## Littoral Processes in a Prograding Coast: the Case Study of the Atlantic Ocean Coast of Uruguav

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#### Abstract

The Atlantic Ocean coast of Uruguay extends from Punta del Este outer limit of the Rio de la Plata Estuary, to the Brazilian border, over 220 kms. This case study applies to a homogeneous coastal stretch of 80 kms long, north of Punta del Este. The main coastal features are three littoral lagoons, Jose Ignacio, Garzón and Rocha, whose mouths open and close by natural or antropic actions every year. The coastline is formed by 1-2 mm coarse sand on highly reflective beaches. Beach berm is overwashed by the SE storm waves. Landward there is a dune system. This beach-dune structure is approximately 100 m wide. At least three similar morphological structures may be landward identified. which were developed during a period of time when the sea level was about 5 m higher than today's sea level (approximately 5000 years BP). <sup>14</sup>C technique applied to chalk samples shows a relative decrease of the sea level in the last 5000 years. Furthermore, gravimetric data shows that there is an anomaly, which supports the existence of an isostatic rise of the continental shelf. As a result, the Atlantic Ocean Coast of Uruguay is prograding. The beach coarse material is provided by the wave action from the continental shelf, while the fine dune material seems to be obtained from the erosion of the land weathered granite.

#### 1 Introduction

The Atlantic Ocean Coast of Uruguay is part of the eastern coast of South America. It extends over 220 km, from Punta del Este, outer limit of the Rio de la Plata estuary to the Brazilian border, at the NE. The case study refers to a part of about 80 km of this coast,

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from Punta del Este to Cabo Santa María (La Paloma) (Figure 1). It is an homogeneous and almost straight coastline, oriented perpendicular to the SSE (N 65° E) and whose middle point is at the coordinates 34°45' S and 54°30' W (Figure 2).



Figure 1. Zone of interest

The main coastal features are three littoral lagoons, José Ignacio, Garzón and Rocha whose mouths open and close intermittently, each year, by antropic or natural actions. These lagoons constitute a rich and sensitive ecosystem, that has to be preserved, as the remaining coastline, which is still almost unexploited by the tourist trade.

East of Punta del Este, the outlet of the Maldonado River, and 30 km eastern, about in the middle of the studied stretch, José Ignacio rocky point, are located.



Figure 2. Studied coastal stretch and bed contours

To establish the bases for a management plan of this coast, today non-existent, but urgently needed, the long term evolution pattern has to be determined. It must be considered that Punta del Este is one of the main summer tourist resort in South America, and La Paloma placed in Cabo Santa Maria, can be considered the second one in Uruguay.

In this paper the main geological and morphological features of this coastline are considered, as well as the main hydrodynamic variables. The existent gravimetric data and mollusk samples analyzed with the <sup>14</sup>C technique, as well as the recognition of lines of previous coasts, sustain the hypothesis of the prograding character of the studied stretch.

# 2 Geological and morphological data

This zone of the Uruguayan coast presents a crystalline rock substratum from 500 to 660 million years, which is exposed in some areas and in other is covered by deposits from the cenozoic and quaternary (UNDP, URU.73.007 1980).

The crystalline rocks that crop out in the immediate zone at the east of the José Ignacio Lagoon are intrusive granites, porphyries, with phenocrysts of up to 8 to 10 cm. The

quaternary deposits include clays, sands and mudstones, from the pleistocene, which provide large quantities of detritus sediments to the coastal environment through gullies and ravines.

In the vicinity of Garzon and Rocha lagoons, series of coastal dunes, formed by coarse and very coarse moderately sorted sand, belonging to the recent, can be found (UNDP, URU.73.007 1980). Beaches have steep slopes (about 12%) and coarse sand as large as 2 mm. For example in Las Garzas beach, located approximately in the middle of the stretch, indicative grain diameters are  $D_{90}=1.62$  mm and a  $D_{50}=0.96$  mm. These are immature sands, both texturally and mineralogically, with evidences of little transportation by rolling.

Behind these beaches there is an eolian dune system of fine sands. That beach-dune structure is approximately 100 m wide. Landwards, it can be easily recognized three similar geomorphologic structures, which were formed in the past (5000 years B.P), when the sea level was about 5.0 m above the present sea level

Large sandy spits separate the three coastal lagoons from the ocean. These spits are formed by sand provided by the ocean. Their natural opening and closure are produced by the dynamic ocean action over the coast.

## 3 Hydrodynamics and wave energy flux

### The mean sea level

This coast stretch has a semidiurnal astronomical tide regime with diurnal inequality. The difference among the mean high water level and the mean low water level is 0.45 m in La Paloma and 0.54 m in Punta del Este (east and west borders of the studied stretch, respectively). On the other hand the meteorological tide, associated with strong southeastern winds, provokes higher mean sea level. For example in Punta del Este the average of annual maximum levels recorded in this century is 1.41 m and the highest record is 2.15 m. In Cabo Santa Maria the average of annual maximum levels is 1.22 m.

# Wave climate

Deep water wave climate was established on the basis of data from the UK Met. Office's Main Global Marine Data Bank, for the area limited by coordinates 34.0° S, 36.0° S and 55.0° W, 53.0° W. These data were obtained by merchant ships during the period from 01/1949 to 06/1996 and constitute a total of 5558 records of significant wave height, period and direction, grouped at sectors of 30°. Furthermore, the significant wave height exceedence curve obtained by the U.S. Navy GEOSAT with records from November 1986 to March 1989, for a 4° by 4° area (Young I. R., 1996) was used.

These data were compared to the significant wave height satellite records for the region between 35°S to 36°S and 53° W to 56° W, provided by the Global Real Near Real –Time

Significant Wave Height Visualization Program, sponsored by the Colorado Center for Astrodynamics Research at the University of Colorado were recorded by ERS and TOPEX/POSEIDON satellites for a period of 15 months starting in July 1996.

On the other hand wave records obtained during some months between 1976 and 1978, by a non-directional Datawell type buoy which was installed close to Punta del Este were analyzed.

Wave propagation based on the obtained wave climate was computed with a refractiondiffraction model. This parabolic weakly non-linear wave propagation model, named OLUCA-RD, was developed at the Oceanographic and Coastal Engineering Group of University of Cantabria, Spain. Bed contours are given schematically in Figure 2.

Wave propagation with periods in the range 6 and 12 seconds and all the directions which arrive to the studied stretch was computed. In this way, wave direction and wave height at the coast (10 m water depth), that is coastline wave climate was established. Moreover, the net percentage of the annual energy flux arriving to the coast, corresponding to each direction, was determined. The results obtained are shown in Figure 3.



Figure 3. Wave energy flux in deep water and at the coast

Even though in deep water the net annual energy flux spreads in a wide direction range, the effects of the wave propagation over the existing bed contours determine that at the coast the net flux of energy is concentrated on the direction perpendicular to the coast. The vector sum of these results shows that the net annual energy flux over the 10 m depth bed contour is esentially perpendicular to the coastline (Figure 4).



Figure 4. Resultant annual net energy flux

On the basis of this result it becomes apparent that the net longshore sediment transport is minimum in this stretch of coast. That is verified by the comparative analysis of sand characteristics of the neighboring beaches.

# 4 Relative sea level changes

It is well known that the relative sea level is the result of the balance between the isostasy, determined by the tectonic activity, and the eustasy or modifications of the sea level due to the changing volume of ocean water or the capacity of ocean basins.

At a global scale it is accepted that the eustatic level in the last 5000 years has been growing. Between 5000 and 3000 years B.P there was a growth of 20 to 30 cm each 1000 years, and during the last 3000 years the sea level has been oscillating or growing with a lower rate. Summing up it can be said that the eustatic level during the last 5000 years has been growing with a rate of 0.01 cm per year.

In the zone under study there exists evidence of the fact that during the last holocenic transgression the sea level had reached a level of +5.0 m relative to today's sea level. As it will be shown in the next paragraph, from those days up the present, a relative decrease of the sea level up to the current sea level was produced. This statement implies that during the last 5000 years the isostatic change rate was greater than the eustatic change rate.

## 5 Verification of descendant sea level: prograding coast

Martin and Suguio (Martin, M. and Suguio K., 1989) determined a curve of sea level fluctuation in the holocenic period, for three different zones of Brazil. This curve establishes an increase of the relative sea level up to a maximum transgression 5000 years BP, a regression 4000 years BP and successive variations up to present level, with a negative rate of 1 mm per year. Moreover, Bracco and Ures (Bracco et al 1997), (Bracco and Ures, 1998) through <sup>14</sup>C technique applied to mollusk samples confirmed the results from Martin and Suguio (Figure 5).



Figure 5. Sea level fluctuation curve and data from <sup>14</sup>C

Furthermore gravimetric data show the presence of a strong anomaly in the zone. The interpretation of this data supports the hypothesis of an isostatic rise for this stretch of the SE coast of Uruguay.

The Figure 6 reproduces an aerial photograph of Garzon lagoon, in which many different paleocoasts can be observed.

Thus, it may be established the hypothesis of a relative sea level decrease, with a medium rate of 1 mm per year, for this stretch of Uruguayan coast. This fact allows to forecast a progression of the coastline in parallel lines to the actual one and perpendicular to the annual net energy flux.

## **6** Conclusions

In this paper the long term evolution of the Uruguayan coastline between Punta del Este and Cabo Santa María (La Paloma) is analyzed. Based on the existing information the following conclusions may be drawn:

- Gravimetric anomalies show that SE Uruguayan earth's crust is rising.
- Eustatic world sea level is rising.
- Relative sea level change in this stretch of coast is decreasing.
- The Uruguayan Atlantic stretch of coast between Punta del Este and Cabo Santa María is prograding.
- The progression of the coast is in parallel lines perpendicular to the annual net energy flux.



Figure 6. Garzón Lagoon

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