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Beach differentiation along the Rio Grande do Sul coastline (Southern Brazil)

Diferenciación de las playas a lo largo de la costa de Rio Grande do Sul (Sur de Brasil)

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ABSTRACT

Changes in sediment properties (grain size and composition) associated with shoreline orientation and local hydrodynamics induce beach differentiation along the Rio Grande do Sul coastline between Rio Grande (32° 10' S) and Chuí (33° 45' S). Three zones with distinct morphodynamic behavior can be identified: fine sandy beaches near Rio Grande display dissipative characteristics; further south, a 40 km stretch of coast called "Concheiros", is composed of shell debris and fine sand, and represent intermediate to reflective beaches; at all other locations beaches show an intermediate stage. Differences in morphodynamic behavior between these regions are characterized by beach face steepness, frequency of secondary morphological features, erosional characteristics and associated hydrodynamics. A seasonal behavior is superimposed on this general morphodynamic pattern, owing to the wave climate regime with a tendency to develop a swell profile, between November and March, and a storm profile in the remainder of the year. The "Concheiros" area displays low abundance and diversity of the benthic macrofauna and the highest storm-induced subaerial sediment volume change when compared with other beach systems along this area. The combination of distinct morphological features, like well developed beach cusps, scarps and shelly gravel sands provides this area with unique characteristics along the 210 km of coast.

Key words: beach morphodynamics, grain-size distribution, gravel beaches macrofauna.

RESUMEN

La interacción entre el tamaño del grano y los regímenes hidrodinámicos y eólicos causan la diferenciación de las playas a lo largo de la costa sur brasileña entre Río Grande (32° 10' S) y Chuí (33° 45' S). En base a varios parámetros medidos a lo largo de un año se caracterizaron tres zonas de diferente morfodinámica: playas disipativas cercanas a Río Grande; playas de "concheros" al sur del faro de Albardão que oscilan entre estados intermedios y reflectivos y playas que tienden a permanecer en estados intermedios en el resto de la costa. Las diferencias en el comportamiento morfodinámico entre estas zonas se manifiestan por la inclinación de las playas, frecuencia de tipos morfológicos secundarios y características de erosión e hidrodinámica. Cuando comparados con las otras playas, los "concheros" muestran baja abundancia y diversidad de macrofauna bentónica y los mayores cambios en el volumen de los sedimentos subaéreos provocados por tormentas. La combinación de aspectos morfológicos particulares como media lunas playales (cuspilitos), escalones y sedimentos de grava calcárea confiere a esta área características únicas a lo largo de 210 km de costa.

Palabras clave: morfodinámica de playas, distribución del tamaño del grano, macrofauna de playas de grava.

INTRODUCTION

Energy derived from the action of winds, waves and currents interact with the existing landform morphology of beaches by active surf-zone and shore processes. The result is a transfer of energy and subsequent change in morphology due to accretion or erosion. This interaction between existing beach material and incoming energy determines the morphodynamic behavior of a beach system (Wright & Short 1984). A complete understanding of beach morphodynamics encompasses an understanding of processes of wave energy transformation across the entire continental shelf, sediment characteristics, and the entire beach area including the foredunes and the backshore region (Short & Hesp 1982).

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Changes in sediment properties (grain size and composition) associated with shoreline orientation and local hydrodynamics induce beach differentiation along the Rio Grande coastline between Rio Grande and Chuí in southern Brazil (Fig. 1). These differences are characterized by beach face steepness, frequency of secondary morphological features (beach cusps and scarps), erosional characteristics and associated hydrodynamics. This study analyses from a morphodynamic approach (Short 1980, Wright & Short 1984, Short & Hesp 1982) the spatial and temporal variations of the southern Brazilian beaches during a one year period. Faunal studies of a beach composed of

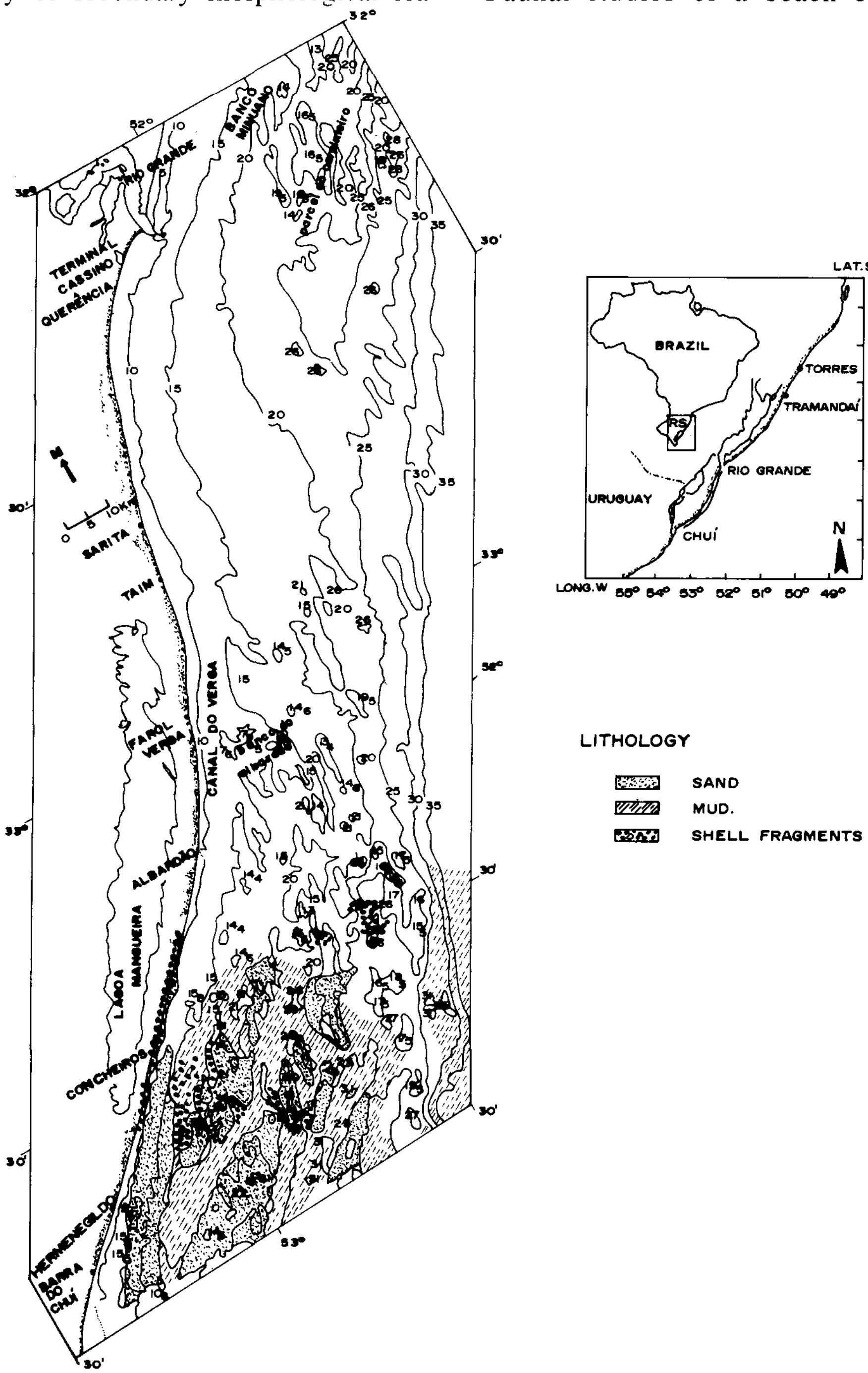

Fig. 1: Study area at the coast of Southern Brazil.

Area estudiada en la costa del sur de Brasil.

bimodal sediments (shell debris and fine sand) was studied in order to compare the abundance and diversity of the benthic macrofauna with previous results obtained from adjacente beaches composed of unimodal sediments (fine sand).

STUDY AREA

The lenght of the study area is 210 km and includes the beaches located between Rio Grande and Chuí (Fig. 1). The Rio Grande do sul coastline is a long barrier island (640 km) which is separeted from the mainland by a large lagoonal system consisting mainly of the Patos and Mirim Lagoons. The barrier is characterized by well-developed beach, dunes and aeolian flats. Most all the beaches along the coast are exposed. Exception to this pattern is found in the northermost part of the barrier, where rocky headlands protusions formed by sandstone and basalt reach the coast and provide beaches with some degree of sheltering. Association between shoreline configuration, continental shelf width and the wave climate provides a good example of a wave dominated barrier island. According to Motta (1963) incident swell and sea entering shallow water are respectively from southwest and east. Annual average significant wave height is 1.5 m with a period of 9 seconds (Motta 1963).

Based on a three year observation period, Malaval (1923 in Duprat da Silva 1941) found that winds predominate from the northeast during spring and summer (September to March) and from the southwest during autum and winter (April to August). Although the dominant wind direction along the barrier comes from northeast, the strongest winds are associated with the passage of frontal systems (cold fronts) coming from the south. The astronomical tide along the Rio Grande do Sul coastline is insignificant, the mean annual daily range being 0,47 m However, wind and barometric pressure play the major role in the sea level oscillations along the coast. During the passage of frontal systems the water line can reach the basement of the dunes which is aproximately 1.7 m above the mean sea level.

METHODS

During a one year period (mainly at monthly intervals) beach profiles at eight locations were conducted along the coast with an automatic level and stadia rod. Each profile was measured from a bench mark located at the dune toe. Survey lines proceeded seaward approximately perpendicular to the shoreline along established azimuths. Volume changes and shoreline changes were obtained using the Interactive Survey Reduction Program (ISRP), developed by Birkemeier (1985). This computer program enable calculations of areal parameters for cut and fill cels from superimposed profiles.

Morphometric parameters such as: subaerial beach slope, modal beach stage ($\Omega = H_b/W_sT$, where H_b = breaker height; W_s = sediment fall velocity and T = wave period), mean beach width (Y_b), standard deviation of the mean beach width (σYb), coefficient of variation of the mean beach width (CV), and changes in subaerial beach volume (V_v), as described by Short & Hesp (1982), were calculated for each beach profile location. According to these authors such parameters are sensitive to different beach stages.

Significant wave height (breakers) and period were visualy obtained at a point inside the surf zone. The grain size distribution between 0 and 4 phi (1 to 0.062 mm) for 80 sediment samples representing the upper 20 cm collected with a cilindrical tube from the beach face was determined by sieving using 0.25 phi intervals. The grain's settling velocity (W_s) was obtained from tables which take in account the conversion of sphere diameters produced with Gibbs et al. (1971) equation to that of natural grains using the equation of Baba & Komar (1981).

At three occasions (May, June and July of 1993), triplicate samples totalizing 12 samples of 0.03 m^2 to 30 cm sediment depth were obtained at the "Concheiros"area for the study of the intertidal benthic macrofauna. Sampling was conducted from the lower foreshore landwards at five meters interval across a 20 m transect. Quantitative values for the macrofauna were obtained based on mean density of organisms per square meter.

RESULTS

Since the beginning of the field trips spatial variability in beach morphology was evident along the study area. These differences were primarily expressed by changes in beach face steepness, and the more frequent occurence of beach cusps and scarps at the "Concheiros" area. Figure 2 illustrates the longshore variation in foreshore slope and grain size. The lowest values of foreshore slope (1 to 2 degrees) and grain size were found near Rio Grande (Terminal and Querencia beaches). The highest values of foreshore slope (> 5 degrees) and mean grain size was found along a 40 km stretch of beach called "Concheiros".

Alongshore temporal variations of beach morphology was evident when the profile envelope of each site was ploted as done by Wright & Short (1984) (Fig. 3). The beach envelopes for Terminal and Querencia beaches show that vertical changes in the sweep zone and in beach width were low. Maximum vertical changes during the period were 1.25 m and occured from the lower foreshore to the berm for the Sarita, Taim, "Concheiros"and Hermenegildo beaches. Although for most of the sites, data related to the subaqeuos part of the profile are scarce, the surf-zone displayed vertical mobility similar to the subaerial beach. Bar occurence were common to all the beaches. More than fifty surveys for Querencia beach indicate the occurence of at least one longshore bar generally located at 100 from the water line. Seasonal patterns indicate the occurence of well developed berms south of Querencia beach (swell profiles) from November to March. Differences in morphodynamic characteristics among the beach systems are evident when the morphometric parameters defined by Short & Hesp (1982) are compared. Table 1 indicates that the highest and lowest values of the standard deviation of the mean position of the shoreline (σY_b) and the coefficient of variation of mean shoreline position (CV) were respectively associated to Sarita and Hermenegildo and Terminal, Querencia and "Concheiros" beaches.

Despite the few and instantaneous data obtained for the omega (W) parameter, it can be seen that the beaches of Terminal and "Concheiros"displayed respectively the highest and the lowest values for this parameter.

Table 2 displays the mean values of density and biomass for all the macrofauna species found during the sampled period. The polychaete *Hemipodus olivieri* was the most abundant organism, reaching in July 245 individuals per square meter. Less abundant organisms found were the isopods *Excirolana armata* (Dana, 1852) and *Excirolana braziliensis* (Richardson, 1902) the hipid crab *Emerita brasiliensis* (Schmitt, 1935) and the bivalve *Donax hanleyanus* (Philippe, 1842).

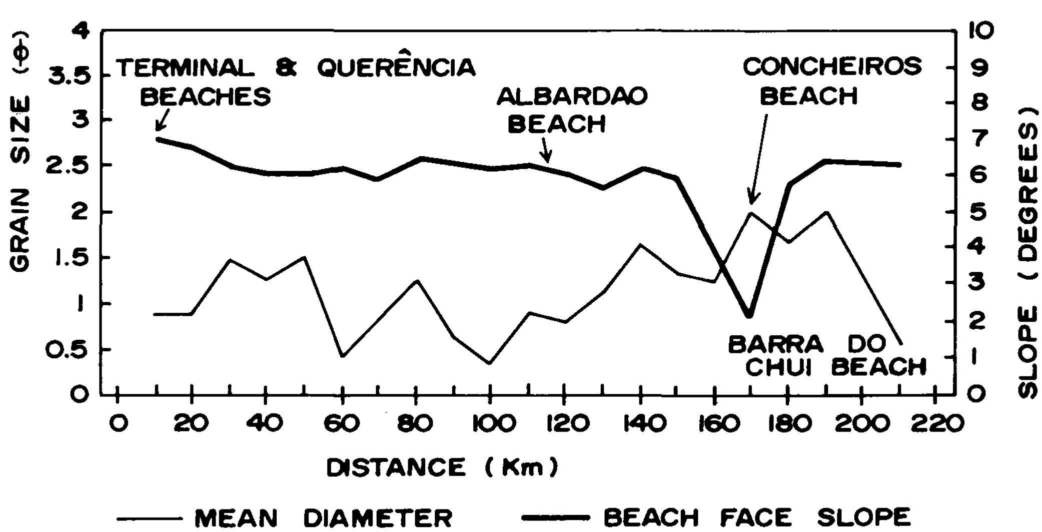

Fig. 2: Spatial variability of mean grain size x foreshore slope along the study area.

Variabilidad espacial del tamaño y pendiente de la zona del barrido a lo largo de la zona estudiada.

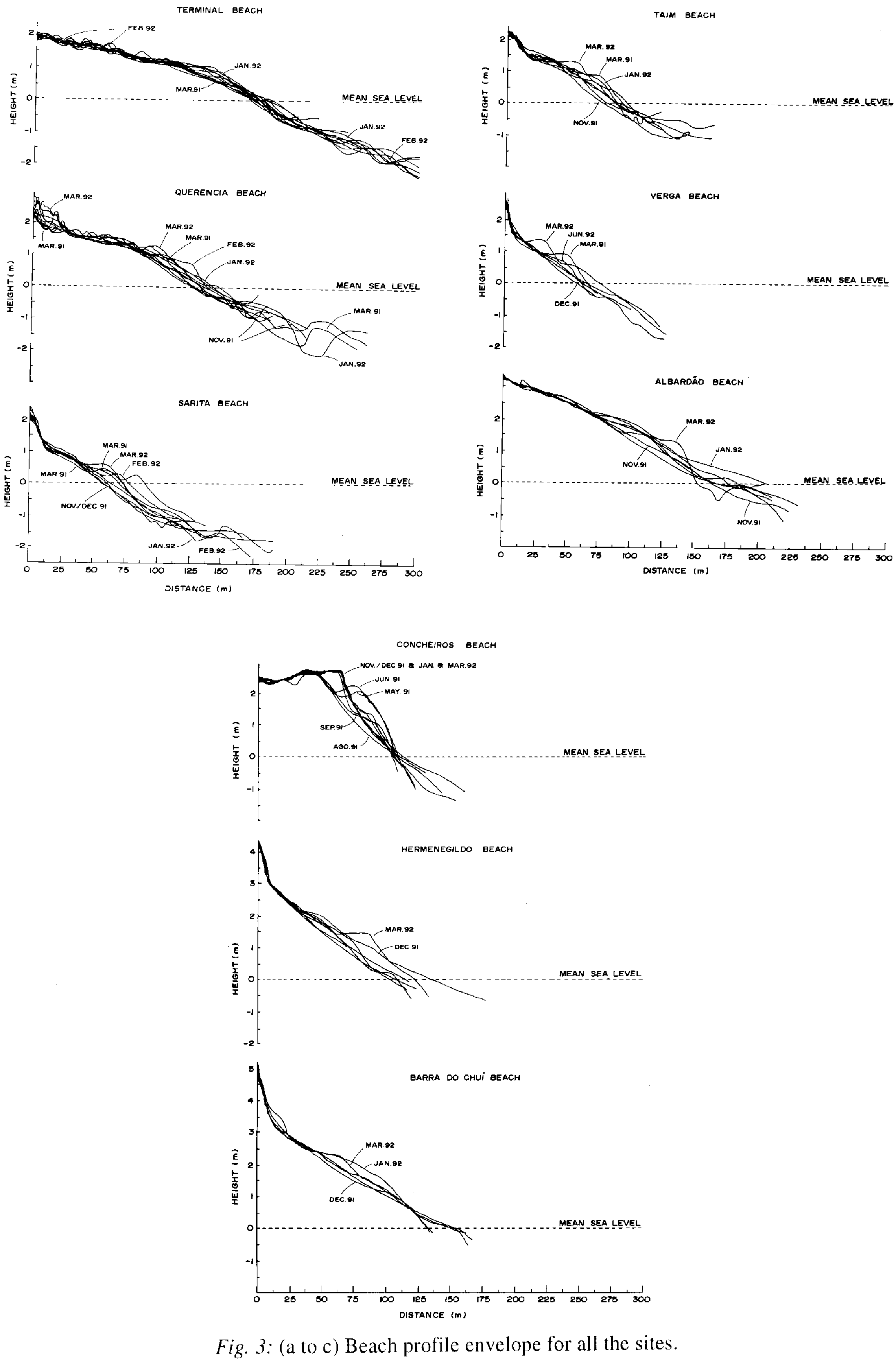

Fig. 3: (a to c) Beach profile envelope for all the sites.

(a - c) Perfiles sobrepuestos para todos los sitios estudiados.

TABLE 1

Measured morphometric parameters for the studied beaches. N = number of surveys; M = months; H_b = breaker height; T = wave period; M_z = mean grain size; Ω_s = mean sediment fall velocity (cm/s); $\Omega = H_b/T\,\Omega_s$; Y_b = Mean beach width; σY_b = standard deviation of mean beach width; CV = coefficient of variation of mean beach width; V_v = volume changes above the datum; * denotes bimodal sands the omega (Ω) values are related to both the coarse and fine grains;- = no data

Parámetros morfométricos medidos para las playas estudiadas. N = número de levantamientos; H_b = altura de la rompiente; T = período de la ola; M_z = tamaño medio del grano; Ω_s = velocidad media de caída del sedimento; Y_b = ancho medio de la playa; σY_b = desviación estándar de la media del ancho de la playa; CV = coeficiente de variación del ancho medio de la playa; V_v = cambios de volumen por encima del datum

	BEACHES								
	Terminal	Querencia	Sarita	Taim	Verga	Albardão	Concheiros	Hermenegildo	Chuí
N	14	15	9	8	7	7	10	7	5
M	10	11	8	7	5	6	8	5	5
H_b (m)	0.70	0.64	0.74	0.80	0.77	1.02	0.99	0.86	0.90
T (s)	8.2	8.7	8.5	8.4	9.0	9.9	10.5	7.5	7.5
M_z(phi)	2.88	2.50	2.50	2.38	2.50	2.38	0.5/2.25 *	2.50	2.50
W_s	1.25	1.81	1.81	2.04	1.81	2.04	2.20/15.00	1.81	1.81
Ω	7	5	5	5	5	-	0.5/4	-	-
SLOPE	1:30	1:30	1:23	1:22	1:18	1:19	1:13	1:22	1:26
Y_b (m)	183	134	70	85	63	170	109	118	147
σY_b (m)	5	7	10	6	5.5	9.5	2.5	15	12
CV(%)	3	5	14	7	8	6	2	12	8
V_v (m^3/m)	5	4	4	8	8	17	9	19	20

TABLE 2

General characteristics of the macrofauna studied at the "Concheiros" area. B = dry biomass (mg/m^2); D = density (ind/m^2); Taxa: (P) = Polychaeta; (B) = Bivalvia; (I) = Isopoda; (An) = Anomura

Características generales de la macrofauna bentónica estudiada en la región de los "Concheiros". B = biomasa seca (mg/m^2); D = densidad (ind/m^2); Taxa: (P) = Polychaeta; (B) = Bivalvia; (I) = Isopoda; (An) = Anomura

	MONTHS					
	May		June		July	
TAXA	D	B	D	B	D	B
Hemipodus olivieri (Orensanz & Gianuca, 1974) (P)	186	197	245	224	45	4
Excirolana armata (Dana, 1852) (I)	7	14	9	77	-	-
Excirolana braziliensis (Richardson, 1902) (I)	-	-	-	-	40	467
Emerita brasiliensis (Schmitt, 1935) (An)	19	10944	6	1137	-	-
Donax hanleyanus (Phillipe, 1842) (B)	4	11737	6	42757	-	-

DISCUSSION

Several studies (Bascom 1951; Sunamura & Horikawa 1974; Sunamura 1984) have show that the main controlling factors of the beach face slope are related to grain size and wave parameters (wave steepness and period). Since the wave parameters obtained along the study area were similar, the spatial differences in beach face slope are mainly due to changes in grain size. The low beach face gradient found for Terminal and Querencia beaches were due to the fact that they have the finest mean grain size which depict the small and recent contribution of the Patos Lagoon discharge to the coast. The occurence of bimodal sediments (shell debris and fine sands) are responsible for the highest beach face slope values found along the "Concheiros" area. In this area, the presence of a beach scarp with 0.5 to 1.20 m height at 50 m from the water line and the occurence of well developed beach cusps on the foreshore are frequent (Fig. 4).

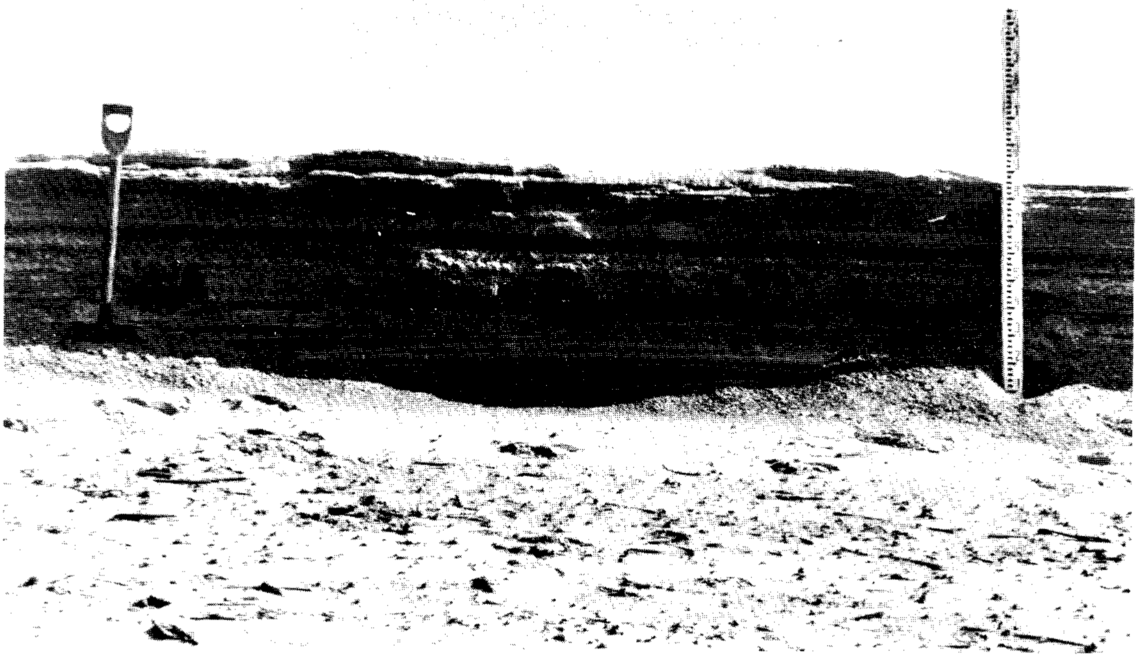

Fig. 4: Beach scarp at the "Concheiros" area.
Escarpamiento de erosión en los "Concheiros".

Temporal variability of the beach profiles as indicated by the envelopes (Fig. 3) show that different morphodynamic behavior occurs along the study area. Terminal and Querencia beaches display the lowest temporal variability. South of these beaches, temporal variability increases. According to Wright & Short (1984) low temporal variability is associated with both dissipative and modally reflective beaches. Dissipative beaches are generaly found in open areas with high wave energy and abundant fine grained sediment. Such beaches display the lowest gradients and the maximum width. This is the case for these two sites specially for Terminal beach where the dissipative characteristic is corroborated by mean values of omega (Ω) greater than seven, low values of standard deviation of the mean position of the shoreline (σY_b) and by the coefficient of variation of the mean shoreline position (CV) (Table 1).

According to Short & Hesp (1982) the morphometric parameters σY_b and CV portray respectively beach mobility (movement normal to the shoreline) and backshore mobility. Low values indicate low mobility, high values indicate a mobile beach or backshore and therefore higher susceptibility to erosion-accretion episodes. Higher values of σY_b and CV were found for the beaches of Sarita, Taim, Verga, Albardão, Hermenegildo and Chuí (Table 1). The higher beach mobility for these sites is indicative of intermediate beaches systems. The values of CV were specially high for Sarita and Hermenegildo. In fact these beaches display the highest susceptibility to erosion and accretion episodes. The presence of erosion scarps at the frontal dunes and the subsequent profile recovery are common features there.

The temporal evolution for the "Concheiros" area show that at this site, beaches oscillate between the intermediate and reflective states. From November to June this beach display reflective characteristics such as a predominantly steep profile with sand storage in the subaerial beach.

Comparative studies during storm events indicate that at the "Concheiros"area, beaches display higher values of subaerial volume change (40 m^3/m) when compared with the other beaches along the barrier (20 m^3/m). The temporal changes displayed by the beach envelope at all sites indicate that a subtle seasonal behavior exists with the swell profile dominanting between November and March (late spring and summer) and the storm profile occuring between April and October (fall and late winter).

The low values of density and diversity of macrofauna found in the "Concheiros" area were mainly due to the high subaerial beach volume change displayed by this beach. Such results are corroborated by those of Defeo et al. (1992) which found similar values for intermediate beaches located in Uruguay (few kilometers to the south). In addition, the high concentration of shell fragments, and the high runup velocity attained at this site may determine a negative effect on the faunal density and diversity. This observation is corroborated by Gianuca (1985) who always found densities of *Excirolana armata, Excirolana braziliensis* and *Donax hanleyanus* greater than 200 individuals per square meter, for the intermediate beaches located northward of the "Concheiros "area. These findings indicate that dissipative and intermediate beaches composed of fine and medium sand, having a smaller slope and a low runup are better sites for the development of these three organisms.

Summarizing we conclude that the variability of the morphodynamic behavior along the studied beaches is mainly due to grain size changes associated to the area under the influence of the Lagoa dos Patos discharge and to the local occurence of coarse shell fragments south of Albardão beach. Changes described by the morphometric parameters and the profile envelope for each site indicate the occurence of three zones with distinct morphodynamic behavior: the beaches near Rio Grande with dissipative characteristics; an area called "Concheiros", located south of Albardão lighthouse with intermediate to more reflective beaches and beaches with intermediate stage. There is a seasonal behavior related to the regional wave climate regime, with a tendency to develop a swell profile between November and March, and a storm profile during the remainder of the year. The beach morphodynamic model (Wright et al. 1979, Short & Hesp 1982, Wright & Short 1984) proved to be a efficient approach in explaining the existing differences in morphology and morphodynamic behavior between adjacent beaches along this barrier island.

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LITERATURE CITED

BABA J & PD KOMAR (1981) Measurements and analysis of settling velocities of natural quartz sand grains. Journal of Sedimentary Petrology 51: 631-640.

BASCOM WN (1951) The relationship between sand size and beach face slope. Transaction American Geophysical Union 32: 866-874.

BIRKEMEIER WA (1982) Fast accurate two-person beach survey. Coastal Engineering Technical Aid 81-11. U.S. Army Engineer Waterways Experimental Station. Coastal Engineering Research Center, Vicksburg, Mississipi, 22p.

DEFEO O, E JARAMILLO & A LIONNET (1992) Community structure and intertidal zonation of the macroinfauna on the Atlantic coasts of Uruguay. Journal of Coastal Research 8: 830-839.

DUPRAT DA SILVA F (1941) Relatório da Enchente de Maio de 1941. Diretoria de Obras do Porto e Barra do Rio Grande. Rio Grande Ministério dos Transportes-DNPVN. Relatório Interno.

GIANUCA NM (1985) Ecology of a sandy beach in southern Brazil. Ph.D. Thesis, University of Southampton, England. 330 pp.

GIBBS RT, MS MATTHEW & DA LINK (1971) The relationship between size and sorting velocity. Journal of Sedimentary Petrology 41: 07-18.

MOTTA VF (1963) Relatório análise e previsão das alturas das ondas em Tramandaí. Instituto de Pesquisas Hidráulicas da UFRGS. Porto Alegre, 30 pp.

SHORT AD & PA HESP (1982) Wave, beach and dune interaction in southeastern Australia. Marine Geology 48: 259-284.

SHORT AD (1980) Beach response to variation in breaker height. Proceedings of the 17th International Conference of Coastal Engineering. Sidney, ASCE: 1016-1035.

SUNAMURA T (1984) Quantitative predictions of beachface slopes. Geological Society of America Bulletin 95: 242-245.

SUNAMURA T & K HORIKAWA (1974) Two dimensional beach transformation due to waves. Proceedings of

the 14th International Conference of Coastal Engineering, ASCE: 920-929.
WRIGHT LD, BG CHAPELL, MP BRADSHAW & P COWELL (1979) Morphodynamic of reflective and dissipative beaches and inshore systems: Southeastern Australia. Marine Geology, 32: 105-140.
WRIGHT LD & AD SHORT (1984) Morphodynamic variability of surf zones and beaches: a synthesis. Marine Geology 56: 93-118.