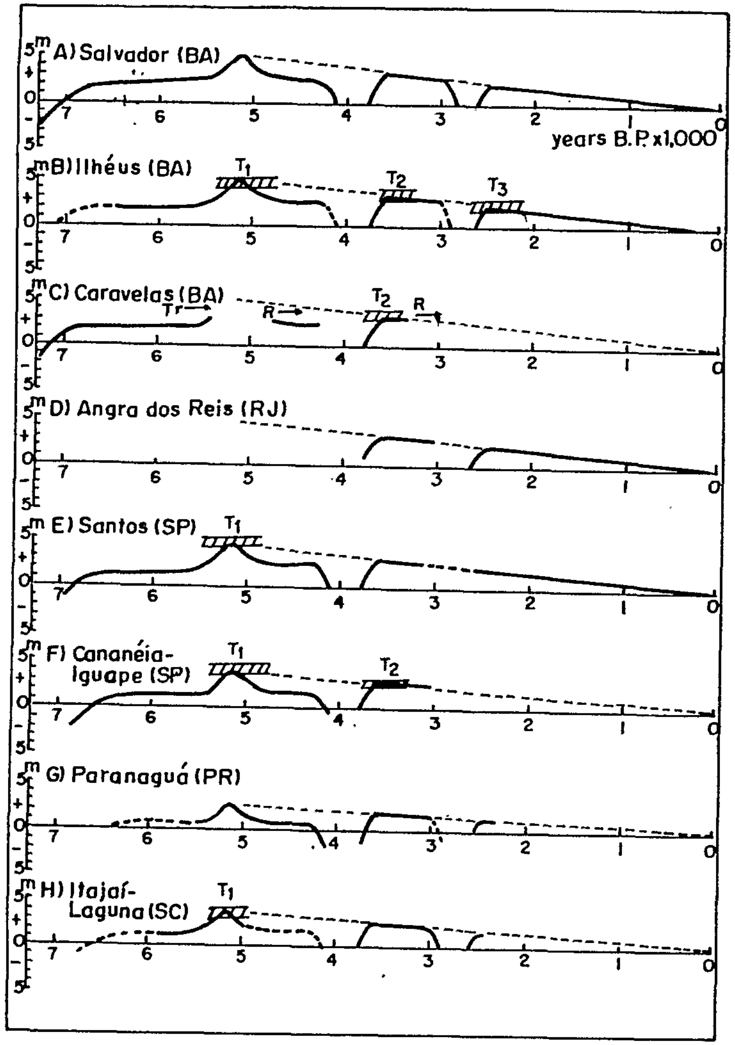

Figure 3. Relative sea-level fluctuation curves, during the Holocene, for several sectors of the Brazilian coast from Salvador (State of Bahia) to Itajaí-Laguna (State of Santa Catarina).

MAIN STAGES OF DEVELOPMENT OF COASTAL PLAINS IN EASTERN AND SOUTHEASTERN COASTS OF BRAZIL

Relative sea-level fluctuations and longshore drift of sands, associated with paleoclimatic changes, controlled the origin of these coastal plains, whose most complete evolutive model has been established for the coast of the State of Bahia (Figure 4). This model is valid for the sector of the coastal plain between Macaé (State of Rio de Janeiro) and Recife (State of Pernambuco) but, in some areas, records corresponding to one or more of these stages can be absent (Martin et al., 1980; Martin et al., 1983).

a) Stage I: Sedimentation of the Barreiras Formation

Continental deposits of the Barreiras Formation have been deposited during Pliocene under semiarid paleoclimate and subjected to concentrated and torrential rainfall, originating coalescing alluvial fans which, according to Ghignone (1979), filled up extensive segment of the Brazilian coast. During this period, relative sea-level was much lower than it is today, then their sediments covered most of the adjacent continental shelf areas (Bigarella and Andrade, 1964). Barreiras Formation deposits occur from the State of Rio de Janeiro northward to the mouth of Rio Amazonas.

b) Stage II: Maximum of the Ancient Transgression (older than 120,000 years BP)

According to Vilas-Boas et al.,(1981), the paleoclimate became wetter at the end of sedimentation of the Barreiras Formation, then giving place to Ancient Trangression that originated extensive erosional cliffs carved into this formation. The original cliffs have been preserved only in the coastal plains of the States of Alagôas, Bahia and Sergipe and, probably they have been destroyed in other areas by the Penultimate Transgression.

c) Stage III: Sedimentation of post-Barreiras continental deposits

After the maximum level of the Ancient Transgression, and during the following regression, the paleoclimate re-acquired semiarid characteristics, at least in the areas corresponding to the States of Alagôas, Bahia and Sergipe. This turn-back to semiaridity propitiated sedimentation of new continental deposits as coalescing alluvial fans, which were laid down at the foot of the cliffs carved into the Barreiras Formation during the Stage II.

d) Stage IV: Maximum of the Penultimate Transgression (about 120,000 years BP)

During this period, corresponding to maximum of the Penultimate Transgression (Cananéia Transgression in the State of São Paulo), sea eroded totally or partially the continental deposits formed during the Stage III. The downstream courses of the rivers were drowned and transformed into estuaries and lagoons and where the continental deposits of the previous

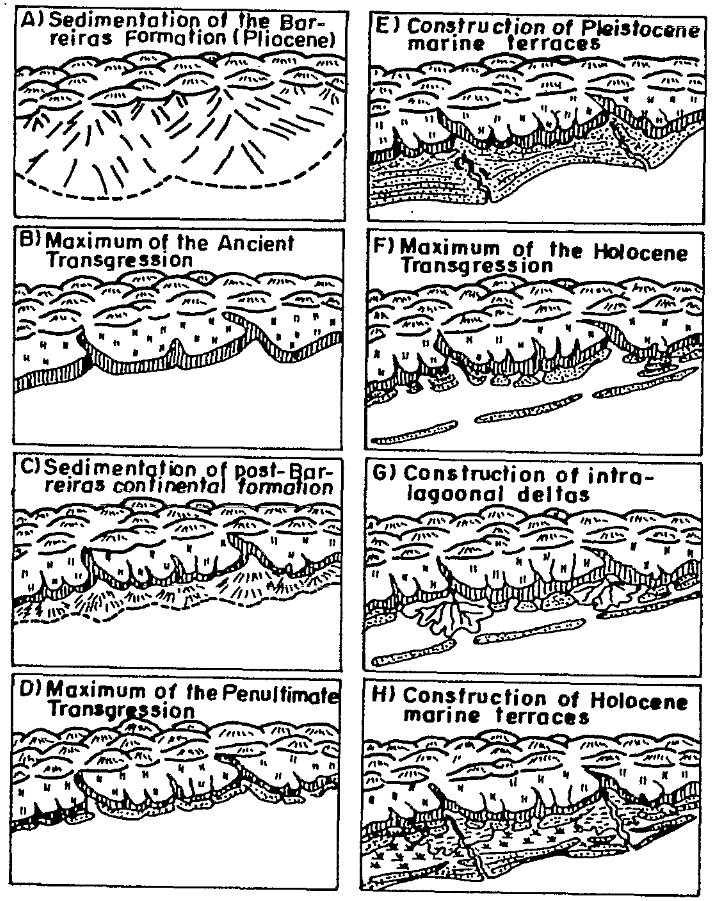

Figure 4. Evolutive model during the Neocenozoic valid for sector of the coastal plain between Macaé (State of Rio de Janeiro) and Recife (State of Pernambuco).

stage were completely eroded, the sea reached the cliffs of the Ancient Transgression which were sometimes entirely eroded.

e) Stage V: Construction of the Pleistocene marine terrace

In this phase, the regression followed by coastal plain progradation through successive accretion of sandy ridges took place, giving rise to extensive coastal plains.

f) Stage VI: Maximum of the Holocene Transgression

The drainage net established on the Pleistocene marine terrace eroded these deposits totally or partially and, sometimes, the valleys reached the Barreiras Formation. The downstream courses of the rivers were once again drowned by relative sea-level rise during the Holocene Transgression (Santos Transgression in the State of São Paulo), being transformed into estuaries. Continuously, barrier-islands/lagoonal systems have been formed and, in some places, they attained huge dimensions. Mollusc shells and wood fragments contained within lagoonal deposits furnished radiocarbon ages of less than 7,000 years BP, indicating that barrier-islands were formed previously to the maximum level of this transgression.

g) Stage VII: Construction of intralagoonal deltas

Intralagoonal deltas essentially nourished by fluvial sediments were deposited within lagoonal systems formed around the mouths of the most important rivers flowing into the Atlantic Ocean.

h) Stage VIII: Construction of Holocene marine terrace

The relative sea-level drop following the maximum level of 5,150 years BP promoted the construction of successive sandy ridges departing from the original barrier-island and forming marine terraces. Besides the construction of marine terraces, the sea-level drop caused gradual transformation of lagoons into lakes, followed by marshes and swamps. Several lakes, for example, Lagôa Bonita in the Rio Doce mouth or Lagôa Feia in the Rio Paraíba do Sul mouth, still occurring in these coastal plains, represent vestiges of more extensive ancient lagoons (Martin et al., 1984). Small and relatively rapid transgressive episodes of Holocene, clearly shown on sea-level fluctuation curves, played a very important role in the construction of coastal plains. A second lagoonal episode has been recorded in the Rio Doce coastal plain, associated with a transgressive event of 3,800-3,600 years BP (Suguio et al., 1982; Suguio and Martin, 1982b) with construction of new barrier-islands and drowning of lowlands situated between the sand ridges of first generation Holocene terraces. In the Rio Jequitinhonha coastal plain, these transgressive episodes are represented by drowned river mouth associated with shifting of river course by the process of avulsion (Dominguez, 1983).

THE VALIDITY OF THE WORD "DELTA" TO DESIGNATE COASTAL PLAINS ASSOCIATED WITH MOUTHS OF THE MOST IMPORTANT RIVERS OF THE BRAZILIAN COAST

There are progradation zones associated with the mouths of the most important Brazilian rivers flowing into the Atlantic Ocean. They were classified by Bacoccoli (1971), based on concepts of Scott and Fisher (1969), as "wave-dominated", highly destructive deltas" (Rios Parnaíba, Jaguaribe, São Francisco, Jequitinhonha, Doce and Paraíba do Sul), and "tide-dominated, highly destructive delta" (Rio Amazonas). Moreover, this author assumed a Holocene age and proposed an evolutive scheme entirely related to the Flandrian Transgression, in some cases with an intermediary transition through estuarine phase until constituting more typical deltas, which advanced oceanward causing progradation.

Nevertheless, along the coast of Brazil there are also extensive areas without any relationship with present or past rivers mouths. The most impressive case is situated near Caravelas (State of Bahia) where, besides fluvial deposits, there are all the types of deposits commonly found in "wave-dominated deltas" of the Brazilian Quaternary coastal plain. For that reason, Bacoccoli (1971) proposed that this area would represent delta of the ancient Rio Mucuripe, associating it with a negligible river situated there.

The occurrence of such a kind of coastal plain, without any evident association with river mouths, attracted our attention. The classical models of coastal sedimentation, as proposed by Fisher (1969), Galloway (1975), Hayes (1975) and others, emphasize the roles played by wave energy, tidal range, river load, etc., as essential factors but no one mentions the possible influence of relative sea-level fluctuations. In their classical work, Coleman and Wright (1975) analysed about 400 parameters which could be active during sedimentation of sandy deltaic deposits, but they also forgot perhaps one of the most important factors, that is, the relative sea-level drop during the Holocene. We have seen that sea-level drop promotes sandy transfer from foreshore to beach, which can be partially transported by longshore currents until being trapped by an obstacle, like a river mouth, in a same way as an artificial groyne in the coast. When longshore drift is the dominant process, the fluvial sediments will be accumulated only at downdrift side, since at updrift side, it will be accumulated only marine sands blocked by the river flow. On the other hand, only in absence of longshore drift, that is, when the wave front is parallel to shoreline, the fluvial sediments will be reworked by the waves and deposited on both sides of the river mouth. Detailed surveys accomplished in the coastal plains associated with the mouths of the Rio Paraíba do Sul, Doce, Jequitinhonha and Sao Francisco showed that the direction of longshore drift has been constant during the last 6 to 7,000 years (Bittencourt et al., 1982a; Dominguez et al., 1981a, 1981b, 1983). As the most important portion of the coastal plains of the mouths of these rivers was not constructed directly by fluvial sediments, it is possible to call in question if the word "delta" is the most suitable to designate these progradation features (Dominguez et al., 1982; Suguio and Martin, 1982b; Suguio et al., 1984).

CONCLUSIONS

The relative sea-level fluctuations, associated with longshore drift of sediments, is one of the most important mechanisms responsible for the morphological evolution of sandy shorelines. In general, the submergence episodes are represented by barrier-island/lagoonal systems and the emergence periods by extensive beach-ridge plains. In fact, the relative sea-level drop promotes voluminous sand supply from foreshore toward the beach. This sand is transported by longshore currents until being blocked by an obstacle. Sediments supplied by this mechanism play a very important role in the construction of sandy marine terraces along the Brazilian coast. However, if the rivers mouths are less important as source of sands, they have an essential role as trap of the drifted sediments and, consequently, they are very important in the construction of the beach-ridge plains.

Very rapid sea-level fluctuations, like that occurred in Brazil after 5,100 years BP (2 to 3m in 200 years), can introduce strong modifications in coastal morphology and dynamics. Then we must try to delineate more-and-more accurate curves to identify each sea-level change because they have been significant in the evolution of the littoral zones.

ACKNOWLEDGEMENTS

This work has been made possible thanks to financial support from FAPESP (Fundação de Amparo a Pesquisa do Estado de São Paulo) and CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico).

REFERENCES

Bacoccoli, G. 1971. Os deltas marinhos holocênicos brasileiros: Uma tentativa de classificação. Boletim Técnico Petrobrás, 14:5-38, Rio de Janeiro.

Bigarella, J.J. & Andrade, G.O. 1964. Considerações sobre a estratigrafia dos sedimentos cenozóicos em Pernambuco (Grupo Barreiras). Universidade de Recife, Arquivos Instituto Ciências da Terra, 2:2-14, Recife.

Bittencourt, A.C.S.P.; Martin, L.; Vilas-Boas, G.S. & Flexor, J.M. 1979. Quaternary marine formations of the coast of the State of Bahia, Brazil. Proceedings 1978 International Sumposium on Coastal Evolution in the Quaternary. p.232-253. São Paulo.

Bittencourt, A.C.S.P.; Dominguez, J.M.L.; Martin, L. & Ferreira, Y. de A. 1982a. Evolução do "delta" do Rio São Francisco (SE/AL) durante o Quaternário: Influencia das variações do nível do mar. Atas IV Simpósio Quaternário no Brasil, p.49-68. Rio de Janeiro.

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

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

Carvalho, K.W.B. & Garrido, J.L.P. 1966. Reconhecimento geológico da Bacia Sedimentar da Bahia Sul - Espírito Santo. Petrobrás, DEXPRO, Relatório 2496, 77pp. Salvador.

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

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

Dominguez, J.M.L. 1983. Evolução quaternária da planície costeira associada a foz do Rio Jequitinhonha (BA): Influencia das variações do nível do mar e da deriva litoranea de sedimentos. Dissertação de Mestrado, Universidade Federal da Bahia, 73pp. Salvador.

Dominguez, J.M.L.; Bittencourt, A.C.S.P. & Martin, L. 1981a. Esquema evolutivo da sedimentação quaternária nas feições deltaicas dos rios São Francisco (SE/AL), Jequitinhonha (BA), Doce (ES) e Paraíba do Sul (RJ). Revista Brasileira Geociências. 11:227-237. São Paulo.

Dominguez, J.M.L.; Martin, L. & Bittencourt, A.C.S.P. 1981b. Evolução paleogeográfica do delta do Rio Jequitinhonha durante o Quaternário: Influencia das variações do nível do mar. Atas IV Simpósio Quaternário no Brasil, p.69-82. Rio de Janeiro.

Dominguez, J.M.L.; Bittencourt, A.C.S.P. & Martin, L. 1983. O papel da deriva litoranea de sedimentos arenosos na construção das planícies costeiras associadas a desembocaduras dos rios São Francisco (SE/AL), Jequitinhonha (BA), Doce (ES) e Paraíba do Sul (RJ). Revista Brasileira Geociências, 13:98-105. Rio de Janeiro.

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

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

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

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

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

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

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

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

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

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

Larras, J. 1961. Cours d'Hydraulique maritime et des travaux maritimes. DUNOD, 459pp. Paris.

Martin, L.; Bittencourt, A.C.S.P. & Vilas-Boas, G.S. 1982. Primeira ocorrencia de corais pleistocênicos da costa brasileira: Datação do máximo da penúltima transgressão. Ciencias da Terra. 1:16-17. Salvador.

Martin, L.; Dominguez, J.M.L.; Suguio, K.; Bittencourt, A.C.S.P. & Flexor, J.M. 1983. Schéma de la sédimentation Quaternaire sur la partie centrale du littoral bresilien. Cahier ORSTOM Série Géologie. 13(1):59-81. Paris.

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

Martin, L.; Flexor, J.M.; Vilas-Boas, G.S.; Bittencourt, A.C.S.P. & Guimaraes, M.M.M. 1979a. Courbe de variation du niveau rélatif de la mer au cours de 7000 dernieres annees sur un sécteur homogene du littoral bresilien (nord de Salvador). Proceedings 1978 International Symposium on Coastal Evolution in the Quaternary, p.264-274. Sao Paulo.

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

Martin, L.; Suguio, K.; Flexor, J.M.; Bittencourt, A.C.S.P. & Vilas-Boas, G.S. 1980. Le Quaternaire marin bresilien (Littoral pauliste, sud-fluminense et bahianais). Cahier ORSTOM, Série Géologie. 4(1):95-124. Paris.

Martin, L.; Suguio, K.; Flexor, J.M.; Dominguez, J.M.L. & Azevedo, A.E.G. 1984. Evolução da planície costeira do Rio Paraíba do Sul (RJ) durante o Quaternário: Influencia das variações do nível do mar. Atas XXXIII Congresso Brasileiro Geologia. 1:84-97. Rio de Janeiro.

Martin, L.; Suguio, K.; Tessler, M.G. & Eichler, B.B. 1985. Roundness degrees in Holocene sands of the Paraíba do Sul coastal plain, Rio de Janeiro, Brazil. Journal of Coastal Research. 1(4):343-351.

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

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

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

Suguio, K. & Martin, L. 1978a. Quaternary marine formation of the State of Sao Paulo and southern Rio de Janeiro. 1978 International Symposium on Coastal Evolution in the Quaternary Special Publication n° 1, 55pp. São Paulo.

Suguio, K. & Martin, L. 1978b. Mecanismos de genese das planicies sedimentares quaternárias do litoral do Estado de São Paulo. Anais XXIX Congresso Brasileiro Geologia. 1:295-305. Ouro Preto.

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

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

Suguio, K.; Martin, L. & Dominguez, J.M.L. 1982. Evolução do "delta" do Rio Doce (ES) durante o Quaternário: Influencia das variações do nível do mar. Atas IV Simpósio Quaternário no Brasil, p.93-116. Rio de Janeiro.

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

Suguio, K.; Martin, L. & Flexor, J.M. 1980. Sea-level fluctuations during the past 6,000 years along the coast of the State of São Paulo. In: N.A. Mörner (ed.) Earth rheology, isostasy and eustasy, 471-486. London: John Wiley & Sons.

Suguio, K.; Martin, L.; Flexor, J.M.; Tessler, M.G. & Eichler, B.B. 1984. Depositional mechanisms active during the Late Quaternary at the Paraíba do Sul River mouth area, State of Rio de Janeiro, Brazil. International Symposium on Late Quaternary Sea-Level Changes and Coastal Evolution, Mar del Plata, Argentina. Quaternary of South America and Antarctic Peninsula, 1985. 3:175-185. Rotterdam: A.A. Balkema.

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

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