Journal of Coastal Research	9	3	823–830	Fort Lauderdale, Florida	Summer 1993

Utilization of Coastal Geomorphic Features as Indicators of Longshore Transport: Examples of the Southern Coastal Region of the State of São Paulo, Brasil[1]

Moyses G. Tessler and Michel M. de Mahiques

Oceanographic Institute of the University of São Paulo (USP)
Praça do Oceanográfico, 191
Cidade Universitária—Butantã
P.O. Box 9075
05508-900 São Paulo, Brasil

ABSTRACT

TESSLER, M.G. and MAHIQUES, M. de, 1993. Utilization of coastal geomorphic features as indicators of longshore transport: Examples of the southern coastal region of the state of São Paulo, Brasil. *Journal of Coastal Research*, 9(3), 823–830. Fort Lauderdale (Florida), ISSN 0749-0208.

On the Brazilian coast, where sandy shores predominate, not only the form of the coastline but depositional features associated therewith (spits, sandbanks, etc.) have also been frequently used as geomorphic indicators of the predominant direction of the longshore transport of sediments. On the southern coastal region of State São Paulo, the growth of prominent features is related not only to the longshore drift but also to the interaction between these processes and internal dynamics strongly conditioned by the action of tides. This intense interaction takes place especially in the proximities of lagoonal mouths. In the lagoonal mouth of Ararapira (on the boundary of the states of São Paulo and Paraná) the growth of the sandy spit occurs in the opposite direction to that of the drift of the current responsible for the transport of sediments along the coastline. On the other hand, on the lagoonal mouth of Icapara, to the northeast of Iguape (SP) the growth of the sandy feature occurs in the same direction as that of the drift current most effective in the transport of sediments, inasmuch as there is conformity between this and the vector resulting from the currents of the lagoonal region. Therefore, the simple observation of the direction of the growth of coastal features, when associated with lagoonal or estuarine systems, strongly controlled by tidal conditions, cannot be used without reservations as indicative of the predominant direction of the transport of sediments along the coastlines.

ADDITIONAL INDEX WORDS: *Lagoon, longshore current, sediment dynamics.*

INTRODUCTION

In sandy shores, not only the evolution of the form of the coastlines but depositional features associated therewith (spits, sandbanks, etc.) have also been frequently used as geomorphic indicators of the predominant direction of the longshore transport of sediments as a fast and sure method in the attempt to understand the mechanisms of coastal dynamics, present and past (GODOLPHIM, 1983; MARTIN *et al.*, 1984).

On the southern coastal region of the state of São Paulo, the growth of prominent features is related not only to the processes of the coastal drift but also to the interaction of these mechanisms and internal lagoonal dynamics strongly conditioned by the tidal action. Therefore, a superficial evaluation of the coastal sand features, especially those the growth of which is associated to lagoonal mouths, may result in errors of interpretation of the predominant direction of the in depth transport of longshore sand sediments.

LONGSHORE GEOMORPHIC FEATURES OF THE SOUTHERN COASTAL REGION OF THE STATE OF SÃO PAULO

The geomorphological peculiarities presented by the extensive coastal plain as well as by the sandy features close to the coastline of the southern coastal region of the state of São Paulo (Figure 1) have led several authors to attempt to recognize their evolution mechanisms with the objective of arriving at a deduction as to the predominant direction of the longshore transport of sand along this section of the coast (SADOWSKY, 1952, 1954; PETRI and SUGUIO, 1971; SUGUIO and TESSLER, 1983).

Among these many features, two in particular are the object of the present study (lagoonal mouths of Icapara and Ararapira), due to the fact that they present growth of sand spits associated with their mouths in opposite directions.

92026 received 22 May 1992; accepted in revision 21 August 1992.
[1] Support by CNPq (N° 303301/84-8).

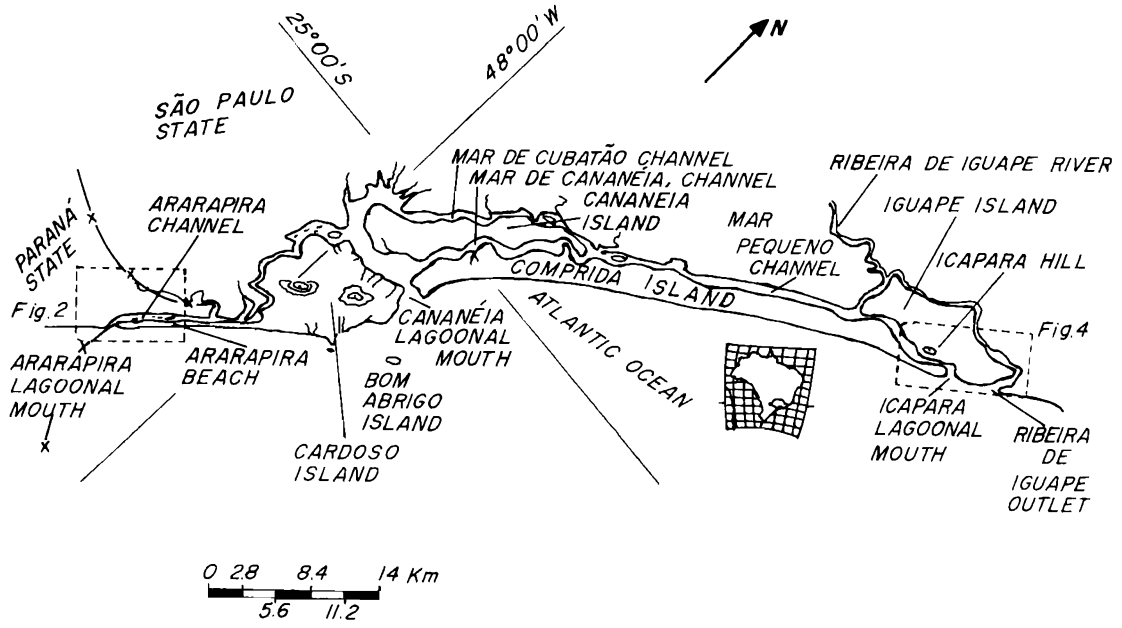

Figure 1. Location map of the study area.

LAGOONAL MOUTH OF ARARAPIRA (SP/PR)

The lagoonal mouth of Ararapira is the political coastal border between the states of São Paulo and Paraná.

The Ararapira Channel, the interconnecting channel between the lagoonal region in the south, separates Cardoso island from the Continent and is separated from the ocean to the southwest by a narrow and straight feature locally known as Ararapira beach (Figure 2).

This sandy point is anchored to Cardoso island and is approximately 18 km long and 300 m wide. The beach ridge present in this sandy feature is oriented in a N 45°E direction, similar to the longitudinal beach ridge present on Comprida island, the most prominent barrier island located northeast of the Ararapira lagoonal mouth. An analysis of the form of the perimeter of the lagoonal mouth obtained from the superposition of aerophotogrammetric surveys carried out on three different occasions (1953, 1963 and 1981) confirms that this interconnection feature between the lagoon and the ocean runs in a southwesterly direction. This trend obtained from the aerophotogrammetric surveys could lead to the assumption that the longshore transport along the Cardoso island coastline proceeds from the northeast to the southwest (Figure 3).

However, a more accurate observation, especially along the margins of this channel in the areas close to the lagoonal mouth, shows that the movement of old sand deposits towards the southwest occurs by erosion during the intensive periods of ebb tides, and it aligns generally in a southwest to northeast direction.

Associated with this erosive margin characteristic, there is coupled in a lateral direction a feature of the sandy spit type. This spit, based on the outside portion of this concave margin, grows in an opposite direction to the direction of the channel, that is, towards the northeast.

On the other hand, the internal margin, that is, the lagoonal mouth margin of Ararapira beach, develops in a southwesterly direction, originating from deposit features similar to those found in the lagoonal channels of the Cananéia–Iguape lagoonal region located to the northeast. In these lagoonal channels, TESSLER and FURTADO (1983) described the growth of sand islands, similar to that observed in the Ararapira channel, which are associated with convex margins, and located on opposite margins with concave erosion features.

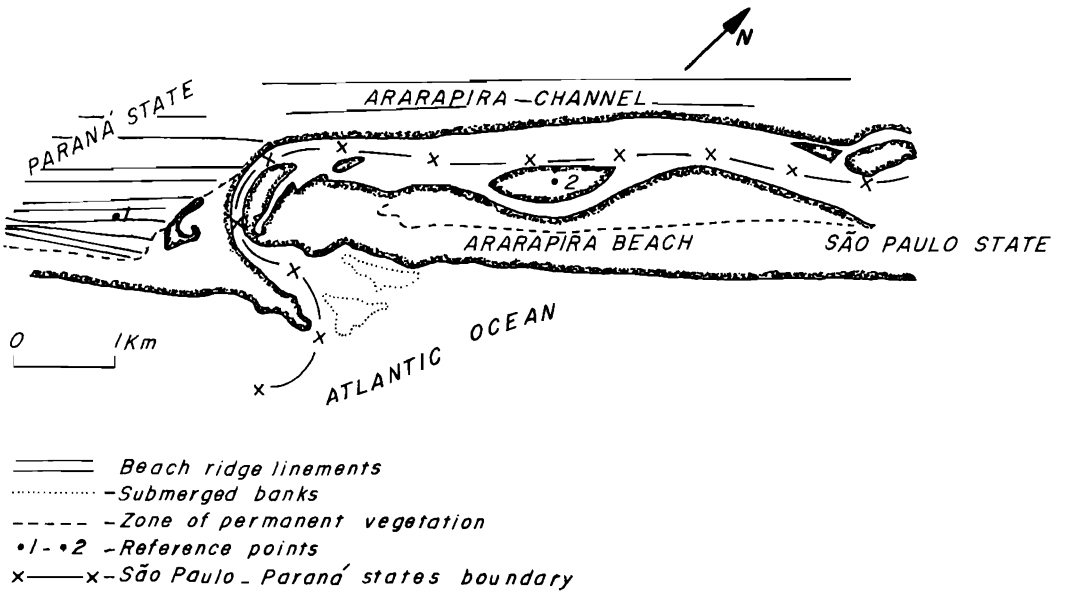

Figure 2. 1981 configuration and coastal features in the vicinities of the Ararapira lagoonal mouth.

This pattern is very similar to that found in meandering rivers with the difference being that in lagoonal channels the directions of the drifts are alternatively dependent upon the tidal cycles which results in the growth of deposit features in the direction of the predominant tidal current. Therefore, it seems obvious that the growth of the Ararapira beach on its lagoonal margin occurs as the result of the deposition of sandy sediments eroded from the opposite margin of the channel.

On its external face, the growth of the "beach" appears to be a condition of the mechanism of the blockage of the longshore transport by the drift of the ebb tide at the lagoonal mouth, which is similar to the mechanism described for lagoonal mouths by SUGUIO *et al.* (1985).

This blockage must also be responsible for the formation of the sandy spit on the concave margin of the channel of Ararapira, as well as for the deposit of the sandy sediments on the seaward side close to the lagoonal mouth, carried there by the ebb tide waters coming from the channel.

This mechanism is even more efficient when the intensity of the flow of water that runs out through the lagoonal mouth is at its maximum, an event which occurs predominantly with the passage of frontal systems (cold fronts).

At this time, the more intense tidal cycles and the south to southeasterly winds cause the imprisonment of waters in the lagoonal systems resulting in an increase in the volume of water retained in these systems for a period of time greater than that of the normal tidal cycles. Even after the effect of these atmospheric events has ceased, the increased intensity of the flow of the ebb tide accelerates the erosive process of the concave margins and contributes significantly, with sand sediments, to the increase of the deposition margins and lagoonal islands. Since it is also during these events that the more intensive longshore transport occurs, the construction of the sand spit of the lagoonal mouth is accelerated (TESSLER, 1988).

The increase of the dimensions of the spit, added to the submerged sand existing on the shallow coastal region in front of the lagoonal mouth, tends to obstruct the exit of the deeper channel which connects the lagoonal region with the sea. When the period of more intensive ebb tide occurs, this obstruction is eliminated, with the consequent displacement of these sand sediments towards the ocean.

Subsequently, in the intervals of the action of the frontal systems, the coastal drift remobilizes the sediments, incorporating them to the Ararapira beach, particularly in the areas located closer to its portion located more to the southwest. This

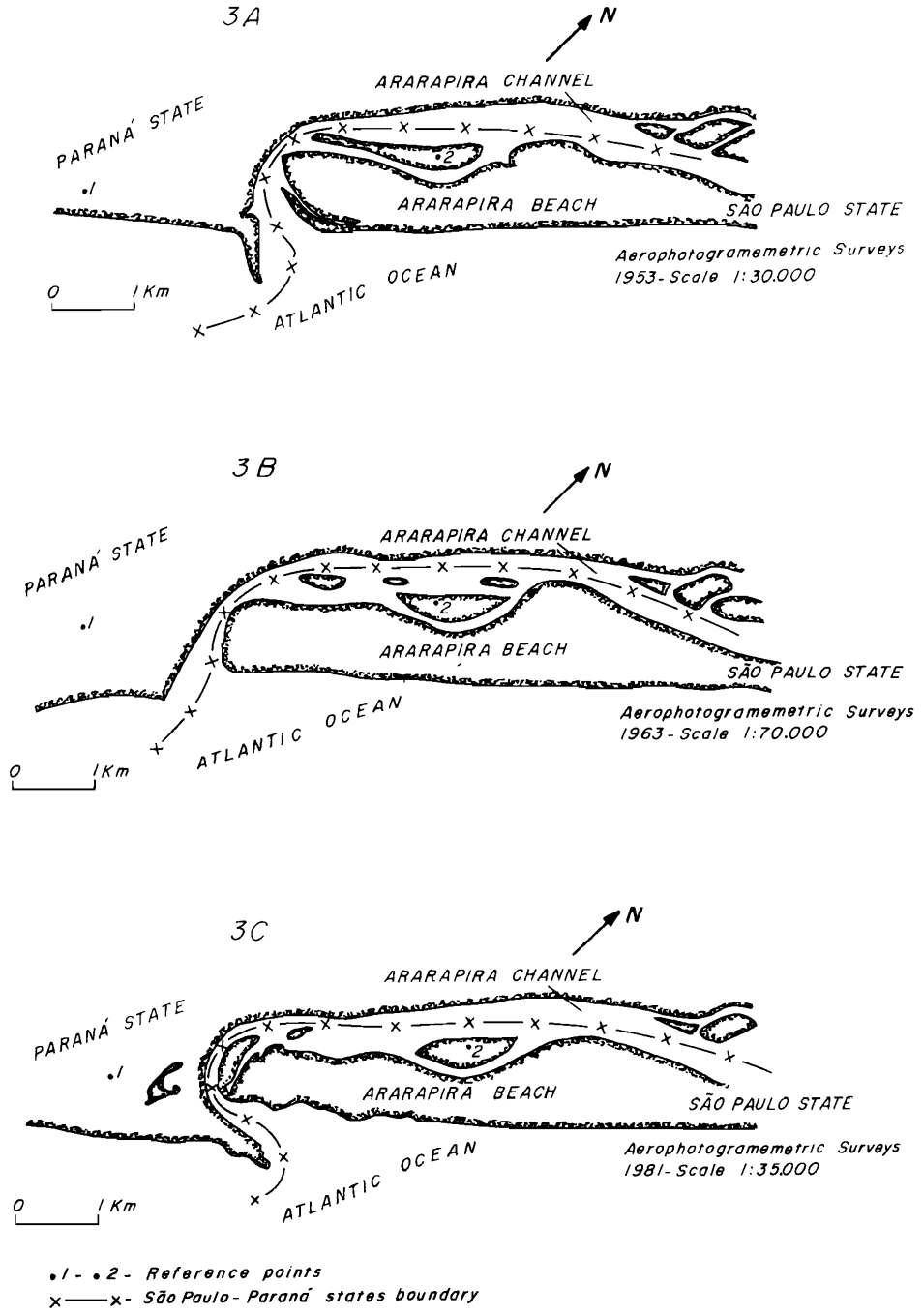

Figure 3. Evolution of the Ararapira lagoonal mouth: (A) 1953, (B) 1963), and (C) 1981.

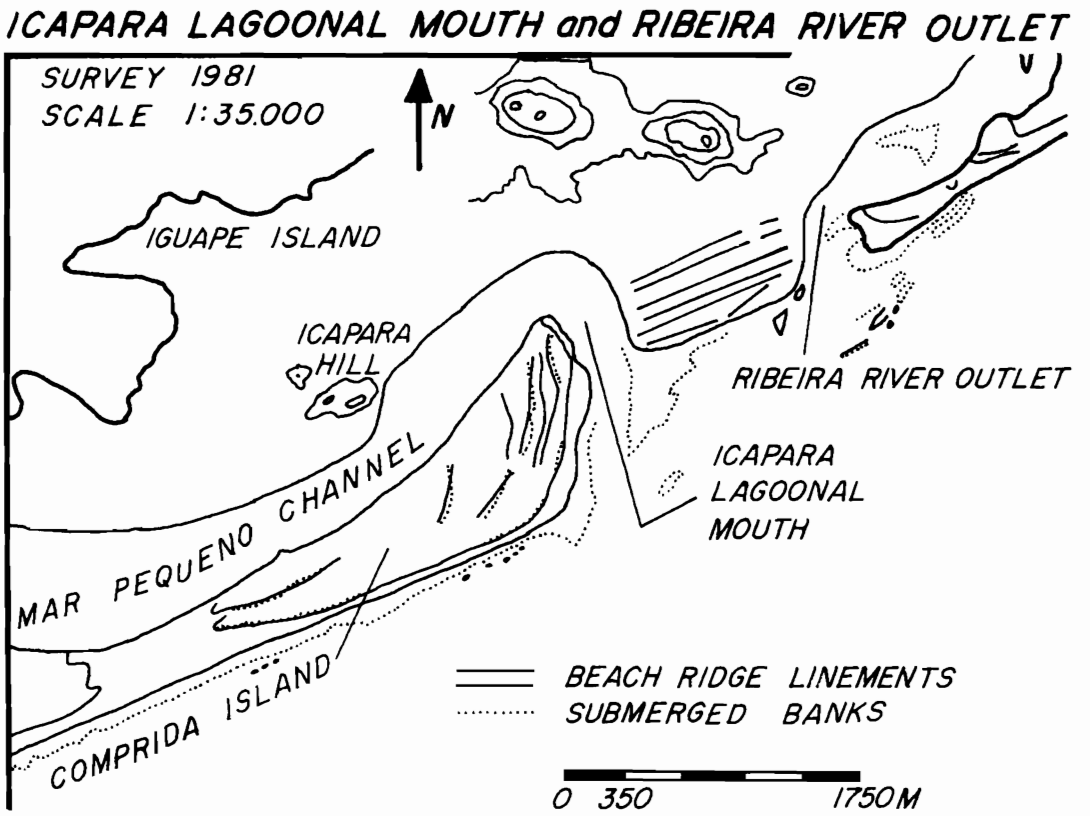

Figure 4. 1981 configuration and coastal features in the vicinities of the Icapara lagoonal mouth and the Ribeira river outlet.

mechanism of incorporation of sand associated with the erosive process produced by the ebb tide currents in the Ararapira channel is responsible for the displacement of the Ararapira lagoonal mouth towards the south.

Consequently, the displacement of the lagoonal mouth occurs in the opposite direction to that of the predominant transport of the sandy sediments of the southern coastal region of the state of São Paulo (NE), as identified by TESSLER (1988), and therefore cannot be used simply as a geomorphic indicator of the predominant direction of the longshore transport.

LAGOONAL MOUTH OF ICAPARA AND MOUTH OF THE RIBEIRA DE IGUAPE RIVER (SP)

To the northeast of the Cananéia–Iguape lagoonal complex, there are present two other important geographic features, the lagoonal mouth of Icapara and the outlet of Ribeira de Iguape river, to which there is also associated a series of sandy features which can be used as indicators of growth trends (Figure 4).

Based on a set of bathymetric charts drawn up between the years of 1882 and 1943 and supported by two aerophotogrammetric surveys made in 1953 and 1962, GEOBRÁS S/A (1966) carried out a comparative evolution study of Comprida and Iguape islands in the region of the lagoonal mouth of Icapara (Figures 5 and 6).

In this study, the growth of Comprida island to the northeast was detected as well as a rotation movement to the north (in relation to an extension of the coastline of the ocean margin of the island) of the lagoonal mouth of Icapara. Associated with the growth of Comprida island, the erosion of Iguape island on the opposite margin of the lagoonal channel was also observed.

The phenomena of the advance and retreat of

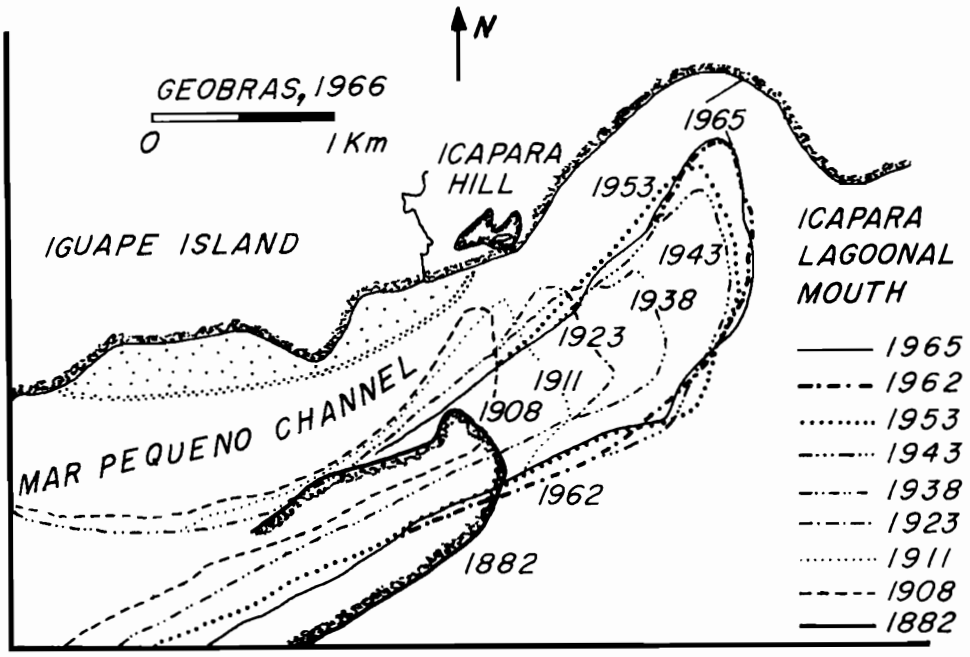

Figure 5. Evolution of the Comprida island in the vicinities of the Icapara lagoonal mouth.

Comprida and Iguape islands are very similar to those observed in the channel and lagoonal mouth of Ararapira.

The basic difference between these two areas is evident in the hydrodynamic mechanisms acting in the lagoonal channels and in the interaction of these "internal systems" with the mechanisms of the longshore drift.

In the Ararapira channel, the predominant ebb tide current moves to the southwest; whereas in the channel of the Iguape region, the predominant direction of the deep sand transport on the ebb tide is to the northeast, starting from a region named Pedra do Tombo which is the meeting point of the inflowing tides coming from the lagoonal mouths of Cananéia to the southwest and Icapara to the northeast.

Since the predominant direction of the longshore deep sand transport in the southern state of São Paulo coastal region occurs to the northeast, it is observed that in the Ararapira lagoonal mouth the predominant direction of the ebb tide is opposite to the direction of the predominant longshore drift. In the Icapara lagoonal mouth, both take place in the same direction (TESSLER, 1988). This fact results both in the growth of Comprida island and the erosion of Iguape island to the northeast.

According to GEOBRÁS S/A (1966), the growth of Comprida island between the years 1882 and 1965 presented an average displacement to the northeast of 35 m/year, while the retraction on the opposite margin, Iguape island, during the same period presented an average of 32 m/year. An average calculation of the eroded area on Iguape island showed approximately 60,000 m^3 of sandy sediments were removed from the margin annually.

These sediments, transported in the direction of the ocean, are retained by the action of the waves in the lagoonal mouth region of Icapara, generating a group of submerged sand banks, aligned in parallel to the margin of the lagoonal mouth on Comprida island.

Between this lagoonal mouth and the mouth of Ribeira river, there is a sequence of sand deposits aligned in parallel to the coast, formed by the deposition of the sandy sediments, and reworked

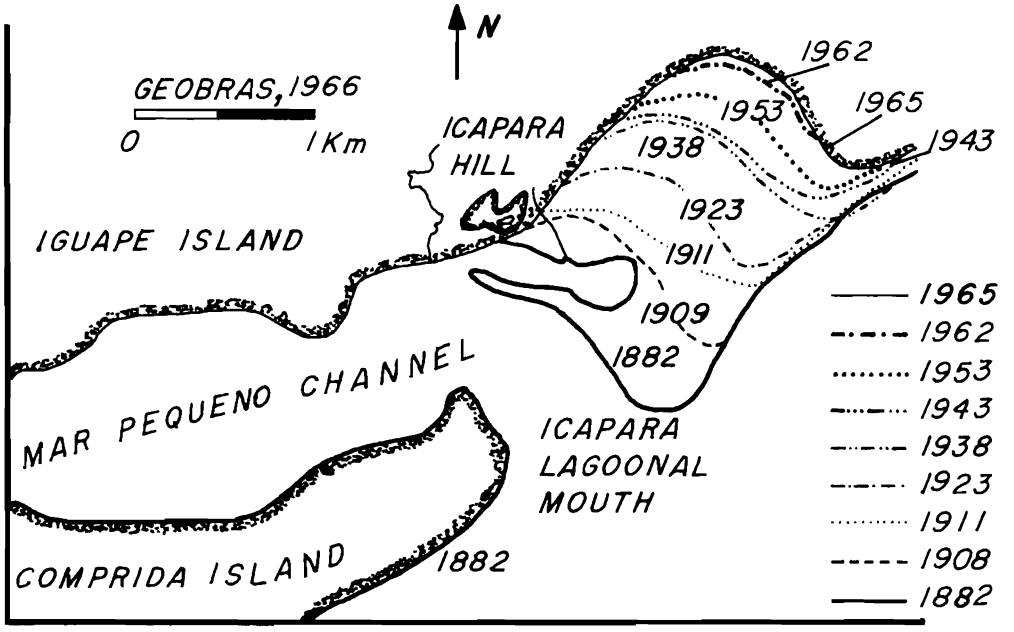

Figure 6. Evolution of the Iguape island in the vicinities of the Icapara lagoonal mouth.

starting from the submerged deposit centers of the sand banks of Icapara and the mouth of the Ribeira.

At the outlet of the Ribeira de Iguape river, there is a spit growing to the southwest; *i.e.*, in the opposite direction to the ebb tide current on the southern coastal region (Figure 4).

The ebb tide currents which move predominantly to the northeast are subject in the region of the Icapara lagoonal mouth and the mouth of the Ribeira to a blockage of the lagoonal and fluvial ebb tides, which in addition to retaining the displacement of the sediments which are moving to the northeast also interfere in the local hydrodynamic characteristics.

Therefore, the predominance of the coastal ebb tide currents coming from the southwest, and influenced by the systems of waves from the south to southeast, will only be fully reestablished along the coastline located to the northeast of the Ribeira de Iguape river (CTH/USP, 1973).

In addition, as was determined during the observations of waves and currents conducted by researchers of the Oceanographic Institute of São Paulo University (I.O.USP) in 1984, in the area of the mouth of the Ribeira, it is noticed that the greatest frequency of waves coming from the northeast to east occurred in this area with the consequent generation of ebb tide currents directed to the southwest.

Therefore, the greater frequency of coastal ebb tide currents generated by the systems of waves coming from the northeast and east, associated with the blockage of the ebb tide generated by the systems of waves coming from the southeast to south, in the region of the lagoonal mouth of Icapara and the mouth of the Ribeira, resulted in the formation of a slight spit at the mouth of the river, with a tendency to grow to the southwest.

CONCLUSIONS

On the southern São Paulo coastline, the movement of sandy sediments along the present coastline results from the interaction of the existing wave trends that govern the coastal ebb tide currents and the tidal currents. This plays an important part in the retention and remobilization of these sediments in the proximities of the lagoonal mouths.

Longshore geomorphic features are represen-

tative of the principal direction of the ebb tide when they are "rooted" in straight sandy coastlines or on rocky spits.

When interactions occur between coastal and continental hydrodynamic systems, however, the sandy features formed are the result of this interaction process, which could mean that their pattern of evolution cannot be used without reservations as indicators of the predominant direction of the coastal dynamics.

This fact when observed along the coastline in the proximities of the lagoonal mouths is significantly more complex, particularly if in the rear of the coastal plain where these sandy geomorphic features are associated, lagoonal mouth and/or estuarine systems strongly controlled by alternate tidal conditions develop.

Therefore, sandy geomorphic features when related to interacting coastal and continental hydrodynamic processes may very well present a tendency to move in an opposite direction to the predominant coastal current, a fact that makes each lagoonal mouth an area where the sandy geomorphic features cannot simply be described and/or used as indicative of the predominant coastal ebb tide currents.

ACKNOWLEDGEMENTS

We thank Mrs. Barbara Hoverter Facchini for the translation of the text and Mrs. Marizilda Magro for preparing the illustrations.

LITERATURE CITED

CTH/USP., 1973. *Observações das características das ondas do mar de Cananéia.* Relatório de projeto do Laboratório de Hidraúlica da Escola Politécnica da Universidade de São Paulo, São Paulo: Departamento de Águas e Energia Elétrica da Secretaria de Serviços e Obras Públicas, 40p.

GEOBRÁS S/A, 1966. *Complexo Valo Grande, Mar Pequeno e rio Ribeira de Iguape.* Relatório da Geobrás S/A, Engª e Fundações para o serviço do Vale do Ribeira do Departamento de Águas e Energia Elétrica do Estado de São Paulo, Two Volumes.

GODOLPHIM, M.F., 1983. Contribuição ao estudo da evolução da barra do Rio Grande, Brasil: *Pesquisa,* Universidade Federol do Rio Grande do Sul, Instituto Geosciencias, 15, 22–43.

MARTIN, L.; FLEXOR, J.M.; BITTENCOURT, A.C.S.P., and DOMINGUEZ, J.M.L., 1984. Registro do bloqueio da circulação atmosférica meridiana na geometria dos cordões litorâneos da costa brasileira. *In: Anais.* Congresso Brasileiro de Geologia, 35. Rio de Janeiro: Sociedade Brasileira de Geologia, pp. 133–138.

PETRI, S. and SUGUIO, K., 1971. Exemplo de trabalho do mar no litoral sul do Brasil. *Noticia Geomorfologia,* 11(21), 61–66.

SADOWSKY, V., 1952. *Observações sobre as modificações em curso na entrada de Cananéia; de sua barra e da região adjacente.* São Paulo: Bolm Instituto Oceanografico, 3(1/2), 201–212.

SADOWSKY, V., 1954. *Novas contribuições ao estudo da entrada da barra de Cananéia.* São Paulo: Bolm Instituto Oceanografico, 5(1/2), 151–178.

SUGUIO, K.; MARTIN, L.; BITTENCOURT, A.C.S.P.; DOMINGUEZ, J.M.L.; FLEXOR, J.M., and AZEVEDO, A.E.G., 1985. Flutuações do nível relativo do mar durante o Quaternário Superior ao longo do litoral brasileiro e suas implicações na sedimentação costeira. *Revista Brasileire Geosciencias,* 15(4), 273–286.

SUGUIO, K. and TESSLER, M.G., 1983. *Intense coastal sedimentation and erosion in the Cananéia outlet southern State of São Paulo, Brazil.* São Paul: Bolm Instituto Oceanografico, 32(1), 71–75.

TESSLER, M.G., 1988. Dinâmica sedimentar quaternária no litoral sul paulista. Tese de doutoramento. Brasil: Universidade de São Paulo: Instituto de Geociências, 176p.

TESSLER, M.G. and FURTADO, V.V., 1983. *Dinâmica de sedimentação das feições de assoreamento da região lagunar Cananéia-Iguape, Estado de São Paulo.* São Paulo: Bolm Instituto Oceanografico, 32(2), 117–124.