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Geomorphologic Evolution of a Sand Spit Located in the Mouth of a Choked Coastal Lagoon. Lagoa dos Patos: Southern Brazil

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ABSTRACT

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The estuarine portion of the Patos Lagoon behaves as a choked lagoon where circulation patterns are driven mostly by wind and freshwater runoff which can reach up to 10,000 m3/s during the rainfall season. Wind direction influences both local and large-scale circulation patterns. Under NE winds pressure gradient raises along the inlet and retreating coastal waters favors flushing of the lagoon water. Contrarily, a SE and SW wind causes inversion of flow raising the water level in the northern part of both the inlet and the main lagoon body. Although being located in a microtidal area with a mean annual daily range of 0.47m, storm surges induced by southern winds can raise the level up to 2 m. As a result of the strong bi-directional flow an ebb tide delta and sand spit developed in the inner portion of the inlet. A historical sequence of aerial photogrammetry combined with bathymetric charts, (82 years) allowed tracking the morphological evolution of the sand spit located at the extreme end of the inlet. During this period, the spit grew 427 m in the northwest direction at the same time that its north to south length was reduced 304.5 m. The origin, evolution and stabilization of these features along the east margin had been quite frequent even after the construction of two convergent jetties which stabilized the inlet mouth.

ADDITIONAL INDEX WORDS: *Storm surges, coastal lagoons, Patos Lagoon.*

INTRODUCTION

The sand spits into the inner cells of Patos Lagoon are associated with alongshore transport generated by oblique incidence of waves (TOLDO, 1994). However, sand spits in the mouth of Patos Lagoon are a depositional feature governed by interaction between both, oceanic processes and lagoon discharge. Bi-directional flows and storm surges are important factors of spit genesis in this zone. A detailed study about local hydrodynamics is crucial for understanding the formation and the stability of these features since they are extremely fragile (KOMAR, 1976) and its evolution presents important implications in coastal management involving sediment transport and shoreline changes.

GENERAL SETTING

Patos Lagoon is located in southern Brazilian coast between 30° - 32° S. It has 250 km length and approximately 40 km width. Its area is about 10,360 km2 with average depth of 5 m and can be classified as a shallow lagoon (MÖ LLER JR., 1996). It presents a NE-SW orientation and its morphology is marked by several embayments which are limited by sand spits. The lagoon is connected with the Atlantic Ocean through a narrow channel with about 0.7 Km width and 22 Km length. (Figure 1). According to KJERFVE (1986) this lagoon constitutes a chocked coastal lagoon where circulation patterns are driven mostly by wind and freshwater runoff.

Figure 2 displays the location of the sand spit subject of this study which is attached to the base of the east jetty.

Patos Lagoon is enclosed by Tertiary and Quaternary sedimentary deposits which constitute an multi-complex sand barrier (DELANEY, 1965; VILLWOCK, 1984) resultant of eustatic changes of sea level during the Quaternary (VILLWOCK, 1978).. Littoral drift and sea level oscillations were the principal factors responsible for the progressive barrier closure in which only one inlet remained open. The last Holocenic Transgression (5,500 A.P.) molded the barrier III and deposited an external barrier (barrier IV) formed by beach ridges and dune systems. There are two different approaches for the estuarine evolution: (i) the evolution resulted from the interaction of both the lagoonal flow and coastal hydrodynamics (GODOLPHIN, 1976) and ; (ii) fluvial processes are responsible for the estuarine morphologic changes and several migrations of channel's mouth (LONG and PAIM, 1987). The geomorphologic characteristics of the lagoonal system fit the evolutionary model described by ZENKOVITCH (1967) and compiled by ROSEN (1975). Although the area is under a microtidal regime, the sand body morphology at the mouth resembles the characteristics of a flood tide delta. Morphological changes occurred at the base of the east jetty; even before it was built demonstrate a cyclic formation of a small bay limited by a recurved spit. However, these cycles remained the same after the jetties were built, but the shape and orientation of the sand spit changed.

The estuary circulation patterns are mainly driven by wind and the fresh water run off from the Patos and Mirim

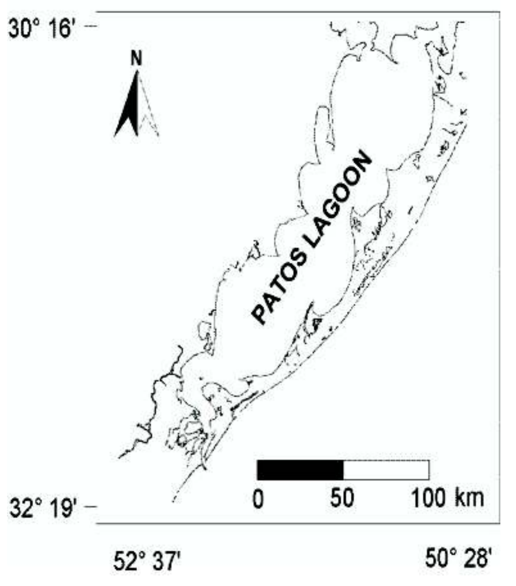

Figure 1. Location map of Patos Lagoon.

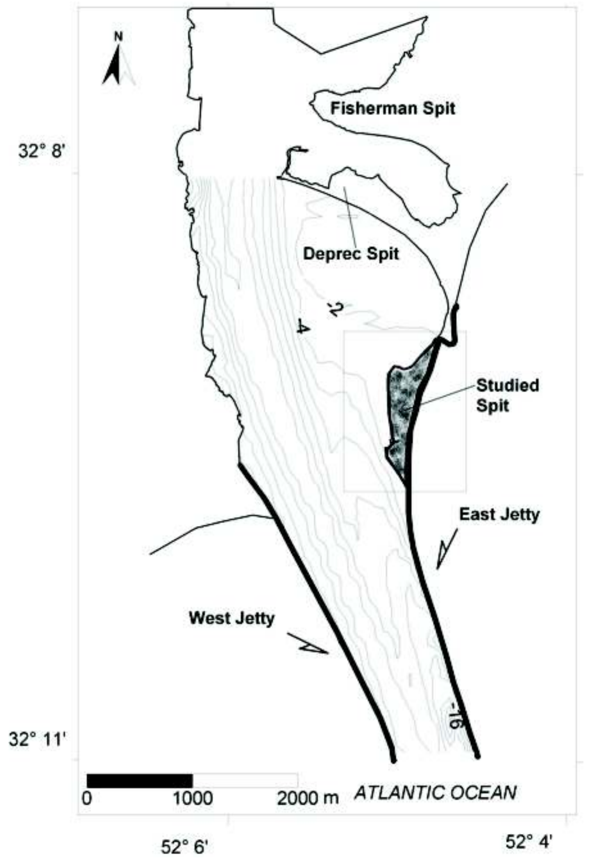

Figure 2. Patos Lagoon mouth and sand spit location

hydrographic basin. The year around dominant northeast wind, increase pressure gradient along lagoon body and favors the lagoon outflow. Winds from the southern quadrant represented mainly by the southeast and southwest produces an inversion flow into the lagoon body and causes a water level increase in its northern extreme (MOTTA, 1969). At the lagoon mouth ebb currents can reach 1,7-1,9 m/s after long raining periods, while flood current generated during storm surges can reach up to 1,3 m/s (DNPVN, 1941; VRANJAC, 2000).

METHODS

Sand spit evolution was observed by comparative analyses between bathymetric charts (1918, 1922, 1941, 1956, and 1996), and historical sequences of aerial-photography (1947, 1964 and 1975) in scales of 1:20000 and 1:40000. Digital photographs from 1998, 2000 and 2003 in scale of 1:5500 were also used.

RESULTS AND DISCUSSION

The sand spit, was first observed and registered during the year of 1918. Since then, several changes occurred in volume and format at different periods of accretion and erosion.

During the period of 1918-2000 (Figure 3 A-H) the sand spit grew 427 m to NW and 304.5 m along its N-S axis.

In 1922 the sand spit started to grow northwards (Figure 3B). In 1947 (Figure 3C), it presented a northwest bending indicating a westward longshore drift. (Silva, 2001). Between 1947-1964 (Figure 3D) it was subjected to an intense erosive process especially in its northern portion displacing to a new eastwards position and maintaining the same orientation. At the same time, a northward additional growth occurred. This new stage was observed until 1981, when it was separated from the body of the sand spit and formed a new independent feature (Figure 3E). This feature is called DEPREC Spit and is used as a logistic support for the jetties improvement. Between 1975-2003 the south end of the sand spit started an erosive process as shown in figures 3F, 3G and 3H. At the same time, its northern end started an accretionary process as it can be seen in the figures.

Observations from 1918 up to 2003 identified two cyclical processes: accretion and erosion. GODOLPHIN (1976) also identified the same behavior for similar sand spits located at the mouth before the jetties were built. During the year of 1981 the DEPREC spit showed features similar to the mesotidal inlet model described by HAYES (1979).

Analyzing bathymetric changes at the mouth, a longitudinal depression similar to a trench with depths reaching up to 20 m was noticed. This trench is the result of a continuous erosion

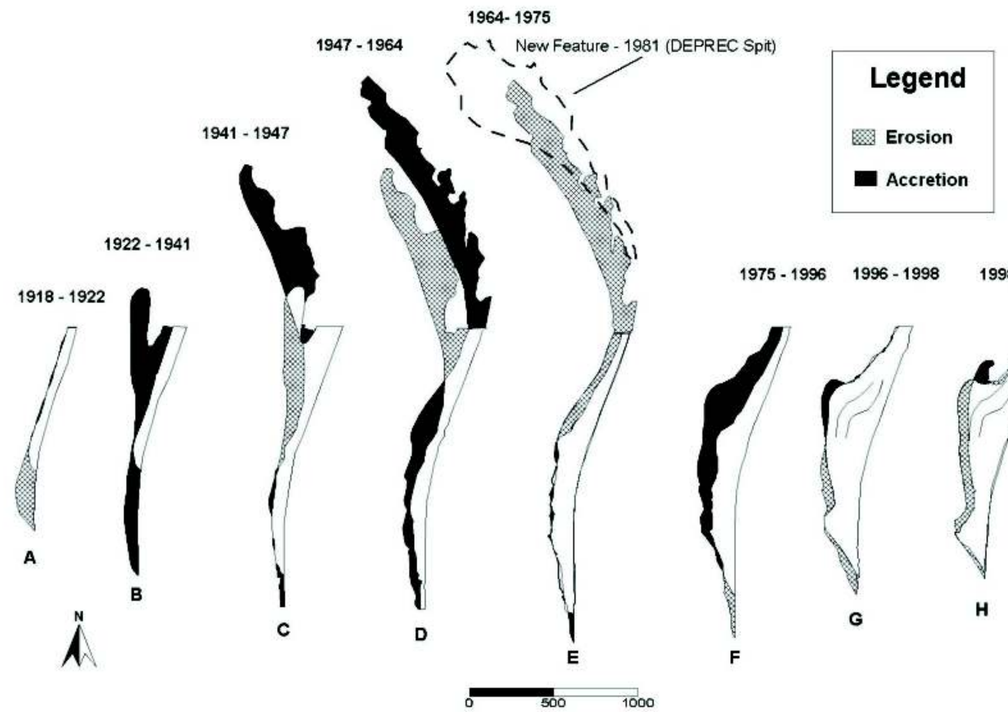

Figure 3. Sand spit evolution.

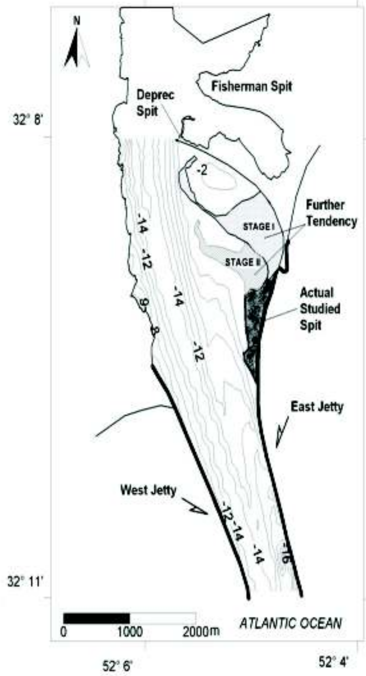

Figure 4. Predicted evolution for the sand spits at the mouth of Patos Lagoon.

process along the East Jetty which is caused by strong flood tide currents driven by southeast and southwest winds, during the cold front passages. As shown in figure 4 the trench is separated from navigation channel by an axial bank.

According to DUPRAT DA SILVA & HOFFMAN (apud MOTTA, 1969), the formation of this axial bank-trench system is mainly due to the flood tide currents which cause sand transport from the coast to the estuary.

Sand spits occurrences are linked to following factors: (i) supply of sand from the ebb and flood tide delta; (ii) occurrence of unidirectional longshore transport towards northwest specially after the sand reaches shallow waters; (iii) the occurrence of this specific morphology; and (iv) shallow waters.

Sand spits can occur by successive addition of beach ridges, in a process similar to berm formation over estuarine beaches (OTTMANN, 1967). It can grow by longshore transport and frequently give rise to beaches. Other times spits go straight over the trend of coastline and grow aligning itself nearly at right angles to the prevailing wave direction. Its free end takes a hook shape due wave refraction processes (EVANS, 1942, apud KOMAR, 1976) or to wave incidence from different angles (KING & MCCULLAGH, 1971, apud KOMAR, 1976). Aerial photos obtained in 2003 show clearly the hook shape at the end of the spit resembling the ideal spit proposed by CARTER (1988).

Analyzing aerial photos between 2000-2003 it is possible to observe regressive beach ridges (Figure 3G and 3H) which show the sand spit evolution. Part of the eroded material is has been used to build a submerged bar leading to earlier stages of the new spit (Figure 3C, 3D and 3E) in agreement with the evolutionary model proposed by Bird (1969) and Carter (1988). Successive measurements point out to a permanent evolution intercalated by erosive and accretive periods. This behavior is typical to the model of microtidal regressive barriers (LEATHERMAN, 1982).

Generally, the beach hook shape points out the direction of the net littoral drift (Figure 3G and 3H). According to BIRD (1969) and CARTER (1988), ZENKOVICH (1959 and 1967), EVANS (1942, apud KOMAR, 1976), OTTMAN (1967), KOMAR (1976), BIRD (1969) and CARTER (1988) this spit is a free feature resulting from a unidirectional longshore transport. According the evolution observed sand spits in this area important factor in the regularization of the coastline (JOHNSON, 1919 apud KOMAR, 1976). Such considerations together with earlier studies about spits evolution into the inner cells of Patos Lagoon, give us some clues about future tendencies of the coastline.

A period of 120 years indicate that two complete accretion-erosion cycles of 60 years each were necessary for the feature to get its current shape. The changes on the shape are imposed mainly by the building of the East Jetty, the evolution of the DEPREC spit and the navigation channel.

CONCLUSION

Despite the microtidal regime on the area, the feature here discussed display characteristics of a estuarine mouth dominated by a mesotidal regime. Such behavior indicates the importance of storm surges as the main process responsible for its evolutionary shape. In fact, bi-directional currents driven by local winds and storm surges associated with cold front passages are the main forces for the morphodynamic behavior of this spit. Based on the morphologic evolution and the dynamic character or the area, the formation of two new spits are predicted (Figure 4).

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